Accumulating Flood Risk

A Model Study to Quantify Flood Damage Mitigation Measures under Dynamic Vulnerability

by

Seth Bryant

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Department of Civil and Environmental Engineering
University of Alberta

Abstract

Responding to rising disaster damages and shrinking budgets, Canadian cities are looking for ways to maximize protection from flood damages while minimizing costs. To inform such mitigation investments, quantitative decision-making tools have been used for decades to evaluate structural protection measures (e.g. levees), where estimating the current risk using a 'static view' (where vulnerability does not change through time) is thought to be adequate. However, no such tool exists to evaluate time-sensitive mitigation measures such as Flood Hazard Regulations (FHRs). Unlike structural protection measures, FHRs mitigate flood damage over time as flood-specific building rules guide new development towards less vulnerable buildings. Despite widespread application of FHRs in Canada since 1975, decision makers have no method to quantitatively evaluate FHRs or answer questions like: *how much flood risk do FHRs mitigate?*

To address such questions, a dynamic view of flood risk is needed. This dynamic view conceptualizes the intersection of increasing flood hazard and heightened urban vulnerability as driving an accumulation of flood risk. Working towards such a dynamic view, this thesis develops the novel Stochastic Object-based Flood damage Dynamic Assessment model framework (SOFDA) and applies it to single-family homes in the Sunnyside/Hillhurst neighborhood of Calgary, Canada. SOFDA builds on the 2014 Rapid Flood Damage Assessment Model (developed by the Government of Alberta) to create a framework that includes: stochastic uncertainty; property level mitigation measures; and urban redevelopment. Using SOFDA to quantify dynamic flood risk in the study area, a simulation experiment is used to: 1) evaluate the shortcomings of the traditional static view of risk; and 2) explore the potential for optimizing Calgary's current FHRs.

Model results suggest that, for structural protections in redeveloping neighborhoods (like Sunnyside/Hillhurst), traditional static-methods underestimate the present value of flood risk mitigations. Further, a novel FHR that avoids onerous building restrictions was evaluated and shown to improve the risk mitigation of the current FHRs by 9.7%.

While the transferability of this specific case study is unclear, the significance of vulnerability dynamics for flood risk assessments is obvious. Further, this study unlocks the quantification of FHRs and other time-sensitive mitigations for decision makers, allowing them to optimize from a wider range of flood defenses for their communities, including more tailored and effective FHRs. With this new tool, decision makers can move past a static view of risk focused on today's communities — and towards more robust and resilient mitigations for the uncertain risks of tomorrow.

Preface

This thesis is an original work by Seth Bryant. The survey portion of this thesis work received ethics approval from the University of Alberta Research Ethics Board under the project name "Homeowner flood response and recovery" (No. Pro00075880, dated 2017-10-16). Significant guidance for the model study described in this work was provided by Evan G.R. Davies (supervisor) and David Sol of IBI Group (project partner).

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Glossary of Key Terms and Acronyms

Actual year of building construction (AYOC)	Estimated date of substantial building completion (does not consider major renovations or additions).
Alberta Curves	Eleven residential and 20 commercial loss functions developed by the Government of Alberta to predict direct-structural (S) and direct-contents (C) damages to buildings (by floor) from flood depth.
Anchor elevation	The elevation at which an object's relative flood depths are considered zero. For House objects, this is generally the main floor elevation.
Annual recurrence interval (ARI)	The statistical expectation of time between events derived from some observed time-series (e.g. a 100 ARI magnitude flood or larger has occurred 10 times in the past 1000 years). The inverse of an event's ARI is the annual exceedance probability of that event (e.g. a 100 ARI flood has a 1% chance of occurring each year). Often, the suffix 'ARI' is replaced with '-year' (e.g. a 100 ARI flood is equivalent to a 100-year flood).
Base flood elevation (BFE)	Water surface elevation of the regulatory flood, as determined by a flood hazard mapping study.
City of Calgary (CoC)	The municipal government of Calgary and its departments.
Cost benefit analysis (CBA)	In a flood management context, CBA is a decision-making method which compares the financial costs and benefits of flood mitigation options to estimate financial efficiency (relative to other options).
Exposure	The raw hazard intensity experienced by an asset during an event (absent any reduction) (e.g. a 'flood depth of 1 m').
Flood Hazard Identification Program (FHIP)	The Government of Alberta's program that executes, manages, and distributes flood hazard mapping studies across the province.
Flood hazard regulation (FHR)	A set of regulations to help optimize land use in floodprone areas. For example, FHRs may place limits on new development to avoid increasing the region's flood vulnerability. FHRs are comprised of: 1) rules governing land use; 2) spatial extents of the rules (FHZ); and often 3) some base flood elevation (BFE). Minnery (2013) makes a useful distinction between: 1) *retrofit* FHRs applied to already built-up areas; and 2) *greenfield* FHRs targeting undeveloped or new neighborhoods.
Flood Hazard Zone (FHZ)	The "area of land that will be flooded during the design flood event" (Alberta Environment 2011, 15) as determined by a flood hazard mapping study.

Flood risk management (FRM)	The pro-active planning, mitigation, or preparation activities to bring about flood risk reduction that are carried out in a risk-based framework.
Flood risk mitigation measure; *flood damage mitigation measure;* or *flood mitigation*	Decisions or policy interventions implemented to reduce flood risk (e.g. building levees or legislating FHRs).
Floodplain	A geographical area that receives sediment deposition from flood-cycles.
Floodprone	An asset or area with a reasonable likelihood of some future exposure to flood hazard.
Floodproofed	An asset with substantial flood damage mitigation (i.e. reduced vulnerability).
Government of Alberta (GoA)	The provincial government and its ministries and departments.
Government of Canada (GoC)	The federal government and its ministries and departments.
Hazard	A dangerous phenomena which may cause damage to humans and the things they value (UNISDR 2009).
Marginal-dynamic-benefits	Those benefits that a static view of risk fails to consider.
Mechanical and electrical (M&E) equipment	Often the target of elevating requirements (within flood hazard regulations), these include water heaters, furnaces, electrical boxes, and any similar (difficult to move) common household features.
North American Datum (NAD)	Arbitrary vertical datum for elevations (in meters) in this thesis.
Property-level protection measures (PLPM)	Small-scale, property-level measures to reduce the flood vulnerability of structures (e.g. backflow prevention valves, electrical improvements, penetration improvements, building elevations, foundation drainage systems, flood walls/barriers).
Rapid Flood Damage Assessment Model (RFDA)	Flood damage prediction tool developed by the Government of Alberta in 2014 to estimate direct tangible flood damage using the Alberta Curves (IBI Group and Golder Associates 2015).

Regulatory event; or *design event;* or *design flood*	Single, often hypothetical, flood event around which some policy or structural protection is designed. Often expressed as an annual recurrence interval (ARI). For example, under "Alberta's Flood Hazard Identification Program the […] 1:100 year return period flood calculated at the time of the study [is the design flood]" (Alberta Environment 2011, 15). Design events are the foundation of any *standards-based* flood management. This contrasts with *risk-based* decision-making which strives to consider all possible event probabilities and their outcomes.
Resilience	"Ability of a system to perform and maintain its functions [under] hostile or unexpected circumstances" (Simonovic 2013, xiv). In the context of this thesis, resilience refers to the flood damage reduction of a mitigation measure after it has failed.
Risk	In a hazards context, the Knighton definition is most useful: "risk is the combination of the probability of an event and its negative consequences" (UNISDR 2009, 25), or in mathematical terms: *risk = hazard probability* x *consequence*. Applied to flood hazards, risk is the (conceptual or quantitative) product of the damage caused by the set of all possible floods and their likelihoods. Risk-based methods are the foundation of any flood risk management (FRM) decisions.
Risk-based framework	In a hazards context, this is a decision-making framework that considers the probability and consequence of a wide range of events, rather than the single event considered under a standards-based framework.
Social discounting rate	Financial depreciation rate applied in present value calculations to reflect the view that current spending should be weighted differently than future spending.
Standards-based flood management	Traditional (pre-modern) flood management. Standards-based flood management is a posthumously applied term to any flood management activities that do not use a risk-based framework. Typically, this involves the development of mitigation measures based on some pre-determined design event (e.g. constructing levees to protect from the 100-year flood).
Structural protections	Flood damage mitigation measures that reduce the magnitude or height of a flood event either through: 1) separation of hazards and assets (levees, dikes, floodwalls); 2) increasing conveyance (river widening, flood bypass, debris removal, storm drainage); or 3) attenuating the flood peak (reservoirs, wetlands). These contrast with non-structural measures which seek to reduce the vulnerability of assets.
Vulnerability	"Extent to which changes could harm a system" (Simonovic 2013, xiv). In the context of this thesis, an asset's vulnerability is the expected performance (of its attributes) in reducing flood damage. High vulnerability assets are expected to suffer more damage than low vulnerability assets for the same exposure (e.g. retrofitting houses with backflow valves reduces their vulnerability).

Vulnerability elevation	The lowest elevation at which an asset is vulnerable to flood damage (e.g. basement floor elevation) in the absence of property-level protection measures (PLPMs).
Water surface level (WSL)	Height of a free water surface (from the study datum in meters).

1. Introduction

The relevance of this work lies in three observations: 1) floods continue to damage society; 2) climate change is likely to increase flood hazard; and 3) urban development is likely to increase flood vulnerability. Fortunately, there is a unique opportunity to avoid this catastrophic confluence in Alberta as politics are now relatively disaster-aware following the triple pain of $1.0, $5.1, and $8.8 billion disasters.[1] Most notably, on June 18, 2013, a low-pressure system stalled in the headwaters above Southern Alberta, triggering widespread flooding and devastating many communities — especially Calgary. The significance of the 2013 Flood on flood management in Alberta, and across Canada, cannot be understated.

1.1. Drivers of Change

Climate Change

Climate change studies, focusing on Southern Alberta, project an increase in the frequency of extreme precipitation events (Burn and Whitfield 2016; Gizaw and Gan 2016; Kundzewicz et al. 2014). However, the influence of these precipitation changes on flood flows is less certain, but studies suggest floods will occur earlier in the year (Valeo et al. 2007; Farjad, Gupta, and Marceau 2015). Similarly, in a forensic study of the 2013 Flood, Teufel et al. (2016) concluded that anthropogenic greenhouse gas emissions contributed to the precipitation magnitude, but they found that influences on runoff mechanisms are more complex and less attributable. While more work is needed to improve projections of climate change impacts on the future flood hazard in Southern Alberta, this hazard is likely changing. Developing tools to quantify such dynamics into flood risk decisions is essential to prepare for, and mitigate any rise in flood damages driven by climate change.

Urban Development

In their global analysis, UNDESA (2015) forecasts that by 2050 Canada's population will increase by 27%, with the share of urbanization increasing by 8%. Using their in-house model, the City of Calgary's (CoC) forecasts the city's population to grow 10% by 2023 from the current 1.267

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[1] Estimates for the 2011 Slave Lake Fire (KPMG 2012), the 2013 Southern Alberta Flood, and a preliminary estimate for the 2016 Fort McMurray Fire (Alam and Islam 2017) adjusted to 2016 CAD with Consumer Price Index (Statistics Canada 2017b).

million (City of Calgary 2018a). Similarly, Urban Futures' (2012) demographic analysis predicts a tripling of population by 2075. While this urban growth has historically been outward into the greenfield suburbs, a new Municipal Development Plan strives for more densification of the developed core (City of Calgary 2015), where most of the fluvial flood hazard lies. Figure 1-1 shows the observed and projected shift in these population distribution trends. Such trends will expose more people to flood damage — unless society adopts more resilient and robust strategies than those that facilitated the 2013 Flood.

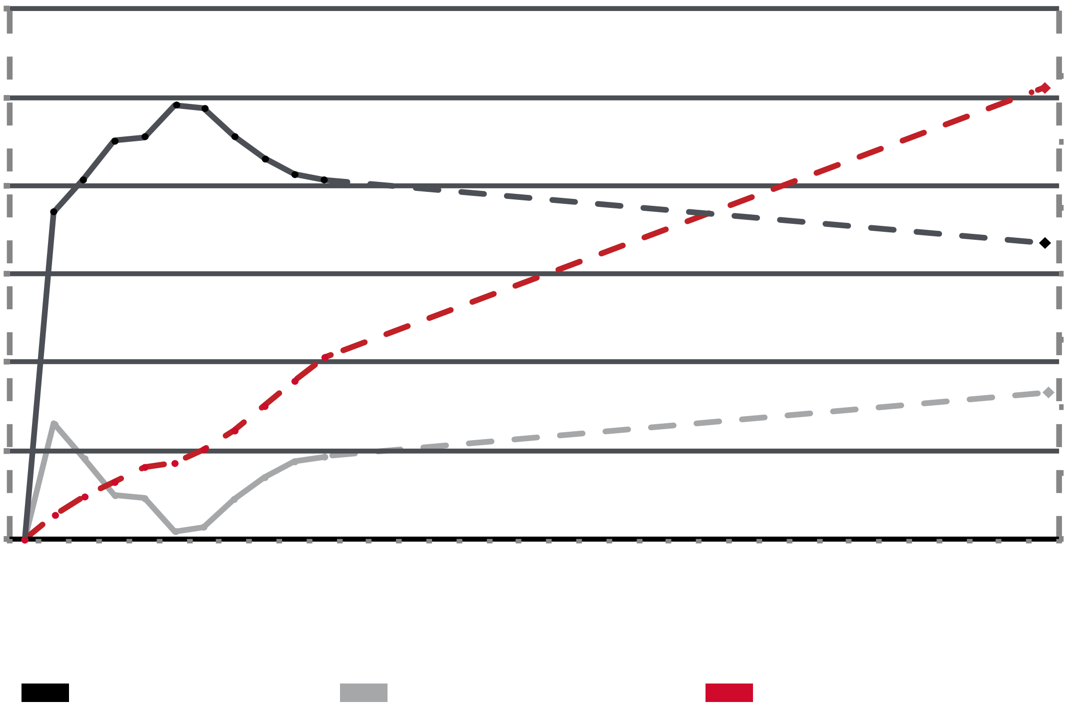

Figure 1-1: Historical and projected population growth in Calgary by area from City of Calgary (2016).

1.2. Moving Forward

Taking a wide perspective of how developed societies have accumulated flood risk, White and Haughton (2017) elucidate the 'tyranny of the present:' a systemic collection of forces that work against sustained disaster harm reduction that include: 1) the over-emphasis on protecting current capital; 2) the uncertainty of the future; and 3) the political desire for short-term gains over long-term disaster avoidance. In the face of such forces, it is easy to understand a decision maker's preference for expensive and prominent structural protections that give defense today for their established constituents. Unfortunately, this type of planning leads to extra-exposed neighborhoods densifying, like Sunnyside/Hillhurst in Calgary. When this densification occurs without restriction and behind the perceived safety of a levee, thousands are left vulnerable to the devastation of floods like the 2013 Flood. Now, the stakes are even higher — with climate-change-induced super storms and rapid urbanization a more robust flood risk management (FRM) is required.

The devastation of the 2013 Flood precipitated a transition in Alberta from the traditional standards-based approach, where flood protection is designed for a single level-of-safety, towards a risk-based approach. This new risk-based approach recognizes that robust planning must consider vulnerability and the full range of floods that may harm a community rather than focus on a single, subjective, design event. Further, a risk-based view allows decision makers to quantitatively optimize mitigations for their community, helping jurisdictions with shrinking budgets spread protections further.

To drive this new paradigm, the Government of Alberta (GoA) developed the Rapid Flood Damage Assessment Model (RFDA) from extensive field surveys and expert knowledge gained during the 2013 Flood recovery (IBI Group and Golder Associates 2015). While RFDA was a significant improvement to decision-making in Alberta, it was designed to calculate the current risk, ignoring vulnerability dynamics like urban growth. This 'static view' of risk biases spending towards fast risk-reducing measures, like structural protections, and against slower acting measures, like flood hazard regulations (FHRs).

Despite this bias, simple FHRs have been widely implemented in Canadian cities since the introduction of the Canada Flood Damage Reduction Program in 1975. Following the US example, these simple FHRs imposed development restrictions in floodprone areas. These regulations were spatially applied using the predicted inundation extents of a single regulatory event, similar to the traditional design of structural protections. While the design of structural protections has largely moved away from this standards-based flood management (towards a risk-based paradigm), decision makers lack the dynamic-tools necessary to extend this progress to FHRs. Without such tools, policy-makers cannot make transparent or informed decisions on the future of FHRs.

Unlike decision makers of the past, who allowed widespread and vulnerable housing in the floodplain, today's decision makers are fortunate to have the hindsight of disasters and a wealth of technology to lead their communities away from the flood's path. To be successful in the face of uncertain climate change, the measures they implement need to be more flexible, resilient, and comprehensive. To be implemented at scale, these measures must be cheap and efficient. Levees alone, like the one that overtopped and permitted the inundation of the Sunnyside neighborhood during the 2013 Flood, may not be suitable to bring about significant risk reduction in developed municipalities like Calgary. Society needs to overcome the tyranny of the present and plan for the risks of tomorrow.

1.3. Research Questions

This thesis is motivated by a desire to avoid future flood damage, through improving decisions around flood risk. As discussed above, there are many indications that the 2013 Flood may become the new-normal if more progress in FRM is not achieved. Fortunately, the momentum from this flood has not abated, and advancements like RFDA provide opportunity and foundation for a more robust FRM. Recognizing the advancement that RFDA represents, the work in this thesis strives towards the next step: shifting from a static view to a dynamic view of risk. Towards the dynamic view, this thesis develops the novel Stochastic Object-based dynamic Flood Damage Assessment modeling framework (SOFDA) and applies it to a floodprone neighborhood in Calgary, Alberta, Canada. SOFDA builds on RFDA to create a framework that includes: 1) stochastic uncertainty; 2) property level protection measures (PLPMs); and 3) urban redevelopment. To explore the value of this dynamic view of risk, the SOFDA model is used to address the first research question:

> *How does the incorporation of vulnerability dynamics change the assessment of benefits for traditional flood mitigation approaches?*

Armed with a dynamic-tool capable of quantifying the risk reduction of slow-acting mitigations like FHRs, more adaptive and efficient solutions can be explored to reduce communal flood risk. To show the value of this, the model is also used to address the second research question:

> *Are there more favorable FHRs that provide as much or more flood damage mitigation than the current FHRs, while avoiding the more onerous restrictions?*

The remainder of this thesis: 1) provides the reader the necessary context to understand flood risk and how it is modeled and managed in Canada; 2) describes the SOFDA model and its setting; 3) analyzes the model results to address the research questions; and 4) concludes with a discussion of the implications of these results and how they might be used to improve FRM decisions.

2. Flood Risk

This chapter seeks to provide the reader an understanding of flood risk modeling in Alberta. Such context spans from the definition of basic terms to explaining how flood risk accumulates, is modeled, and is managed in urbanized societies.

Any discussion of flood risk must begin by defining the term *flood* itself: an “unusually high stage or flow [of water] over land or coastal area, which results in severe detrimental effects” (Ghosh 2014, 1); or which occurs when a “body of water rises to overflow land that is not normally submerged” (Simonovic 2013, 7). The selected authors’ word choices reveal some hallmarks of the traditional attitude towards flooding: something both abnormal and detrimental. From the perspective of someone whose house was swept downstream, such a view is certainly reasonable.

However, elevated water levels and widespread inundation of river systems is a natural consequence of hydrology, and ecologists have identified many aspects of flooding that are necessary for healthy ecosystem function (e.g. nutrient transfer, sediment flush, and reproduction cycles) (Peters et al. 2016). Considering this, it is really the *absence* of floods that is unusual. Unfortunately, urbanized societies have failed to consider the flood cycle in this way (or at this timescale). Instead, cities and towns develop in areas with a high probability of flooding. The product of this probability and the damage it would cause is the basic definition of *flood risk*.

Floodplains are often the most attractive areas for development (at least on short time-scales) as they are flat, fertile, and abut waterways that supply drinking water and transportation. As a result, the floodplains in many regions are densely populated, often leading to destruction and human suffering during floods. Similarly, poor drainage infrastructure can lead to pluvial flooding and damage, regardless of proximity to a river.[2] To manage and reduce this suffering from flood damage, governments have traditionally intervened by investing considerable resources in flood management, response, and recovery. Such flood risk reduction can be thought of as a discipline of diverse stakeholders, methods, applications, and views with the common objective of reducing the likelihood or magnitude of flood-induced harm to humans and the things they value. Figure 2-1 provides a framework for these flood risk reduction activities. Within flood risk reduction,

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[2] This thesis focuses exclusively on riverine floods.

flood risk management (FRM) seeks to reduce flood risk, while balancing communal values. This risk reduction is achieved through implementing mitigation and planning for disaster response and recovery. However, some residual risk always remains — catastrophe strikes — and FRM evolves in reaction to the devastation.

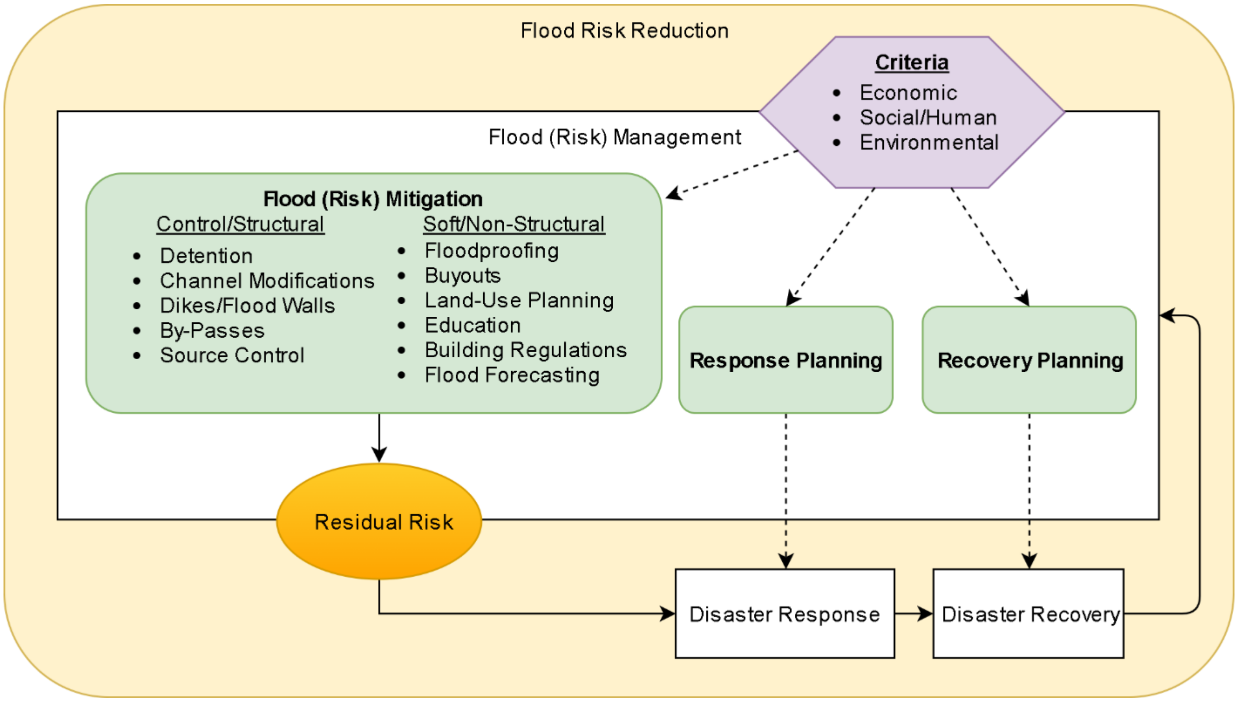

Figure 2-1: Flood risk reduction conceptual framework. Dashed lines show 'influences' while solid lines show that one step 'leads to' the next. White boxes represent different classes of flood risk reduction over the flood risk cycle, and green boxes represent specific activities.

2.1. Governance in Canada

Shrubsole (2013) describes four major eras of modern flood management in Canada:

1. federally-managed structural protections [1953-1970];
2. federally-managed mix of structural and non-structural measures [1970-1998];
3. paralysis [1998-2006]; and
4. municipal and provincial measures [2006-2013].

Behind this timeline is a whipsaw of responsibility between different levels of government. Harrison (1996) describes this as “pass-the-buck syndrome” and attributes it to Canada’s federalist structure. Kreibich et al. (2015) posits that Canada is more liberalism-oriented, and therefore leans towards less federal and more private responsibility. Similarly, Renzetti and Dupont (2017) point to the complicated web of jurisdiction between federal, provincial, municipal, and indigenous governments that leads to long negotiations, conflicting objectives, and an atmosphere of shirking responsibility. Regardless of the drivers, starting in 2006, the federal government has taken a backseat role in FRM, limiting itself to providing funding and advice for municipally- and provincially-led measures. Shortly after the warnings issued by Shrubsole (2013), Canada was struck by the $1 billion Toronto flood (Public Safety Canada 2017) and the $5 billion 2013 Flood in Southern Alberta (Bryant and Davies 2017), the latter being the most expensive disaster in Canadian history at that time.[3] These dual disasters triggered a significant policy shift in Alberta and brought more evidence of the longer trending federal retreat.

Land Use Planning

The recent jurisdictional changes of FHRs in British Columbia provide a Canadian example of responsibility downloading and its effects. In 2003-2004 the province transferred responsibility for implementing and enforcing FHRs to municipal governments. To examine the results of this policy move, Stevens and Hanschka (2013) analyzed 55 such municipal FHRs and found them largely inadequate, with two-thirds having no FHRs despite provincial guidelines. They point to a lack of technical expertise, conflicting incentives, and poorly constructed and optional guidelines.

In Alberta, the province has delegated planning authority to the CoC via the Municipal Government Act which authorizes municipalities to create a land use bylaw that “may prohibit or regulate and control the use and development of land and buildings […] on land subject to flooding” (Province of Alberta 2017). In the aftermath of the 2013 Flood, the GoA passed Bill 27, reclaiming some of this authority, allowing the province to pursue “controlling, regulating or prohibiting any use or development of land that is located in a floodway” (Minister of Municipal Affairs 2013). However, the regulations to enforce these new powers are, five years later, still awaiting approval. This history of poor land-use planning has contributed to an accumulation of flood risk in Albertan communities, motivating policy-makers to invest in mitigation long after the floodplains have been urbanized.

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[3] This event has since been surpassed by the 2015 Fort McMurray fire estimated at $8.8 billion CAD2015 in damages (Alam and Islam 2017).

2.2. Mitigation

Flood risk mitigation measures are those tangible decisions or policy interventions implemented by FRM. Generally, such preventative (ex-ante) spending is more efficient than response and recovery (ex-post) spending, with some studies finding ex-ante spending twice as efficient (Davlasheridze et al. 2017). In other words, an ounce of prevention is worth a pound of cure (or at least two ounces). The task of a flood risk manager (i.e. decision maker) is to select the right set and level of mitigation that satisfies the values of their community. This is a challenging, never-ending, and often thankless task.

The most common classification for flood mitigations in North America is the dichotomous *structural* vs. *non-structural*. This separates engineered, often large-scale, structural protection measures from those non-structural measures that seek to reduce the vulnerability of exposed assets (Zevenbergen et al. 2010). Structural protection measures instead reduce the magnitude or height of a flood event either through: 1) separation of hazards and assets (levees, dikes, floodwalls); 2) increasing conveyance (river widening, flood bypass, debris removal, storm drainage); or 3) attenuating the flood peak (reservoirs, wetlands). While both structural and non-structural measures are considered in this thesis, this chapter focuses on those non-structural measures that are difficult to evaluate under a static view of risk, and provide the mechanism for flood risk reduction under FHRs.

2.2.1. Property-Level Protection Measures (PLPMs)

More localized and less capital-intensive than structural measures, PLPMs are those non-structural improvements made to an individual property that reduce its vulnerability to flood damage. PLPMs can be retrofit, or installed during construction, and are often categorized as:

- *wet-floodproofing*: measures that reduce the damage potential of flood waters without altering the flow paths (e.g. using water resistant building materials, increasing foundation openings to limit pressure differentials, strengthening foundations);
- *dry-floodproofing*: measures that prevent flood waters from entering the property (e.g. backflow valves, sump pumps, sealants, wraps, shields, foundation drainage systems, micro-barriers); and
- *elevating, removing, or relocating*: elevating either the whole or parts of an asset (e.g. leaving basements unfinished, raising houses) (FEMA 2014).

To establish the effectiveness of PLPMs, Lamond et al. (2018, 9) conducted an extensive meta-analysis of 2,271 literature sources and concluded that "estimates of the performance of the measures in limiting damages for the UK are […] largely based on expert judgement and desktop accounting, as there is currently insufficient real world data available to establish an empirical view." The few empirical studies do agree that PLPMs have reduced damages (Kreibich et al. 2015; Poussin et al. 2015; Highfield and Brody 2013; Kreibich et al. 2005); however, there is little consistency in methods and conclusions on specific measures.[4] One generalizable conclusion from this work however is: dry-floodproofing measures are only effective for small floods; while wet-floodproofing measures (being more resilient) can mitigate damage from both large and small events (Kreibich et al. 2015).

To our knowledge, there are no Canadian investigations on PLPM efficacy. Further, it is widely accepted that vulnerability is highly regional and that PLPM efficacy varies from community to community (Poussin et al. 2015). Considering this, the following efficacy summaries are provided with the recognition that their applicability to the study area of this thesis is limited.

Elevating

Elevating assets is probably the second oldest form of flood mitigation (relocating being the first). A classic example are Dutch "terps," which are mounds built to elevate dwellings in the floodplain, a practice dating from around 500 B.C. (Lonnquest et al. 2014) (Figure 2-2; right side). Modern methods include elevating: 1) foundations (Figure 2-2; left side); 2) internal floors; or 3) vulnerable building features (e.g. mechanical and electrical equipment) (FEMA 2014). Elevating for mitigation lowers vulnerability by reducing the frequency building features are damaged by flood waters.

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[4] For example, Kreibich et al. (2005) found "flood adapted use" was an effective damage reducer during a 2002 flood in Germany, while Highfield and Brody (2013) found that communities in the USA classified as having adopted "flood protection" were less vulnerable than their counterparts over a span of 14 years. Discerning which specific PLPMs led to the damage reductions in each study is prohibited by, for example, foundation waterproofing being covered under both 'flood adapted use' and 'flood protection,' while backflow valves are only bundled into 'flood protection.'

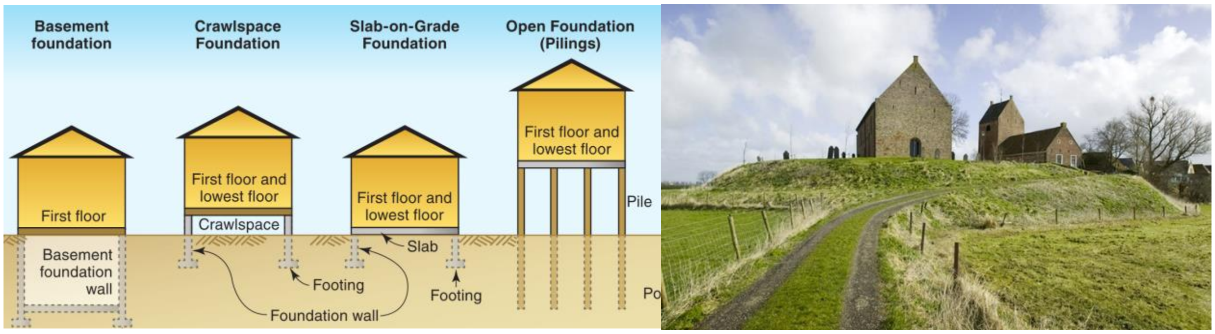

Figure 2-2: [Left] typical foundation options for elevating buildings as a retrofit from FEMA (2014) and [right] a Dutch terp mound from Cornell et al. (2018).

Following the extreme 2002 flooding of the Elbe River in Germany, Kreibich et al. (2005) conducted an extensive and in-depth survey of 1,248 households to establish the performance of 11 mitigation measures. They found that those homes without heating and electrical features in the basement had 36%[5] less damage. Similarly, Poussin et al. (2015) investigated flood-affected households in France to determine the efficacy of 11 PLPMs. They found that homes with raised power sockets performed the best, with an 84% reduction to building damages, while elevated boilers reduced damages by 60%. Extending their analysis to the economic efficiency of measures, Poussin et al. (2015) found that elevating boilers was cost-effective for all flood frequencies, while elevating power sockets and the entire main floor (in new construction) were only cost-effective for small floods (1 and 10 ARI). In summary, elevating above the reach of flood waters certainly reduces damages; however, this mitigation option may cost more than it is worth — especially as a retrofit measure.

Backflow Valves

Extreme precipitation or anthropogenic hydraulic events (i.e. pump failures) can overwhelm and surcharge municipal sewers, driving hydraulic head above the lowest drain of a (connected) building. Unimpeded, this phenomenon can lead to exposure from contaminated water (e.g. bubbling-up sanitary water from a basement floor drain) and often flood damage. To prevent exposure from this reverse flow, backflow valves can be installed on the sewer connection line. Modern backflow valves, like the one shown in Figure 2-3, operate with a buoyant flap that automatically closes during reverse flow. Typical backflow valves do not require power to operate.

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[5] flood damage relative to total building value

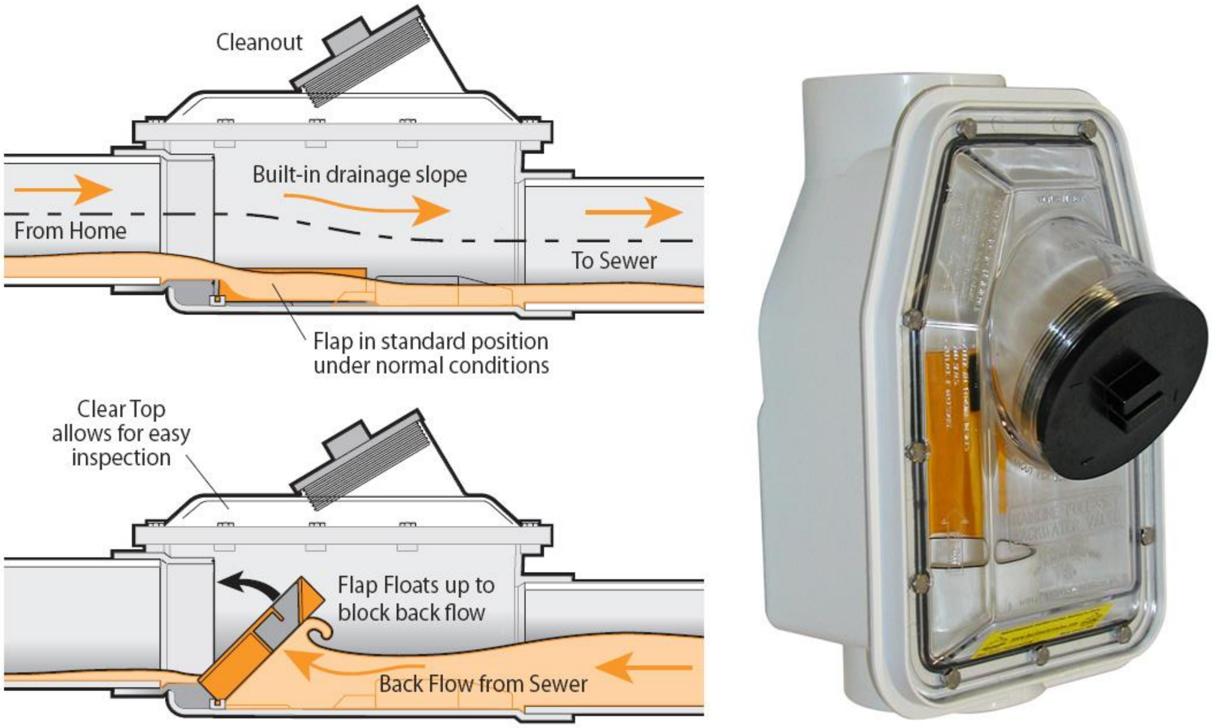

Figure 2-3: Typical modern backflow valve [left] diagram and [right] image from Mainline (2013).

Studies on the efficacy and efficiency of backflow valves are sparse. In one of the few such studies, Poussin et al. (2015) found that backflow valves reduced building damage by 65% and were cost effective for small floods (1 ARI) in France. Despite the sparsity of evidence, some municipalities in Canada have subsidized the installation of backflow valves (Kamerman 2018; Epcor 2018). As of 2014, Calgary's FHRs require backflow valves be installed on new homes built inside the flood hazard zone (FHZ) (Appendix B).

Foundation Drainage

In regions with high groundwater and foundations well below ground level, foundation drainage systems are often used to prevent the buildup of hydrostatic pressure along the foundation wall. This reduces structural loads and the likelihood of infiltration into the building. As shown in Figure 2-4, a typical foundation drainage system is comprised of: 1) a highly permeable backfill zone abutting the exterior of the building foundation to intercept groundwater (i.e. weeping tile); 2) a connection to a local drain to transport the intercepted groundwater; and 3) a local drain to remove the intercepted groundwater from the system. In older homes, this local drain may be a municipal sewer lateral, while in newer homes, this is typically a sump pit. From this sump pit, water can be pumped by a sump pump up to the ground outside the house. While this sump pump system can perform well under normal conditions (when properly maintained), these pumps are often inadequate to drain overland flooding or widespread seepage (Sandink 2009). Further, many foundation drainage systems lack redundancies by relying on: 1) a single sump pump susceptible to mechanical failure; and 2) the municipal electrical grid which is susceptible to outages (especially during extreme flood disasters). Therefore, to improve reliability, backup pumps and independent power supplies are often recommended (Sandink 2009; FEMA 2014).

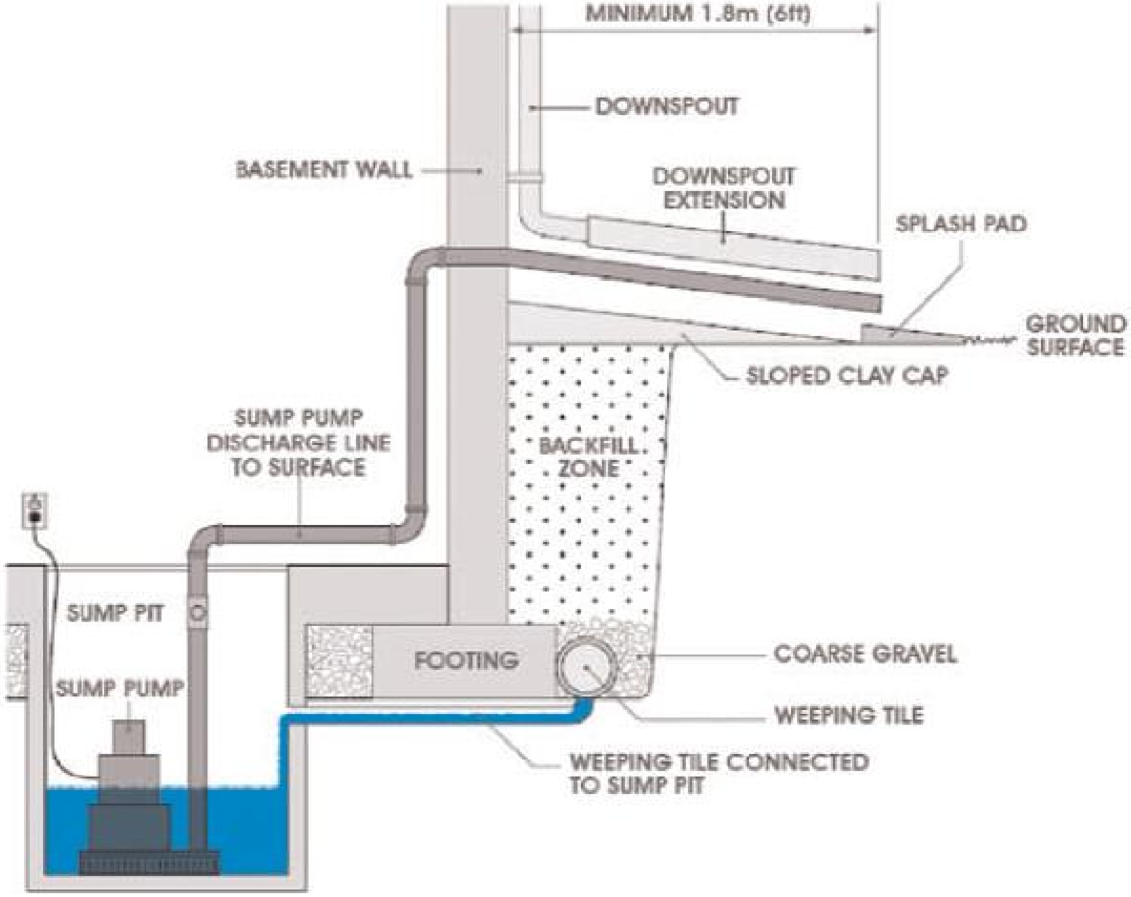

Figure 2-4: Foundation drainage schematic from Sandink (2009).

Prevalence

The limited data on PLPM prevalence in Canada is presented in Table 2-1. The relatively low rates reported suggest significant potential for flood risk reduction in Canada through installing or requiring more PLPMs.

Table 2-1: PLPM prevalence survey results on 3 PLPMs for floodprone homes in Canada from the literature.

Study	**Participant description**	**Backflow valves**	**Sump pumps**	**Backup power**
Thistlethwaite et al. (2018) [a]	2,300 residents in floodprone postal codes Canada-wide	39%	28%	14%
IPSOS (2016)	200 residents in floodprone communities in Calgary	not surveyed	50%	27%
Winterton (2017)[b, c]	1,377 residents in Windsor, ON	24%	53%	not surveyed
Kamerman (2018)[b]	238 participants in a web survey promoted in St. Thomas, ON	35%	16%	not surveyed

a) This study does not adjust for the coarseness of postal codes. In places like Calgary, most homes within a 'floodprone postal code' (those postal codes with some FHZ) can be well outside of the FHZ and have a negligible risk for riverine-flooding.

b) 'Yes' responses divided by total participants.

c) This survey was conducted to measure the efficacy of a backwater valve installation subsidy program.

Much research has been done to explore the drivers of PLPM adoption, with most focusing on voluntary uptake rather than the role of FHRs in mandating PLPMs. Many such studies show a strong correlation between PLPM adoption and *flood experience* (Bubeck et al. 2012; Merz et al. 2013; Winterton 2017; Thistlethwaite et al. 2018). However, the role of *risk perception* or awareness is less conclusive for actual PLPM *adoption* (Thistlethwaite et al. 2018; Rufat et al. 2015; Bubeck et al. 2012), but generally positive for *intent* to adopt (Thistlethwaite et al. 2018). While these drivers are key to informing voluntary policy measures (e.g. subsidy programs), this thesis focuses on mandatory policies (e.g. FHRs) and assumes property owners fully comply with any and all regulations.

2.2.2. Flood Hazard Regulations (FHRs)

FHRs are a type of spatial planning, or land use regulation, imposed by governments in a top-down fashion to reduce flood risk (Burby et al. 2000). By limiting the type and amount of development in the floodplain, FHRs are intended to limit a jurisdiction's future flood vulnerability. Minnery (2013) makes a useful distinction between: 1) retrofit FHRs applied to already built-up areas; and 2) greenfield FHRs which target undeveloped areas (or future developments). These retrofit FHRs are comprised of: 1) rules governing land use and building construction ("flood rules" or "FHR rules"); 2) base flood elevations (BFE); and 3) the planar extents of the rules called the flood hazard zone (FHZ).

Flood Hazard Zone (FHZ)

To evaluate the flood hazard in an area, flood hazard assessments typically combine: 1) a hydrological analysis that develops a flood flow-frequency relation; and 2) a hydraulic analysis using mass and momentum conservation modeling to estimate the inundation extents and water surface levels (WSL) of a given flood flow. This process is used to create flood hazard maps which delineate the flood hazard zone (FHZ) for a given design flood (e.g. 100-year flood flow).[6] In Canada, guidelines further split this zone into the floodway and flood fringe. The floodway is the channel that conveys most of the design flood flow while the flood fringe is the remaining inundated area (Figure 2-5).[7] As well as the planar delineation of hazards, flood hazard maps often provide some base flood elevation (BFE) that corresponds to the design flood WSL.

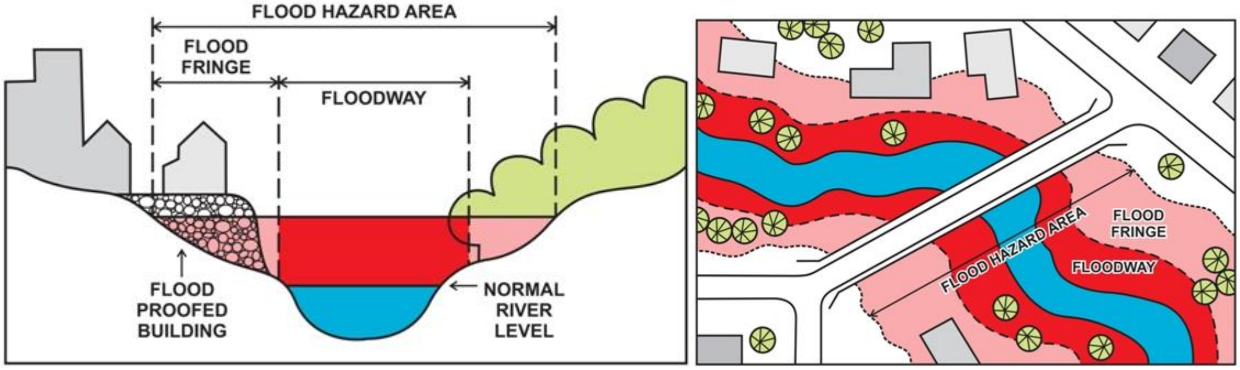

Figure 2-5: Flood Hazard Zone (FHZ) [left] profile and [right] plan-view diagram from Alberta Government (2017a).

Contrary to public perception, flood hazard maps are not inundation predictions for the design event frequency (unlike the hazard layers employed in this study). Instead, they aim to designate areas of risk within their jurisdictional boundaries in a uniform way. For example, flood hazard maps in Alberta assume all levees will fail and reservoirs (without dedicated flood storage) will provide no flood storage (Alberta Environment 2011). Such policies provide a standardized and well described spatial hazard map from which land use planners can mandate flood specific regulations or rules.

In addition to the spatial boundaries of FHZs, FHR application is further narrowed by asset type or activity. For example, the CoC FHRs only mandate backflow valves for new buildings and

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[6] Typically, an assumption of future buildup in the flood channel is also used in hazard mapping studies.

[7] This study focuses on the flood fringe.

additions (greater than 10%) in the flood fringe, excluding accessory buildings like a home office (Appendix B). Therefore, all existing buildings (and some new excluded building types) are unaffected by the regulations — even those inside the FHZ. Only once a property owner (inside the FHZ) applies for a permit to rebuild, or expand, are the FHR rules triggered.

Rules

When a regulated activity occurs on a property (e.g. new home construction) within the FHZ, the regulator can enforce the rules or requirements of the FHRs. In Calgary, these rules make reference to the spatially heterogeneous BFE designated on the hazard maps. This BFE serves as a mandatory minimum elevation for building features. For example, in the Sunnyside neighborhood, the BFE ranges from 1047.3 to 1046.4 m NAD. In some places this is as much as 2 m above ground. Under Calgary's current FHRs, any additions or new buildings within the flood fringe must elevate their main floors and mechanical and electrical equipment above this BFE (Appendix B).

Public Perceptions

In their 1993 study of 114 floodprone homes in London, ON, Shrubsole et al. (1997) found that, despite 62% of participants having flood experience, all felt that FHRs were unnecessary as structural mitigations had removed the flood hazard. Kreutzwiser et al. (1994) had similar findings in their survey of 74 homes within the FHZ of Glen Williams, ON in 1991. The negative views of FHZ residents may be explained by comparing FHRs to structural protections, which are often viewed as alternatives to each other. For example, structural protections are typically financed by all tax payers in a region, while the cost of FHRs are borne exclusively by property owners within the FHZ. In Calgary, this has led to local groups advocating for large-scale structural protections while opposing FHR enhancements (CRCAG 2016).

Effect on Property Values

The influence of hazards on property values is an active area of study in both the insurance industry and social-science. A common lens of these studies focuses on the influence of *natural disasters* on property values. Such studies often have mixed results (Rambaldi et al. 2013; Montz et al. 2017); however, some find a decrease in value immediately after the event, followed by a recovery in value (Babcock and Mitchell 1980; Bin and Landry 2013). A second, more specific lens seeks to understand the influence of *FHRs* on property values. Understanding this relation is important: 1) as a component of the burden of FHRs (necessary to approximate the efficiency of this as a mitigation option); and 2) for public perceptions and willingness to expand FHRs. The burden, or cost, of FHRs can be conceptualized as the value reduction brought about by the restrictions placed on the property (Shrubsole et al. 1997). Such a quantification requires comparing the property value *with* FHRs to its hypothetical value *without*. For example, a parcel designated as floodway, and therefore prohibited from having new structures, could be compared to a similar neighboring parcel, without such a designation, to quantify the value-reduction imposed by the FHRs on the designated parcel. However, generalizing the influence of FHRs on property values is challenging because: 1) both FHRs and property values are sensitive to local and regional context; and 2) separating the influence from level-of-risk and FHZ status (which, by design, should be correlated to the level-of-risk). To explore this, Shrubsole et al. (1997) applied pairwise t-tests for 1,774 property transactions in London, ON from 1978 to 1989, where 9% of the properties were within the FHZ. They found no significant impact on selling price, list price, assessed value, or days on the market due to FHZ designation. These findings were supported by their interview of 27 FHZ residents, 70% of whom felt there was no influence on property value because of FHZ inclusion. Babcock and Mitchell (1980) had similar findings for homes in Galt, ON in the late 70's. In summary, the burden of FHRs does not seem to be reflected in property values; however, disaster damage likely does reduce values in the short-term.

Impediments

Some political and institutional structures can act as impediments to effective FHR adoption and enforcement. Like many municipalities, the CoC relies on property taxes and new development for revenue. Such an arrangement creates a financial incentive (in the short-term) to maximize development (Kreibich and Thieken 2009; Thistlethwaite and Henstra 2017; Morrison et al. 2018). While municipal financial liability should act to counter such incentives, federal and provincial disaster relief neutralizes this somewhat (Thistlethwaite and Henstra 2017). Further, some jurisdictions tie disaster relief to an evaluation of compliance with self-imposed FHRs (i.e. how well municipalities follow the rules they set for themselves), making it more difficult for communities with stringent FHRs to receive payments (Stevens and Hanschka 2013). In such situations, it may be more rational for municipalities to have weak or no FHRs, thereby increasing disaster severity and the likelihood/magnitude of outside cash transfers (i.e. disaster relief). In other words, the municipality (or province) with the highest vulnerability will receive the largest piece of the disaster relief pie. Supporting this, the record of DFAA payments show that Alberta receives a disproportionate share of relief payments compared to the better-regulated and more populous Ontario (Frechette 2016).

Older neighborhoods are particularly challenging for FHR policy-makers. To understand this, Minnery (2013) makes a distinction between *retrofit* FHRs, applied to already built-up areas, and *greenfield* FHRs that target undeveloped areas. Greenfield FHRs are relatively easy for governments to implement as there are few established constituents who would perceive a loss from this regulatory burden. Further, robust greenfield FHRs regulate flood risk more uniformly and rapidly as every structure built within the FHZ is floodproofed. In contrast, retrofit FHRs are weak on all fronts: 1) established property owners may resist new FHRs as they often perceive some economic loss (Shrubsole et al. 1997); 2) grand-fathering and exceptions are carved out for established land use types (see Appendix B for examples) creating a patchwork of adoption; and 3) the slower pace of infilling (compared to greenfield development) means retrofit FHRs are slow to reduce vulnerability and leave communities with extended flood risk.[8] In this light, imposing retrofit FHRs can be politically challenging; however, without robust FHRs vulnerability may rise — leading to disasters like the 2013 Flood.

Moving Forward

In Canada, FHR development uses a standards-based approach where FHZs are mapped from a single design flood. For example, Alberta uses a 100 annual recurrence interval (ARI) flood for FHZ mapping (Alberta Environment 2011) while Saskatchewan uses a 500 ARI event (Moudrak and Feltmate 2017). While this approach certainly provides some gradual vulnerability-reduction, it fails to consider the efficiency of the measure (is the cost worth the benefit?). Further, this standards-based approach omits any consideration for spatially heterogeneous vulnerability and asset value. This omission often leads to high-value, high-density communities (e.g. downtowns) with the same FHRs as low-value, low-density communities. This one-size fits all approach can impose unaffordable requirements in some areas while vulnerability balloons in other areas —

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[8] The relevance of the pace of floodproofing depends on the objectives of the inquiry. If the focus is on reducing flood risk, clearly any floodprone greenfield development will increase flood risk, regardless of how floodproofed. However, this elevated risk may be acceptable considering the benefits of developing the floodplain.

neither suggests a well-managed use of the floodplain. Incorporating value and vulnerability heterogeneities into FHRs may provide greater efficiency as the level of mitigation burden can more closely match the level of risk. However, the current static risk assessment tools are incapable of quantifying the benefits of FHRs, obstructing policy makers from progressing past the standards-based paradigm and onto providing their communities with more robust and efficient FHRs.

2.3. Management

Traditionally, flood risk managers in Alberta have used a standards-based approach when making decisions on the appropriate set and extent of flood risk mitigation measures for their communities. This traditional decision-making method takes an arbitrary design flood (e.g. the 100 ARI flood) and finds the cheapest structural measure that protects the community from damage during a flood of that magnitude (or less). In older communities, many sections may still be at risk from such a flood, while the investment needed to protect from this is well beyond what that community can afford. This all-too-frequent scenario raises several practical questions: *how much should we pay for mitigation?* and *what mitigation option achieves the optimal balance of our communal values?* To answer these, a risk-based framework is needed.

While authors differ on the precise definition of a risk-based framework, the core meaning adopted here is: *any decision-making framework that considers the probability and consequence of a wide range of events, rather than the single event considered in standards-based frameworks*. A useful addition to this is the optimization of a decision maker's communal values (e.g. cost, ecosystem function, etc.) in the pursuit of flood risk reduction. This practice is referred to here as flood risk management (FRM). Sayers (2012, 283) defines FRM nicely:

> *[The objective of FRM is to] implement a portfolio of measures and instruments to reduce risk effectively and efficiently whilst achieving societal preferences for equity, safety, and ecosystem health. The increased resource inputs required to providing progressively greater reductions in risk should not be disproportionate to the additional benefits secured.*

In Alberta, the transition from a standards-based to a risk-based paradigm was largely driven by political dissatisfaction with the 2013 Flood damages. While this transition has significantly improved the transparency and robustness of decision-making around floods, its adoption is far from complete. The patchwork of management practices at different jurisdictional levels have gradually implemented risk-based frameworks to only a few areas of responsibility (Bryant and Davies 2017). For example, following the 2013 Flood, the GoA conducted a cost benefit analysis (CBA) to select the optimal mitigations for Calgary (IBI Group 2015), while (three years later) the CoC paid to upgrade the sanitary lift station in Sunnyside to the 100 ARI design event (City of Calgary 2018c) and passed more stringent FHRs based on the 100 ARI FHZ (Calgary Planning Commission 2014). Further penetration of risk-based management may be limited by a lack of technical expertise (Bryant and Davies 2017) and shortcomings in the current tools used by risk analysts — such as an inability to quantify the benefits of FHRs. Regardless, despite the progress made following the 2013 Flood, there remains substantial room for the improvement of FRM in Alberta.

2.3.1. Cost Benefit Analysis

To reduce flood risk, a FRM decision maker has a wide range of methods at their disposal. CBAs are the simplest risk-based method for evaluating the economic efficiency of a set of options. To establish the relative efficiency of a mitigation option in a CBA, the estimated annual damage (EAD) (described below) realized under the option is compared against the lifetime cost of that option. Both these values must be converted to present values through the application of a social discounting rate. This rate is generally taken as a positive value to reflect the view that current spending is less favorable than future spending (N. Smith, Brown, and Saunders 2016). When calculating the present value of the benefits, EAD is generally considered as a fixed or static price (Merz et al. 2010). This application of a positive social discounting rate in CBAs amounts to a decaying view of benefits and costs. For example, the 3% social discounting rate applied in the Calgary 2017 Options Assessment results in a 50% reduction of the costs and benefits calculated by the 24th year of the analysis.

CBA methods are fraught with shortcomings including: 1) the discounting of environmental benefits in a world with decaying ecosystems (Messner 2007); 2) the failure to account for non-monetary values; 3) the failure to fairly apportion costs and benefits in heterogeneous societies (i.e. externalities) (O’Connell and O’Donnell 2014); and 4) contributing to the ‘tyranny of the present’ discussed in Section 1.2. Regardless, CBAs remain the standard approach for decision support in FRM (N. Smith, Brown, and Saunders 2016).

Expected Annual Damage (EAD)

For risk assessment studies performed as part of a CBA, the cost of a mitigation is compared against the expected value for the damages avoided (generally in dollars per year). To calculate this expected annual damage (EAD) (in the hypothetical case where the full spectrum of outcomes is known) the continuous expected value formula is applied:

$$\mathrm{EAD} = \int_{h_D}^{\infty} f_h(h)\, D(h)\; dh$$

Where *D(h)* is the damage as a function of flood water level *h*, and $f_h(h)$ is the probability density function (with an annual time span) (Merz et al. 2009). However, generally the outcomes of only a few events are estimated (e.g. 5, 50, 100, 500, 1000 ARI) and therefore the expected value calculation must be discretized as:

$$\mathrm{EAD} = \sum_{j=1}^{m} \Delta P_j\ D_j$$

$$D_j = \frac{1}{2}\left(D\left(h_j\right) + D\left(h_{j+1}\right)\right)$$

$$\Delta P_j = P\left(h_j\right) - P\left(h_{j+1}\right)$$

Where ΔP_j is the exceedance probability increment and D_j is the average flood damage for the *j*-th interval, and *m* is the number of increments (Merz et al. 2009). To simplify this, common practice in economic flood risk assessments is to plot the damage and probability of the set of estimated events, then take the area under the curve as the EAD as shown in Figure 2-6 (Messner 2007).

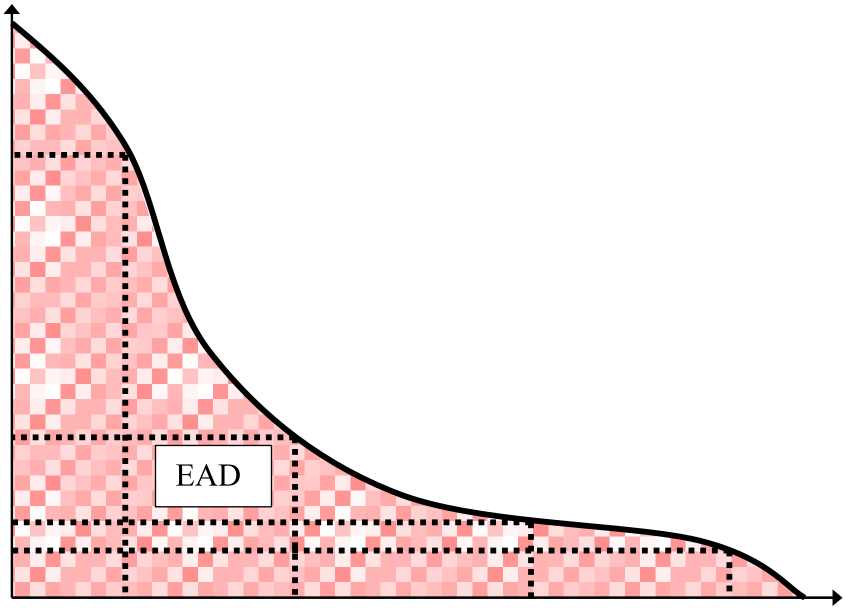

Figure 2-6: Conceptual damage-probability curve from Messner (2007). EAD denotes the area under the curve.

An important behavior of this algorithm is that damage estimates for low-magnitude events have a greater influence on EAD than estimates from high-magnitude events. For example, the damage estimate from a 10 ARI event is weighted 100 times more than that for a 1000 ARI event. In practice, this means FRM investments that focus on small events are generally more efficient than those that focus on large events.

The EAD approach has the following weaknesses and challenges (in addition to those mentioned above for CBAs):

- *Risk-neutral*: EAD monetizes all events proportional to their probability alone. Used in decision-making, this leads to an optimization based on economic efficiency only. While this may be the optimum approach to maximize investments in theory, it is contrary to human (and societal) behavior, which tends to be risk-averse by placing more value on avoiding extreme consequences than would be expected from the risk calculation alone (Merz et al. 2009). In other words, the “not on my watch” sentiment, common among FRM practitioners, is not reflected in decisions based solely on EAD (Haimes 2009).

- *Damage-probability tails*: Merz et al. (2009) evaluated three riverine flooding case studies in Germany and found that the EAD calculation for structural protection is dominated by high probability (low damage) events. Many risk assessments (esp. ones that consider groundwater damage) do not estimate enough events to capture the near-zero damage event (right tail; Figure 2-6 x-axis intercept),[9] requiring some extrapolation to calculate these important high probability events.

In light of these weaknesses, some authors have called for alternate risk metrics (Merz et al. 2009; Haimes 2009). However, in keeping with standard practice in Alberta, this thesis work employs the classic EAD as the sole flood risk metric.

2.3.2. Wet Houses: The Direct Flood Damage Process

What constitutes damage depends on the objective and perspective of the inquiry. For example, a flooded basement would certainly count as damage to the homeowner but would be a pay-day for the contractor. For the purposes of informing public policy decisions, damage evaluation should take a broad definition and include “all costs and benefits to the national or regional economy, including impacts on intangible goods such as ecosystem services and public health” (Merz et al. 2010, 1700). Such an economic evaluation stands in contrast to a financial evaluation, which takes the perspective of a single entity (e.g. just the homeowner). In keeping with standard practice in Alberta, this thesis work adopts a financial evaluation methodology for estimating flood damage (IBI Group and Golder Associates 2017).

Damage Types

Flood damage is often categorized into four groups by metric (tangible/intangible) and mechanism (direct/indirect/business interruption) (Meyer et al. 2013; Jonkman et al. 2008) as shown in Figure 2-7. Considering the broad range of damages fitting under this classification, different modeling approaches are often used for each category.

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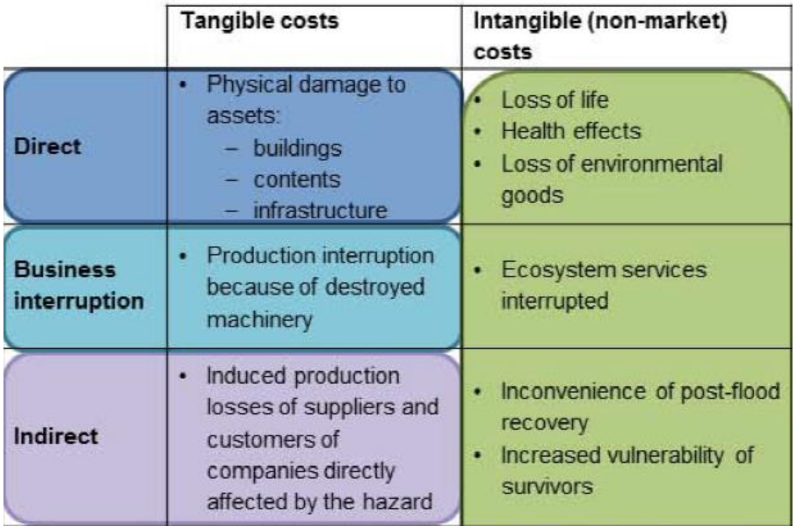
[9] Personal communication with D. Sol. This study assumed a right tail of three years and a left tail equivalent to the 1000-yr event.



	Tangible costs	Intangible (non-market) costs
Direct	• Physical damage to assets: – buildings – contents – infrastructure	• Loss of life • Health effects • Loss of environmental goods
Business interruption	• Production interruption because of destroyed machinery	• Ecosystem services interrupted
Indirect	• Induced production losses of suppliers and customers of companies directly affected by the hazard	• Inconvenience of post-flood recovery • Increased vulnerability of survivors

Figure 2-7: Hazard damage categories from Meyer et al. (2013).

Direct building damage is generally sub-divided by the type of asset damaged (Messner 2007):

- *structural (S)*: building components which are relatively immovable (e.g. furnace, hot water heater, wall-to-wall carpeting); and
- *contents (C)*: movable household items (e.g. furniture, personal belongings).

Building contents are generally assumed to be damaged or destroyed if inundated (IBI Group and Golder Associates 2015) or if the structure fails. Structural damage can be measured by item repair values (e.g. drywall replacement, window repair) (IBI Group and Golder Associates 2015) or, if severe enough, the total value of the structure. Mild flood damage is typically studied in terms of pathway (i.e. how the flood waters entered the home), while severe flood damage is studied in terms of structural resistance (i.e. how the flood waters caused the structure to fail).

Structural Failure

Becker et al. (2011) conducted a model study of the vulnerability of wood frame homes in Canada to severe structural flood damage and proposed the following three failure modes:

- *fill*: structure interior water depth is unsafe for occupation;
- *collapse*: floodwaters cause a collapse of the structure; or
- *float*: buoyancy force of the floodwaters dislodges the structure.

A structure can be driven to *collapse* or *float* failure by excessive (Nistor et al. 2009):

- *hydrostatic force*: water and saturated soil weight applied to one side of a wall (for dry-floodproofed structures) (Figure 2-8);
- *buoyancy force*: weight of the displaced water volume acting vertically on the structure (Figure 2-8);
- *hydrodynamic force*: drag force generated by moving fluid (Figure 2-9);
- *surge force*: wave impact force;
- *debris impact:* impact force of floating debris (or ice) striking the structure; or
- *scour*: the upper layers of soil may be eroded by the floodwaters destabilizing shallow foundations (Figure 2-10).

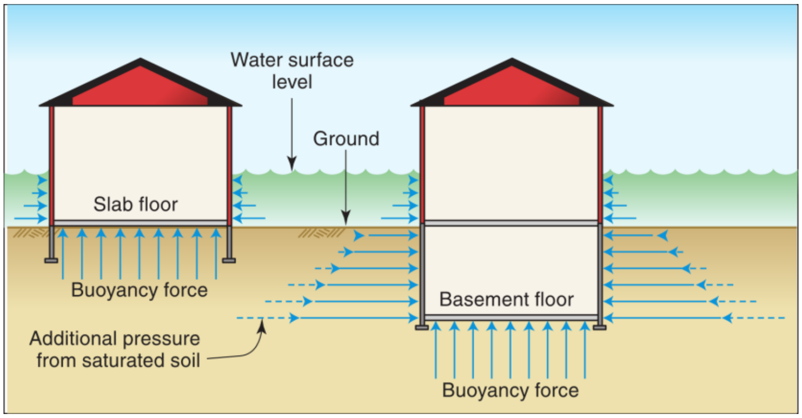


Figure 2-8: Diagram of hydrostatic and buoyancy forces on a typical structure from FEMA (2014).

Figure 2-9: Hydrodynamic loading on a structure from FEMA (2014).

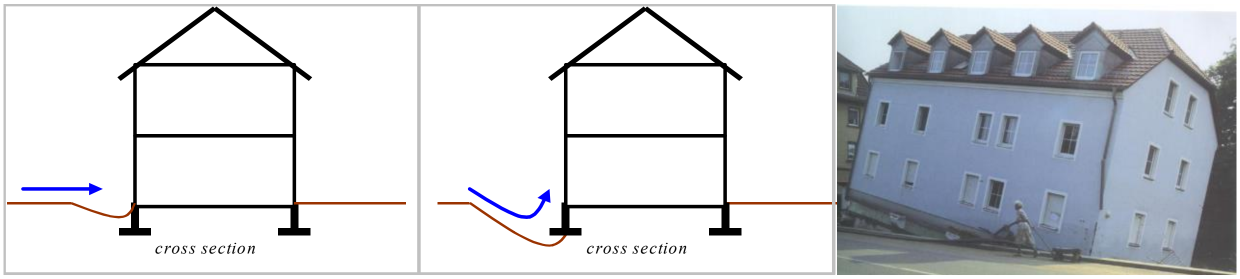


Figure 2-10: Scour failure on a building from Roos (2003).

During the 2013 Flood, no residential structures suffered collapse or float failure in the study area. Flood waters were generally calm, coming from a combination of riverine and pluvial flooding (see Section 4.2). As a result, direct property damage was caused by simple contact with flood waters.[10]

Groundwater Flooding

For communities in permeably floodplains, with significant infrastructure below grade, groundwater flooding can play a substantial role in flood risk (MacDonald et al. 2014). Groundwater flooding is considered a separate (but linked) mechanism to surface water flooding, where the division is determined by the depth of water (relative to the ground elevation at the building face) at the time of interaction with the asset. In other words, if water is inside the building before surface water is outside the building, the event is considered a groundwater flood. Separating ground and surface water flow is valuable for hazard analysts because the behavior of fluid flow differs significantly between the two mediums (which are therefore generally treated with separate models). Further, surface water floods are more visible by definition, contributing to their preeminent role in policy making (e.g. FHZs) and culture.

The groundwater/surface-water flooding dichotomy poses several challenges for flood damage analysis:

- *Ex-post damages:* Many assets are exposed to both surface and groundwater during a single event (e.g. first water bubbles up through the floor drain before spilling in through a window).

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[10] The Alberta Curves used in the model for this thesis assume damage exclusively from this contact mechanism.

- *Ex-post exposure*: Ex-post groundwater levels are generally unavailable and more heterogeneous than surface water levels. For example, few people have groundwater monitoring wells in their yards, while it is relatively simple to establish high surface water marks from debris lines.
- *Vulnerability*: Groundwater vulnerability is influenced by nuances in the building below ground like foundation cracks and plumbing vulnerability.[11] These nuances are generally difficult to investigate.

These challenges, and the fact that not all floodprone communities are vulnerable to groundwater flooding, have led to a lack of understanding of groundwater flood risk (compared to surface water flood risk). Fortunately, flood risk managers and academics have recently recognized the significance of groundwater flooding and progressed the preparedness for, and understanding of, it since the 2013 Flood. To confirm the significance of groundwater flooding in the 2013 Flood, and to better understand the mechanics of basement vulnerability, Abboud et al. (2018) conducted a survey of 189 homes in the flood-affected Elbow River neighborhood of Calgary. They found that 88% of respondents (who answered the question) reported the first entry of floodwater was from groundwater infiltration or a groundwater connection to the sewer.[12] Further, they found a strong correlation (R^2=0.61) between basement floor elevation and damage (i.e. deeper basements experienced more damage). These findings are similar to those of Thistlethwaite et al.'s (2018) Canada-wide survey of floodprone homes. They found that, of those who had experienced flooding in their current home (17%), 84% experienced it from sewer backup or basement-crack infiltration. Such evidence, and the experiences from the 2013 Flood, motivated the CoC to include groundwater flooding in their recent flood risk modeling studies as part of the 2017 Flood Mitigation Options Assessment (IBI Group and Golder Associates 2017). However, groundwater flooding is still not recognized by flood hazard maps in Alberta and few flood risk models consider vulnerability of this type.

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[11] Plumbing flood vulnerability is related to backflow valve presence and reliability, leaky pipes, sewer connection elevation and geometry.

[12] The study did not collect information on backflow valves and incorrectly excludes floor drains from sewer connected flow paths. Further, the study reports all multi-response entries together, preventing the division of damages by flow path. Therefore, it is difficult to quantify any ex-post or ex-ante efficacy of PLPMs.

2.3.3. Flood Risk Models

Hundreds of flood risk models have been developed by universities, governments, and the insurance industry to estimate various flood damage types, with most focusing on direct damage.[13] Various (somewhat overlapping) frameworks are present in the literature to categorize flood risk models (Gerl et al. 2016; Messner 2007; Merz et al. 2010). These are in addition to more classical model categories for sophisticated flood risk models, like agent based models (ABM) (Gordon and Yiannakoulias 2017), and system dynamics models (Di Baldassarre et al. 2015). More broadly, the focus of a flood risk model can be classified as: 1) *practical,* quantifying the flood risk of different scenarios or mitigation measures to inform policy or premiums; or 2) *academic,* pursuing a better understanding of the drivers of flood risk. More recent and holistic flood risk models are *dynamic*, forecasting risk as a function of time, rather than *static*, estimating a snapshot of the current risk. Finally, an emerging class of *integrated* models that simulate feedback between different components in the flood risk cycle shows promise (see Section 2.3.4).

A model's philosophy is often described as either: 1) *empirical*, developed from historical damage data; 2) or *synthetic,* developed from hypotheses and expert judgement of how damage occurs (Gerl et al. 2016). Another valuable dichotomy is a model's concept of either: 1) *deterministic*, producing a single damage prediction; 2) or *stochastic,* incorporating a measure of randomness and uncertainty in the damage prediction (Gerl et al. 2016). Stochastic models take more computing power but can quantify uncertainty while deterministic models can only do this qualitatively. Which model concept and philosophy is most appropriate depends on the: 1) scale; 2) objective; 3) resources available; and 4) data available for the study (Messner 2007).

Figure 2-11 provides a conceptual diagram of a traditional flood risk model. This shows how the scenarios and data are combined to conduct the flood hazard modeling, before the resulting exposure and resistance indicators are fed to the loss function for the damage estimate.

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[13] See Gerl et al. (2016) for a list of 46 direct damage models, see Merz et al (2010) for a list of direct damage models by sector, and see Messner et al. (2007) for a categorization of 10 typical European models.

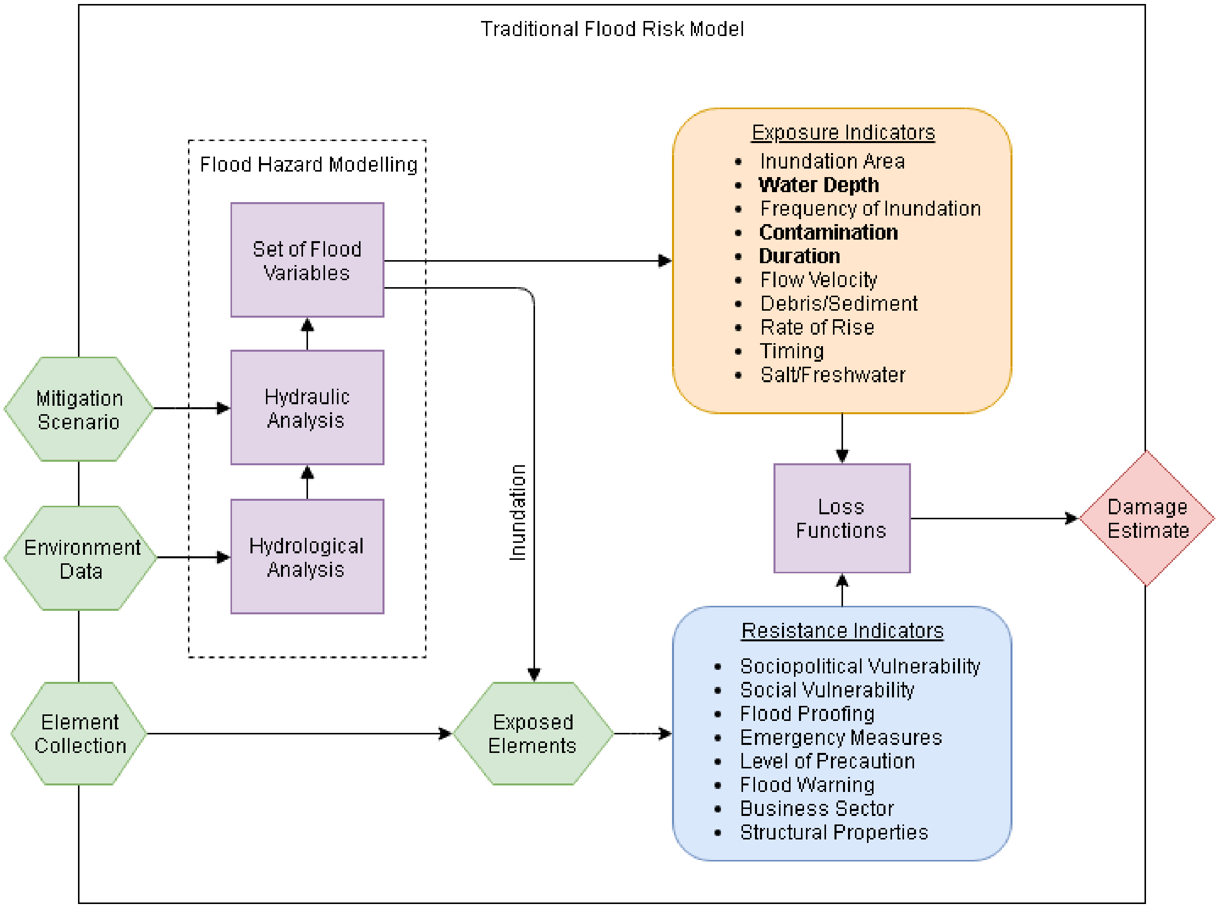

Figure 2-11: Traditional flood risk assessment process diagram. Exposure indicator lists adopted from Merz et al. (2010). Indicators in bold were identified as "significant" by Merz et al. (2013). Element collection is the spatial data set of potential exposed elements from which the exposed elements subset is determined based on the inundation area.

Loss Function

At the core of any flood risk model is the loss function that supplies the mathematical component to relate hazard and vulnerability to damage. The most basic loss functions were introduced by White (1945) and directly relate flood depth to damage — so-called 'depth-damage curves.' These univariable depth-damage relations remain the standard form of loss functions today (D. Smith 1994; Merz et al. 2010; IBI Group and Golder Associates 2017).

Considering the economic and life-safety implications of flood risk model results, surprisingly few studies have been published comparing or validating these models (Jongman et al. 2012; Schröter et al. 2014; Cammerer et al. 2013). Challenges in data collection and availability provide some explanation. In general, the few studies that do compare models against observed damage data find the

> *predictive capability of flood damage models is rather weak, especially when a temporal and spatial transfer is involved, i.e., the damage models are applied to different flood events and/or in different regions than those which have been used to derive the model (Schröter et al. 2014, 2).*

This limited transferability of loss functions seems reasonable considering the diversity of regional building typologies, social systems, and individual responses to flood exposure. This limitation motivated the GoA to develop their own depth-damage curves in 1981 from surveys in Fort McMurray, and again in 2014 from surveys in Calgary and Edmonton to create the 'Alberta Curves' discussed in Section 3.1.

2.3.4. Flood Risk as a System

Traditional flood risk models are simple and static: using historical and current variables for vulnerability and hazard to make an estimate for the flood risk at the time of study (Aerts et al. 2014; IBI Group 2015). While this static view of risk significantly improves upon the standards-based approach, it fails to consider the hazard and vulnerability dynamics that challenge urbanized societies. The most obvious limitation of this static paradigm is the quantification of risk for time-dependent mitigations, like retrofit FHRs. Unlike structural protections, which reduce a community's risk the moment construction is complete, retrofit FHRs influence the development of vulnerability over time as each floodproofed infill replaces a more vulnerable building.

To evaluate such dynamics, a more robust understanding of an urbanized society's interaction with flood hazards is required; specifically, one that considers the processes and components that give rise to flood risk as interconnected and constantly changing (Figure 2-12). Such a paradigm is commonly called *Systems Thinking* (Simonovic 2013; Zevenbergen et al. 2010; Sayers 2012); and models applied quantitatively to evaluate flood risk in this way are often termed *socio-hydrology models* (Di Baldassarre et al. 2013). Under this paradigm, individuals, institutions, and the environment are interconnected and driving a change in flood risk through time.

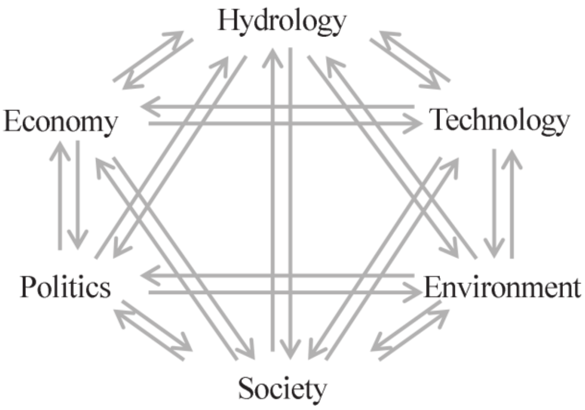

Figure 2-12: Diagram of an inter-connected view of flood risk from Barendrecht et al. (2017).

Many have called for the adoption of such a holistic, dynamic, and interconnected paradigm (Aerts et al. 2018; Barendrecht et al. 2017; Di Baldassarre et al. 2013; Bubeck et al. 2016; Meyer et al. 2013). However, in addition to major practical impediments (understanding human behavior, local data, etc.), there is no consensus on how to move forward. For example, Aerts et al. (2018) emphasizes the need to consider feedback between a major flood event and a society's adaptation and response following that event; while Barendrecht et al. (2017) discusses seven competing frameworks for structuring feedback between society and flood damage.

Table 2-2 provides a summary of recent dynamic and interconnected flood risk studies from the literature. Exploring this dynamic and interconnected nature of flood risk is an active area of research in Europe, with most relevant model studies published after the start of this thesis project. Dynamic, disconnected studies have a longer history, but must acknowledge the limit of making projections without accounting for feedback (Hall et al. 2005). Studies in both categories are admittedly simplified or conceptual and demonstrate the need for more research — especially on the role of individual human behavior (Aerts et al. 2018). A theme pioneered by Di Baldassarre et al. (2013) uses system dynamics models to explore conceptual flood risk dynamics between hypothetical societies. Similarly abstract, Grames et al. (2016) applies a dynamic optimization model to explain differences in flood risk dynamics between rich and poor communities. Models of both types are useful to conceptualize and understand drivers but lack the spatial components and local context to directly inform policy. Incorporating spatially heterogeneous hazard and vulnerability, ABMs have promise but require complex theories of human behavior and extensive high-resolution data (Dawson et al. 2011; Haer, Botzen, de Moel, et al. 2016), making model mechanics opaque and results difficult to interpret (Di Baldassarre et al. 2015). Developing a sophisticated model-chain, Thieken et al. (2016) simulates flood risk changes on an alpine valley in Austria from various climate change and socio-economic scenarios. This may be the most advanced dynamic, direct-damage, flood risk assessment case study to-date implementing: 1) global climate change models; 2) 2D hydraulics; 3) a land use model; and 4) validated vulnerability functions. However, feedback is not directly accounted for (e.g. human response to flood exposure). To our knowledge, no dynamic flood risk assessments have been conducted in Canada, and static models (like RFDA) remain the norm.

Table 2-2: Summary of select dynamic flood risk studies from the academic literature.

Publication	**Study Area**	**System**	**Model Description**	**Conclusion**
Haer et al. (2016)	Rotterdam, NL	Dynamic, Integrated	ABM incorporating household decision-making on berm installation and insurance uptake.	Not including human decision-making in flood risk assessments can overestimate risk by a factor of two.
Hall et al. (2005)	England and Wales, UK	Dynamic	National scale model using coarse datasets and empirical approximations for defense reliability, vulnerability, exposure, land use, climate change, and socio-economic growth.	Climate change and socio-economic growth can significantly influence risk.
Grames et al. (2016)	Conceptual	Dynamic, Integrated	Dynamic optimization model with idealized functions for hazard and vulnerability that includes components for economic output and defense spending. Utility maximization is assumed to identify optimal investment strategies.	Rich communities will invest in flood defense while poor communities will prioritize short-term spending.
Di Baldassarre et al. (2013)	Conceptual	Dynamic, Integrated	Simplified SD model with interactions between the economy, technology, society, politics, and hydrology.	Observed paradoxes (e.g. levee-effect) can be replicated with simple conceptual models.
Di Baldassarre et al. (2015)	Conceptual	Dynamic, Integrated	Simplified SD model that includes development driven increases to flood hazard for two FRM strategies: 1) structural protections; and 2) abandonment.	see above
Dawson et al. (2011)	Wales, UK	Dynamic, Integrated	Spatial ABM of individual vulnerability, evacuation traffic, and flood hazard.	ABMs can support evaluation of emergency management measures.
Haer et al. (2016)	Rotterdam, Netherlands	Dynamic, Integrated	Spatial ABM where agent adoption of PLPMs depends on flood experience, social networks, and risk communication.	Tailored flood risk communication is more effective than generic.
de Koning et al. (2017)	Greenville, NC	Dynamic, Integrated	ABM of home buyers/sellers and real estate agents in a flood-prone housing market.	Devaluation of floodprone properties is dependent on the behavior theory applied and level or risk perception.
Dubbelboer et al. (2017)	London, UK	Dynamic, Integrated	Spatial ABM of residents, insurers, local governments, developers, and banks under surface water flood risk to explore different insurance schemes.	The insurance scheme considered will not be viable in a scenario with increased surface water flooding.
Löwe et al. (2017)	Melbourne, Australia	Dynamic, Integrated	Spatial ABM of urban flood risk, urban development, infrastructure improvements, and buy-back schemes.	Urban planning outperformed other measures; however, this may be sensitive to local variations.
Thieken et al. (2016)	Tyrol, Austria	Dynamic	Dynamic coupling of downscaled GCMs, 2D hydraulic modeling, land use models, and depth-damage functions.	Adaptation by non-structural measures (such as stricter land use regulations or enhancement of private precaution) can reduce flood risk by 30%.

3. Rapid Flood Damage Assessment Model (RFDA)

In line with the post-2013 commitment to a risk-based approach in flood management (Alberta Government 2014), the GoA commissioned IBI Group to develop a "user-friendly, made in Alberta approach to flood damage assessment" (IBI Group and Golder Associates 2015, 67). This yearlong effort resulted in the Rapid Flood Damage Assessment Model (RFDA).[14] RFDA is now the standard flood risk assessment tool in Alberta.

The model work of this thesis relies on both the loss functions of RFDA and the experience gained by the project partner, IBI Group (esp. D. Sol), in applying RFDA across Canada. This chapter therefore provides a brief overview of RFDA with a focus on those elements that are adopted or improved upon by the model work of this thesis. The information presented in this chapter was obtained from: 1) IBI Group and Golder Associates (2015); 2) personal communications with the project partner; and 3) a review of the RDFA source code provided by the project partner.

As shown in Figure 3-1, RFDA uses exposure indicators (i.e. 'HEC-RAS Table'),[15] asset data (i.e. 'GIS Table'), and custom loss functions (i.e. 'Damage Table') to estimate damage from a set of floods for a given scenario (IBI Group and Golder Associates 2015).

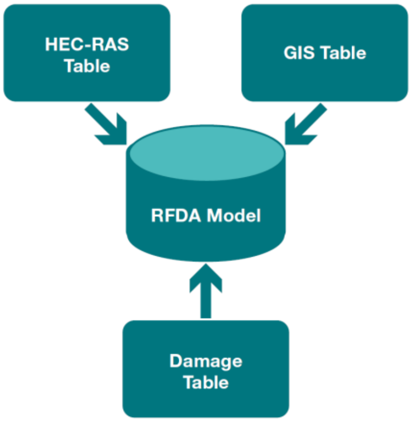

Figure 3-1: RFDA classic conceptual diagram from IBI Group and Golder Associates (2015).

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[14] RFDA is also called the "Provincial Flood Damage Assessment Tool (PFDAT)" or the "Rapid Flood Damage Assessment Model (RFDAM)." Often this is confused with the 'Alberta Curves' (discussed below) which are the default input file for RFDA's loss function.

[15] RFDA's primary exposure inputs are represented by the 'flood tables,' which are a spreadsheet of WSL for each flood under consideration on each asset in the building inventory. Generally, this spreadsheet is compiled from spatial datasets of WSL predictions for the different floods (hazard rasters) sampled at each asset location. These hazard rasters are compiled from the outputs of some river model, generally a 1D HEC-RAS model (see Section 5.2.1 for a description of the hazard modeling for the study area).

Figure 3-2 provides a more complete diagram of how RFDA fits into a flood risk assessment process. This diagram makes a distinction between tasks performed by: 1) a hazard analyst to generate the exposure indicators; and 2) tasks performed by a risk analyst to estimate flood risk using RFDA. Finally, this figure illustrates the elements of this risk assessment process that the model developed in this thesis builds and improves upon.

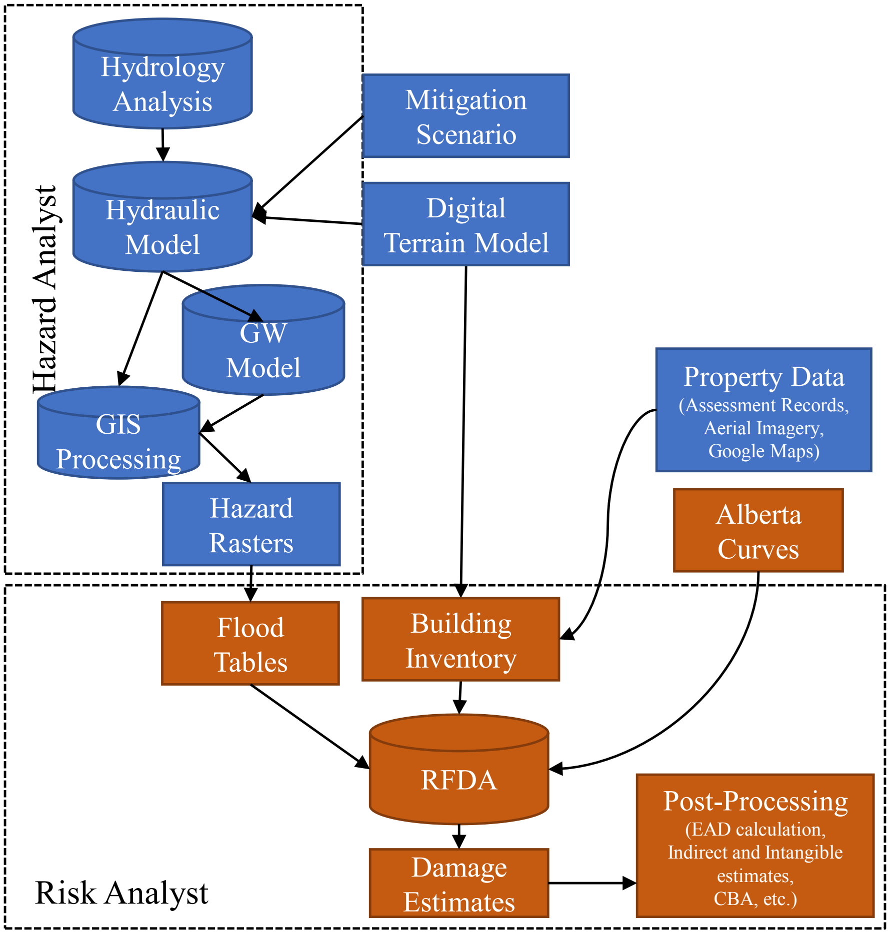

Figure 3-2: RFDA expanded conceptual diagram. Dashed boundaries denote typical division of work on a risk assessment team. Objects in orange denote components expanded by this thesis work.

3.1. Alberta Curves

At the core of RFDA are the 11 residential and 20 commercial loss functions which were developed to predict direct tangible structural (S) and contents (C) damages to buildings from flood depth. These curves further divide damages by main floor (M) and basement (B).[16] These loss functions, commonly called the *Alberta Curves,* are univariable, depth-damage relations (see Appendix D, Attachment D). Residential categories for the Alberta Curves were developed from expert knowledge of typical Canadian building typologies and divide buildings by: 1) size; 2) quality; 3); and 4) number of stories. The three building classes found in the study area are provided in Table 3-1. In practice, analysts use a combination of government datasets (e.g. property assessment construction technique records), aerial imagery, field surveys, and Google Street View to assign categories to houses (p.c. D. Sol). To develop the residential curves, 83 in-person surveys were conducted in 2014 of representative flood-unaffected homes in Calgary and Edmonton.

Table 3-1: Alberta Curve building types in study area adapted from IBI Group and Golder Associates(2015).

Class[b]	**Type**	**Building type**[a]	**Class description**	**Type description**
A	A	AA	Home with living space defined as equal to or between 3,999 and 2,400 ft^2.	1 story
A	D	AD	Home with living space defined as equal to or between 3,999 and 2,400 ft^2.	2 stories
B	A	BA	Home with living space defined as equal to or between 2,399 and 1,200 ft^2.	1 story
B	D	BD	Home with living space defined as equal to or between 2,399 and 1,200 ft^2.	2 stories
C	A	CA	Home with living space defined equal to or less than 1,199 ft^2.	1 story
C	D	CD	Home with living space defined equal to or less than 1,199 ft^2.	2 stories

a) RFDA requires class and type variables from each entry in the building inventory; these are combined to select the appropriate damage curve.

b) See Figure 3-1 for photographs of typical homes.

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[16] Garage damages were also tabulated and reported separately, but combined into both curves (M, B) with the assumption that the garage floor is 2’ below the main floor elevation.

Figure 3-3: Street view photographs of typical buildings representing three (of eleven) Alberta Curve building classes found in the study area from IBI Group and Golder Associates (2015).

Contents Damages (C)

For contents damage curves, the development team recorded quality, price, and item heights (depth at which the item would be completely inundated) for all items of significant value in the surveyed homes. After this, the development team consulted cleaning and restoration contractors on their experiences following the 2013 Flood recovery. These contractors felt that while it may have been possible to salvage impervious flood affected items, during the large 2013 Flood, not enough resources were available to recover and repair such items. Considering this, the development team adopted an assumption of zero-salvageability. They hypothesized that this over-estimation may be countered by the omission of damage to items above the inundation level (e.g. mold or humidity damage). Further, full replacement costs (rather than depreciated costs) were utilized against the recommendations of Messner (2007): “using replacement costs is an overestimation of damage from a broader economic perspective, because replacement usually involves improvements: old goods which are damaged during a flood are usually substituted by new, more productive and better performing goods.” This reflects a financial assessment of damages, rather than an economic one, and limits the direct use of any results by decision makers.

Structural Damages (S)

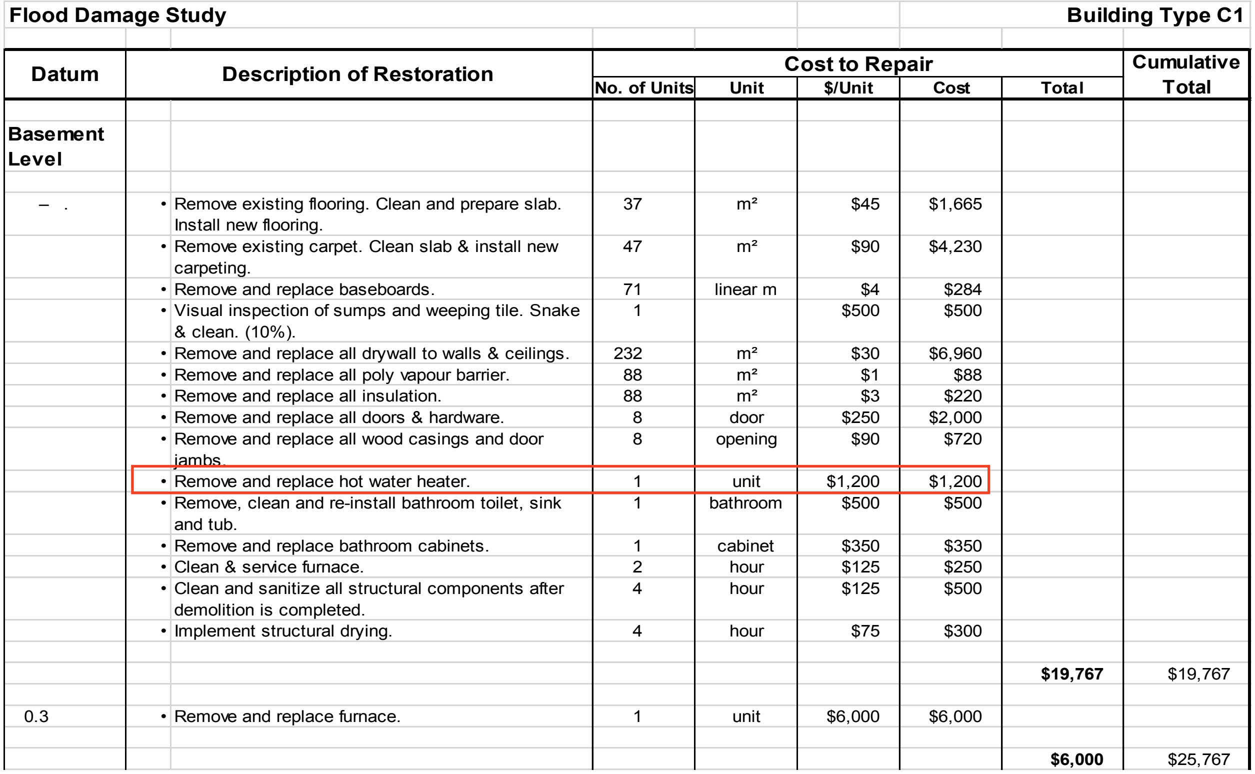
Structural damage curves were synthesized from survey data and field inspections for the 11 residential categories. Local building suppliers and contractors provided replacement cost estimates for Calgary in 2014 $CAD. Like the contents damage curves, no adjustment for depreciation was applied. Further, through consultation with cleaning and restoration contractors, complete destruction of building furnishings was assumed for any depth of flooding on a given floor. Figure 3-4 provides an example damage feature table tabulating these depths and damages (see Appendix D, Attachment C for similar examples). Tables like this were then divided by an average area for each building class to generate the set of structural Alberta Curves. Figure 3-5 provides an example for a class "C" house showing the two structural (MS and BS) and two contents (MC and BC) loss functions.

Basement Damages (B)

For basements, the structural and contents curves are applied to all buildings with a basement. These curves are typical of finished basements having features like 'carpet replacement' and 're-install bathroom toilet.' This assumes that all basements are finished and that PLPMs do not reduce flood damage (or are universally absent). Further, in RFDA, a uniform depth (typically 2.7 m; p.c.) is applied to all assets to assign the anchor elevation for each basement loss function relative to the main floor elevation. In other words, RFDA assumes that all basements are finished and the same height.

Transfers and Indirect Damages

RFDA allows the user to supply secondary scaling factors to adjust the total, contents, and structural damage estimates for each asset. To transfer the Alberta Curves in space (i.e. beyond Edmonton and Calgary) and time (i.e. beyond 2014), IBI Group and Golder Associates (2015) propose scaling factors based on local item pricing and inflation indices. Further, they propose estimating indirect damages from percentages of direct damages using relations found in the literature. In this way, RFDA can use the Alberta Curves to estimate flood risk in a wide range of settings and metrics.



Flood Damage Study **Building Type C1**

Datum	Description of Restoration	Cost to Repair					Cumulative Total
		No. of Units	Unit	$/Unit	Cost	Total	
Basement Level							
– .	• Remove existing flooring. Clean and prepare slab. Install new flooring.	37	m²	$45	$1,665		
	• Remove existing carpet. Clean slab & install new carpeting.	47	m²	$90	$4,230		
	• Remove and replace baseboards.	71	linear m	$4	$284		
	• Visual inspection of sumps and weeping tile. Snake & clean. (10%).	1		$500	$500		
	• Remove and replace all drywall to walls & ceilings.	232	m²	$30	$6,960		
	• Remove and replace all poly vapour barrier.	88	m²	$1	$88		
	• Remove and replace all insulation.	88	m²	$3	$220		
	• Remove and replace all doors & hardware.	8	door	$250	$2,000		
	• Remove and replace all wood casings and door jambs.	8	opening	$90	$720		
	• Remove and replace hot water heater.	1	unit	$1,200	$1,200		
	• Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	$500	$500		
	• Remove and replace bathroom cabinets.	1	cabinet	$350	$350		
	• Clean & service furnace.	2	hour	$125	$250		
	• Clean and sanitize all structural components after demolition is completed.	4	hour	$125	$500		
	• Implement structural drying.	4	hour	$75	$300		
						$19,767	$19,767
0.3	• Remove and replace furnace.	1	unit	$6,000	$6,000		
						$6,000	$25,767

Figure 3-4: Sample structural damage feature table for a 'C' class house from IBI Group and Golder Associates (2015). Red box denotes a single damage feature.

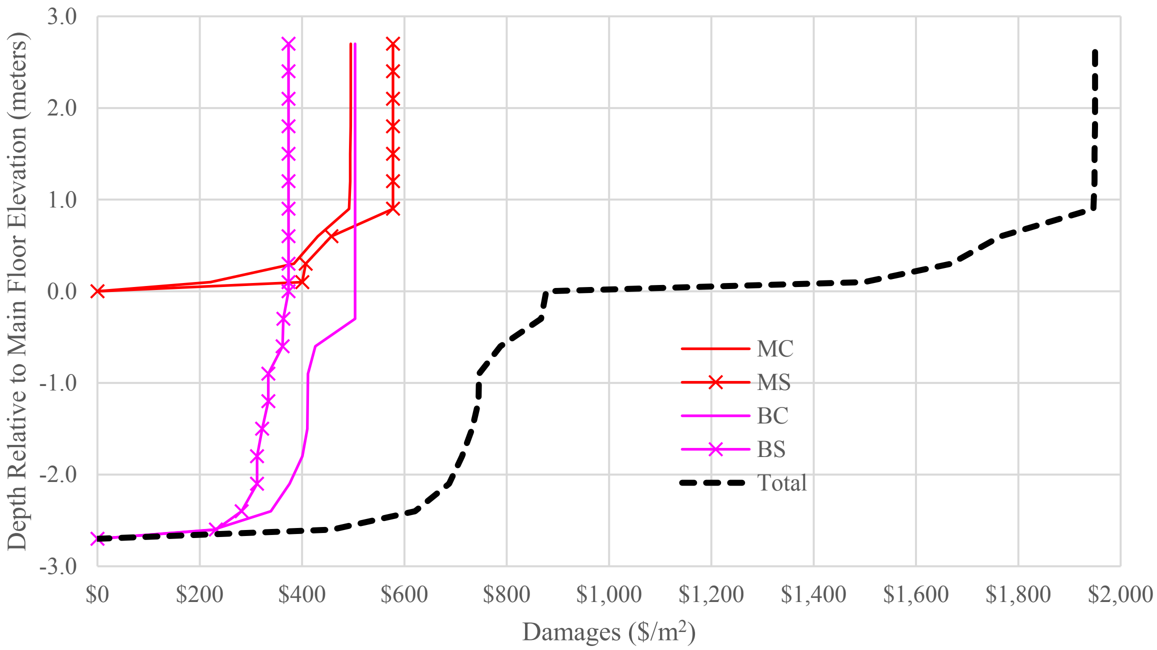
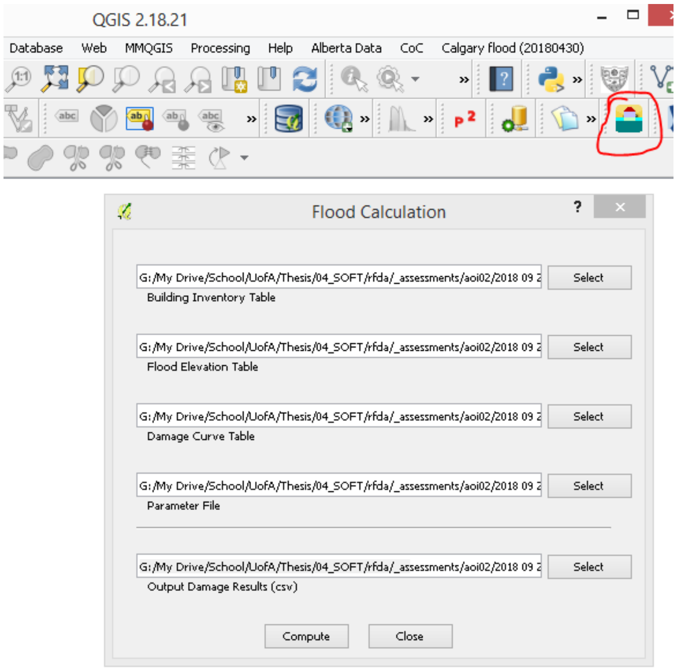


Figure 3-5: Alberta Curve depth-damage relations for a class 'C' house.

3.2. Implementation

RFDA bundles simple routines to estimate damage for each asset in the inventory based on building type, class, and area. Despite implementation as a plugin for the Python-based Quantum GIS,[17] RFDA is not a spatial model; however, pre- and post-processing is spatial.



Building Inventory Table: G:/My Drive/School/UofA/Thesis/04_SOFT/rfda/_assessments/aoi02/2018 09 2

Flood Elevation Table: G:/My Drive/School/UofA/Thesis/04_SOFT/rfda/_assessments/aoi02/2018 09 2

Damage Curve Table: G:/My Drive/School/UofA/Thesis/04_SOFT/rfda/_assessments/aoi02/2018 09 2

Parameter File: G:/My Drive/School/UofA/Thesis/04_SOFT/rfda/_assessments/aoi02/2018 09 2

Output Damage Results (csv): G:/My Drive/School/UofA/Thesis/04_SOFT/rfda/_assessments/aoi02/2018 09 2

Figure 3-6: RFDA user interface in QGIS.

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[17] While the Alberta Curves are available in tabular format as appendices to the publicly available report, the RFDA plugin was provided to the research team directly from the project partner (IBI Group). The model developed in this thesis did not copy any part of, and bears no resemblance to, the RFDA source code.

Figure 3-7 illustrates the damage calculation algorithm RFDA uses to estimate flood damage on each asset from a set of exposure indicators (i.e. flood tables). This algorithm loops through each flood and each asset in the building inventory to extract the appropriate flood depth, loss function, and scaling parameters for that asset. These are used in the depth-damage calculation to interpolate the damage on each asset for each flood, which is finally tabulated in the results table. To obtain flood risk (i.e. EAD) from these damages, the damages from each flood in the results table are post-processed by summing then plotting against the flood's likelihood. From this plot, the analyst calculates EAD from the area beneath the curve (p.c. D. Sol), as described in Section 2.3.1.

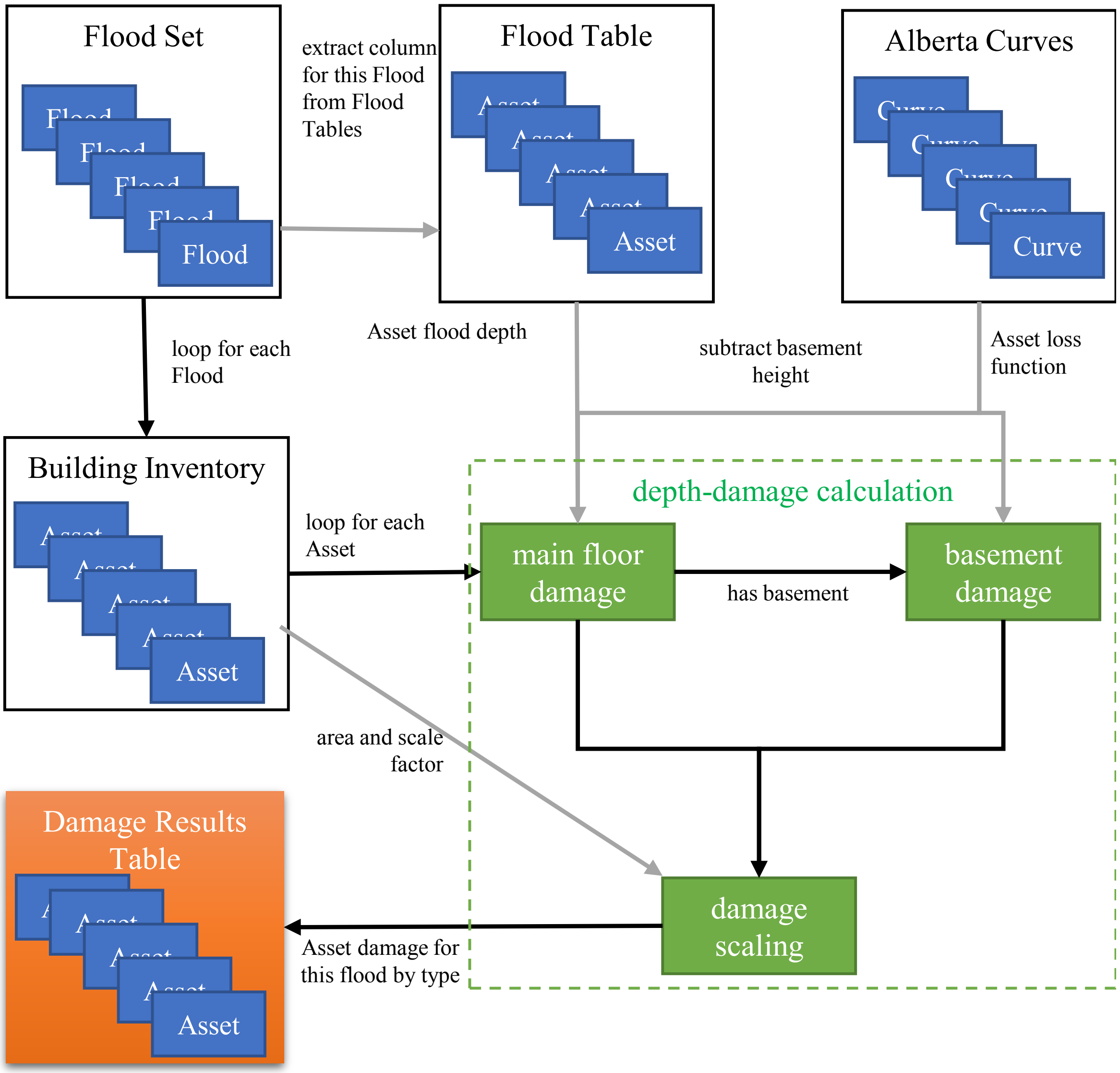

Figure 3-7: RFDA flood damage calculation algorithm simplified conceptual diagram. Black arrows show the algorithm process flow while grey arrows show some information flow; some arrows omitted for clarity.

3.3. Limitations

As the name implies, RFDA was intended to provide *rapid* risk assessments. To accomplish this, RFDA and Alberta Curve development incorporated the following assumptions relevant to the research questions posed by this thesis:

- *Mix of averages*: Being precompiled from the damage feature tables, the Alberta Curves are scaled to floor area. When used to estimate damages, this assumes features not correlated to floor area (e.g. furnace, water-heater) scale with floor area. For example, consider two class 'C' houses exposed to the same flood depth. The first house has an area of 100 m^2, while the second has an area of 150 m^2. From intuition, we would expect the cost to remove and replace the hot water heater to be similar in both houses, as they are both of the same class. However, because the Alberta Curves are precompiled, RFDA would predict the cost of the water heater feature in the second house to be 50% more than that of the first house.[18]
- *Lack of building heterogeneity*: All buildings within a category have the same (scaled) Alberta Curves. This prohibits the modeling of element modifying policies like FHRs (e.g. elevating the furnace to the main floor).
- *Assumption of full exposure*: Exposure indicators provided in the flood tables are passed directly to the loss function (as depths). This prohibits quantifying any exposure reduction provided by PLPMs.
- *Deterministic*: RFDA does not facilitate uncertainty quantification (through stochastic modeling or otherwise).
- *User-friendly*: RFDA supplies limited crash information and a single output metric (damage per flood per asset).
- *Static*: RFDA does not facilitate dynamic vulnerability modeling (e.g. urban re-development).
- *Uniform basement heights*: RFDA assigns the same basement depth to all basement curves, limiting the quantification of vulnerability increasing trends, like the deeper basements of modern homes.

These limitations motivated the development of the model framework of this thesis, described in Section 5.3.

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[18] The bias of this limitation is likely countered (somewhat) by larger houses generally having more expensive utilities than smaller houses.

3.4. Calgary 2017 Flood Mitigation Options Assessment

While the Alberta Curves are publicly available, IBI Group remains the major user of RFDA, with RFDA applied in roughly 30 risk assessments Canada wide (p.c. D. Sol). Despite the limitations discussed above, RFDA is the only model developed specifically for Alberta within the past 30 years (IBI Group and Golder Associates 2017), and it is likely the only flood damage model in use by decision makers in Alberta (p.c.).

For the first application of RFDA, the GoA contracted a flood risk assessment for the Calgary area: 1) quantifying the current city-wide risk (IBI Group and Golder Associates 2015); then 2) ranking major structural protection works with a CBA ('2015 Study') (IBI Group 2015). After the 2015 Study, the CoC contracted the same firms to conduct the *Calgary 2017 Flood Mitigation Options Assessment* ('2017 Study') (IBI Group and Golder Associates 2017). This expanded assessment sought to supply more comprehensive guidance on mitigation options that could be implemented at local and regional scales. Improvements (by the 2017 Study on the 2015 Study methods) included: 1) 2D groundwater hazard mapping; 2) more robust accounting and calculation of indirect damages; and 3) an approach to evaluate intangible loss. The 2017 Study analyzed 13 scenarios with different combinations of structural and non-structural mitigation measures.[19] Despite only evaluating static-risk, this 2017 RFDA study is the most robust and expansive flood risk assessment to-date in Alberta. The resulting wealth of hazard and vulnerability data generated on Calgary supplies an essential foundation from which to explore the dynamic view of risk promoted in this thesis.

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[19] Structural measures considered included: reservoirs, barriers, stormwater improvements, groundwater control, and temporary barriers. Non-structural measures considered included: contingencies, FHRs, and buyouts.

4. Study Area

This thesis explores changes in flood risk for the neighborhoods of Sunnyside and Hillhurst in Calgary, AB, shown in Figure 4-1 (see Figure 4-4 for a less detailed view and Appendix A for a more detailed view). Table 4-1 shows the area, population, and the available estimates for the 2013 Flood damages. Sunnyside and Hillhurst are both developed neighborhoods of mostly single-family homes. Proximity to the Bow River contributes to both property value and flood risk. After briefly describing how and why the study area was selected, this chapter supplies the reader with the necessary background to interpret the model results within the context of these two neighborhoods.

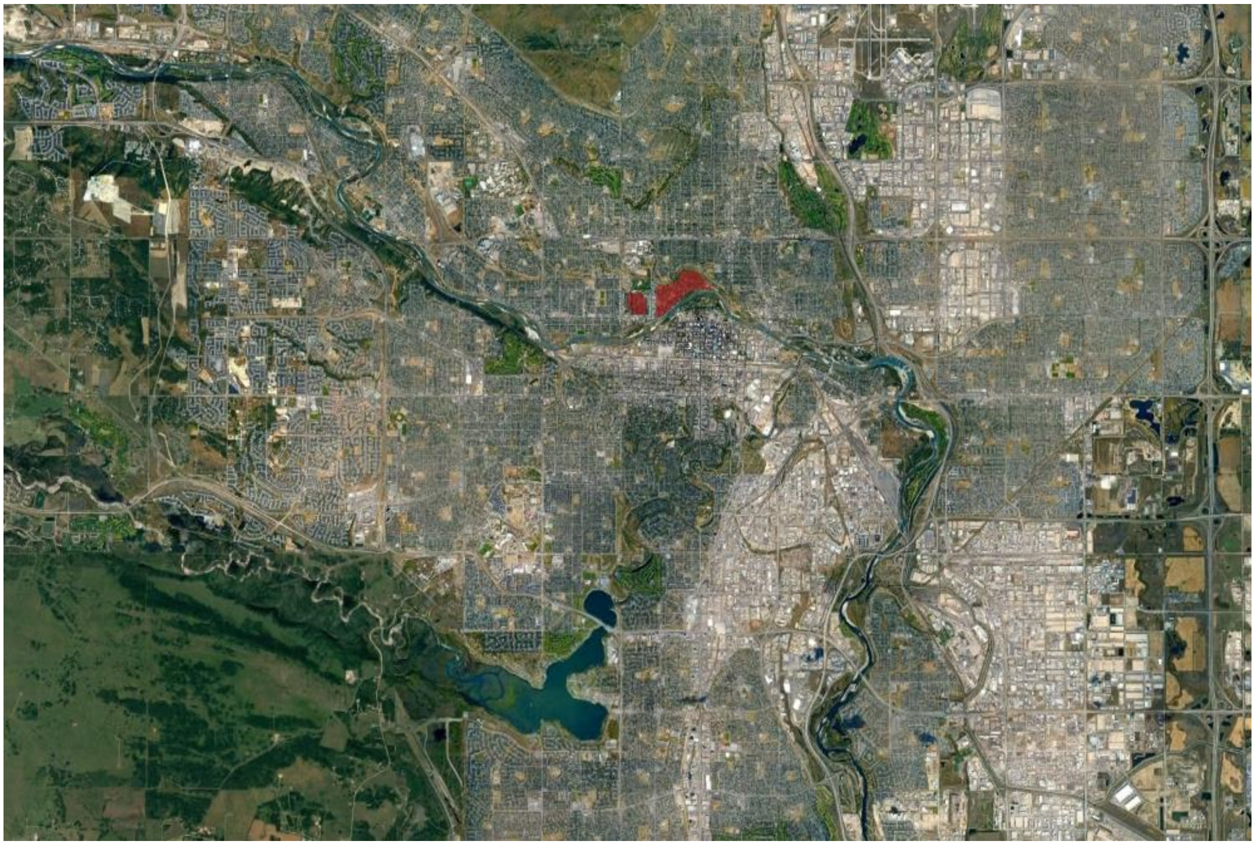

Figure 4-1: Aerial image of Calgary showing study areas highlighted in red. Obtained from Google Earth on 2018-12-12.

Table 4-1: Study area flood risk summary statistics.

Attribute	**Unit**	**Value**	**Source**[a]
Total residential asset count[b]	ea.	1066	IBI_2017CoC_binv_res
Area	ha	82.8	
2014 Civic Census population	persons	4070	CoC_PDA_scenser_2016
Forward Sorting Area		T2N	
GoA's 2013 Disaster Recovery Program (count and total)	ea.	98	GoA_AEMA_DRP_2013_private-claims
	$CAD	1,383,863	
CoC Assessment's request for information on 2013 Flood damages (count and total)	ea.	48	CoC_Ass_ARFI_2013, and CoC_Ass_ARFI_2014
	$CAD	5,900,000	
CoC flood recovery permit records	ea.	470	CoC_Dev_2013flood_permits

a) See Appendix G ‘dataset.’

b) Residential buildings identified as ‘main buildings’ by the CoC’s Planning department. Excludes accessory structures (garages) and considers multi-unit condominium buildings as a single asset.

4.1. Area Selection

Calgary was the obvious choice for a pilot flood risk study considering: 1) the city suffered extensive damage from the 2013 Flood; 2) two recent flood risk studies have been conducted; 3) large and detailed datasets were readily available; and 4) staff at the CoC were extremely supportive of the work proposal (and have proven generous with their time). Both to reduce uncertainty and facilitate a field survey within project constraints, the analysis needed to be limited to a small, floodprone section of the city that suffered substantial damages from the 2013 Flood. Further, a homogenous study area was required to simplify urban re-development modeling. From these objectives, the following criteria were developed to guide the selection of candidate study areas:

- population near 3,000;
- contiguous boundaries;
- within a single postal Forward Sorting Area;[20]

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[20] Some of the early data considered for this study is aggregated by Forward Sorting Area.

- substantial 2013 Flood recovery permit records;
- within the 1000 ARI inundation extents; and
- mostly single-family detached homes.

Applying these criteria, three candidate study areas were found: Inglewood, Elbow Park, and Sunnyside/Hillhurst. From these, the two adjacent neighborhoods of Sunnyside and Hillhurst were selected as they had the most equal division of floodprone assets inside and outside the current FHZ (see Appendix A). Additionally, the two communities have a single harmonized community association with active members who were eager to promote the study survey and who supplied valuable insight on the history of flood policy and the 2013 Flood.

4.2. 2013 Flood Experience

Pomeroy et al. (2016) describe the hydrological setting and subsequent warm, low-pressure system that stalled over the Bow headwaters from June 18th to 22nd in 2013. More than 300 mm of high-elevation rainfall on snow, subsequent rapid snowmelt over frozen ground, and synchronized runoff from the catchments led to record-breaking discharges. As a result, operators opened emergency spillways on the Barrier Lake Dam and the Cascade Dam on days two and three of the flood respectively. While this torrent destroyed many stream gauges, an analysis of records and data across the region by Pomeroy et al. (2016) estimates the flood on the Bow River in Calgary to have been a 40 ARI event[21] — significantly less than the 100 ARI design event of the current FHZs.

Community Response and Resiliency Division (2014) provides an account of the various flood mechanisms that impacted Sunnyside in June 2013, including: 1) overtopping of the levee; 2) closing of the stormwater outfall gates, blocking the release of stormwater; and 3) disabling of the sanitary and stormwater lift stations causing backup. This unfortunate combination, and heroic portable pumping efforts, led to four flood-drain cycles in Sunnyside between June 20th and July 5th.

There are no comprehensive estimates for the 2013 Flood damage citywide, or for the study area.[22] Table 4-1 supplies a summary of the available damage data for the study area. While the count

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[21] Golder Associates (2014) calculated a preliminary ARI of 80 for the Bow River at Calgary.

[22] See Bryant and Davies (2017) for a discussion of the total event estimate.

and severity of property damages is unclear, Figure 4-3 and Figure 4-2 suggest that both communities were damaged extensively.

Figure 4-2: Photo of Memorial Drive at Prince's Island Bridge looking West two days after the flood peak. Retrieved from https://www.flickr.com/photos/elsiehui/9106185796/in/photostream/ on 2018-12-05.

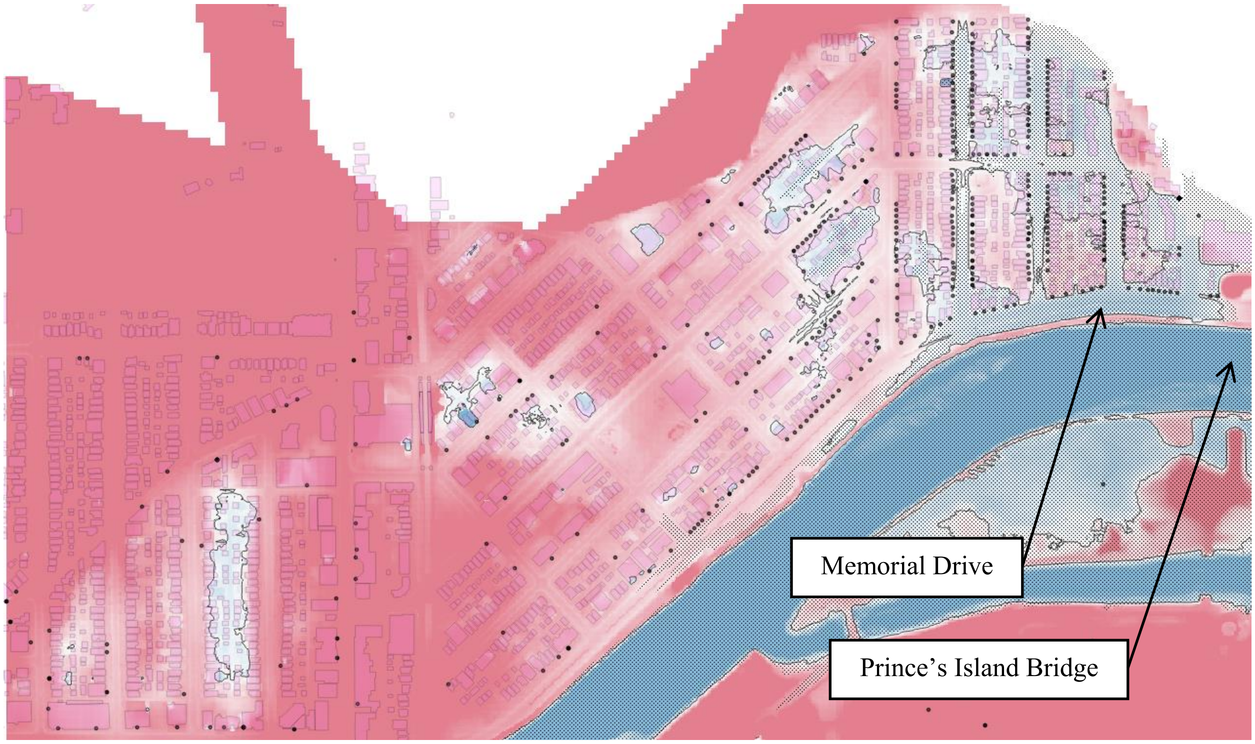

Figure 4-3: 2013 Flood in study area showing: [dot-hatch] aerial observation of inundation (Appendix G, dataset 'WR_flood_201306_inun'); modeled WSL with [red] groundwater depths and [blue] surface water depths; [23] *and [black circles] flood impacted properties (Appendix G, dataset: 'CoC_Dev_2013flood_impacted').*

4.3. Hazard Characteristics

Bow River Basin

The Sunnyside/Hillhurst neighborhoods are situated on the North bank of the Bow River, just upstream of its confluence with the Elbow River. The Bow River catchment drains roughly 12,000 km^2 as it flows from the pristine alpine and subalpine Banff National Park, through the evergreen and deciduous forests of the foothills, down to the agriculturalized and urbanized prairies that hold Calgary (Figure 4-4). Whitfield and Pomeroy (2016) provide an overview of the climatic and regional factors driving flood peaks for the watershed. They describe the weather as one of extremes: a brief cool summer with the occasional sweltering day, followed by a long winter with the occasional arctic-like cold spell. Annual average precipitation varies from 600 mm in the headwaters down to 450 mm in the city.

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[23] This raster is a comparison of the DEM (Appendix G, dataset 'WR_DEM_2013_20170815') and the flood WSL raster that best matched the inundation observation (Appendix G, dataset 'WR_flood_201306_inun'). The selected flood WSL raster provides modeled surface and groundwater levels that approximate the 2013 flood (Appendix G, dataset 'GLD_2017CoC_WSL_um' 10-year).

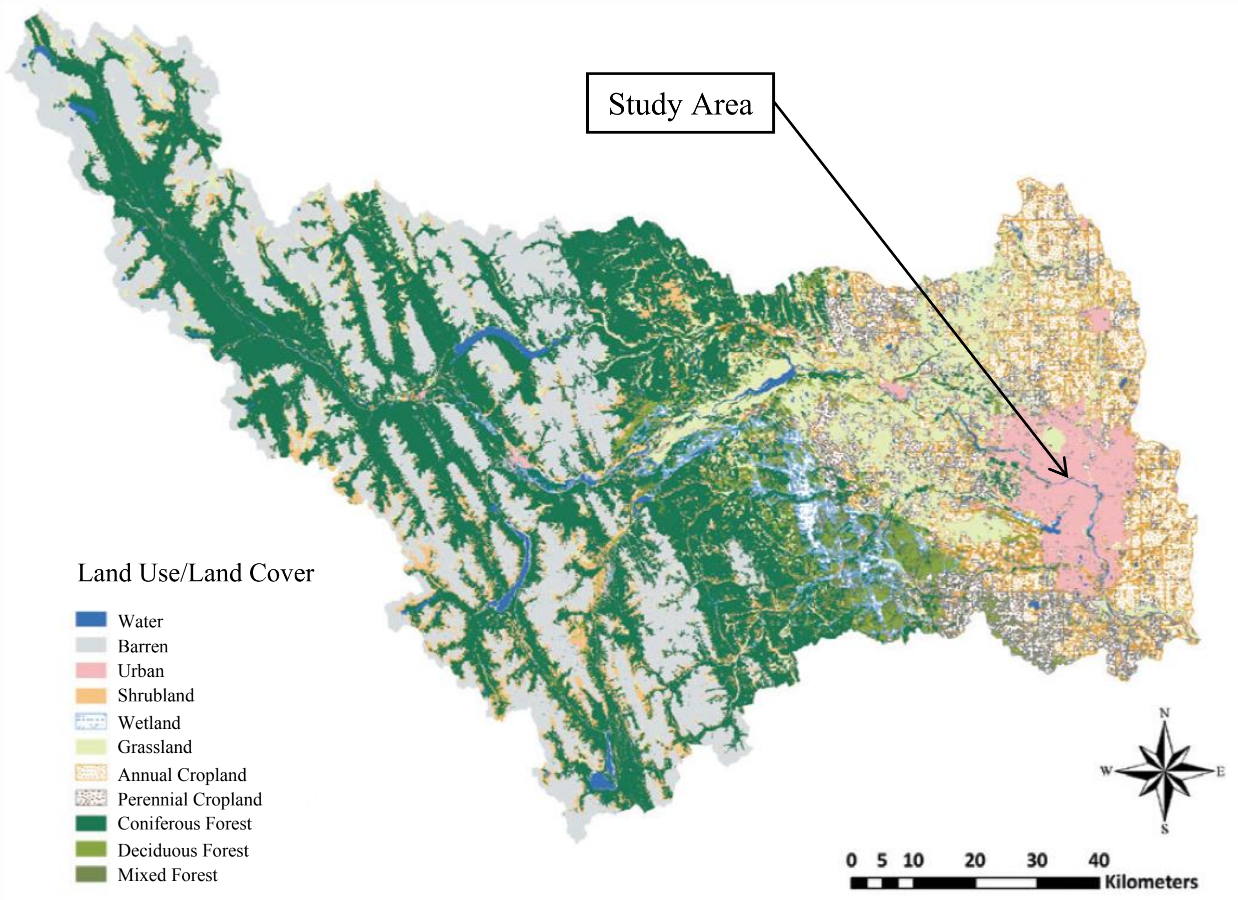

Figure 4-4: Bow River basin land use map from City of Calgary (2012).

Hydrology and Hydraulics

Figure 4-5 supplies the observed annual peak (and minimum) flows just downstream of the study area on the Bow River. This hydrograph shows the 81-year period during which Calgary experienced no major flooding (1932 – 2013), and the record-breaking discharge of the 2013 Flood. Regulating these flows are five major dams upstream of Calgary, most notably the Ghost Dam operated by TransAlta. To improve the flood retention of this reservoir following the 2013 Flood, the GoA negotiated a $27.5 million five year agreement with TransAlta to optimize the operating rules for flood mitigation (Alberta Government 2016).

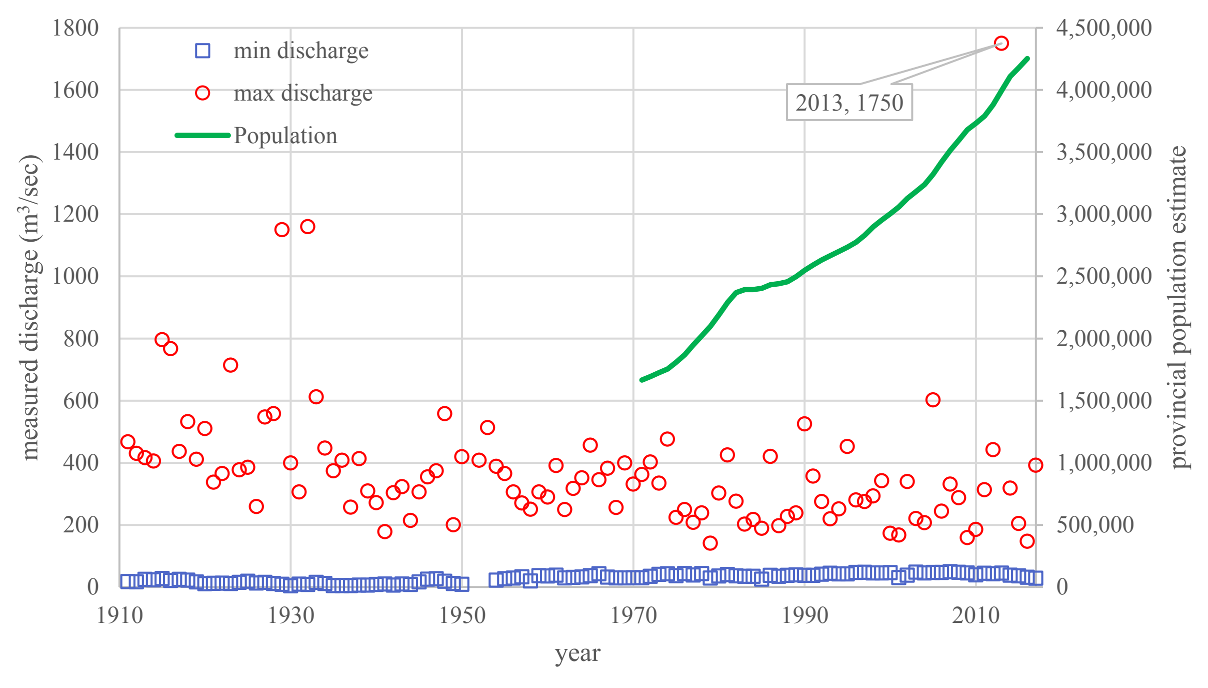

Figure 4-5: Annual maximum and minimum daily discharge records for the Bow River at Calgary.[24]

Rimmed to the south by an old earthen levee, Sunnyside floods like a bathtub (see Figure 4-6 for a typical inundation scenario and levee location). Without emergency barriers, this levee overtops for events larger than 10 ARI,[25] as happened during the 2013 flood. For events that do not overtop the levee, a significant groundwater gradient develops as the river WSL climbs up the South face of the levee. This leads to high groundwater levels behind the levee and often basement flooding. On the upstream side of Sunnyside, Hillhurst is less vulnerable to surface water flooding, but still susceptible to groundwater flooding during small events. Both areas have extensive stormwater infrastructure which has been improved since the 2013 Flood (p.c.).

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[24] Discharge records extracted from the Environment and Climate Change Canada Historical Hydrometric Data web site on 2018-12-12 (https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html). Population estimates obtained from 'Statistics Canada. Table 051-0001 - Estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual.'

[25] See Appendix G, dataset 'GLD_2017CoC_WSL_sc0_sw'.

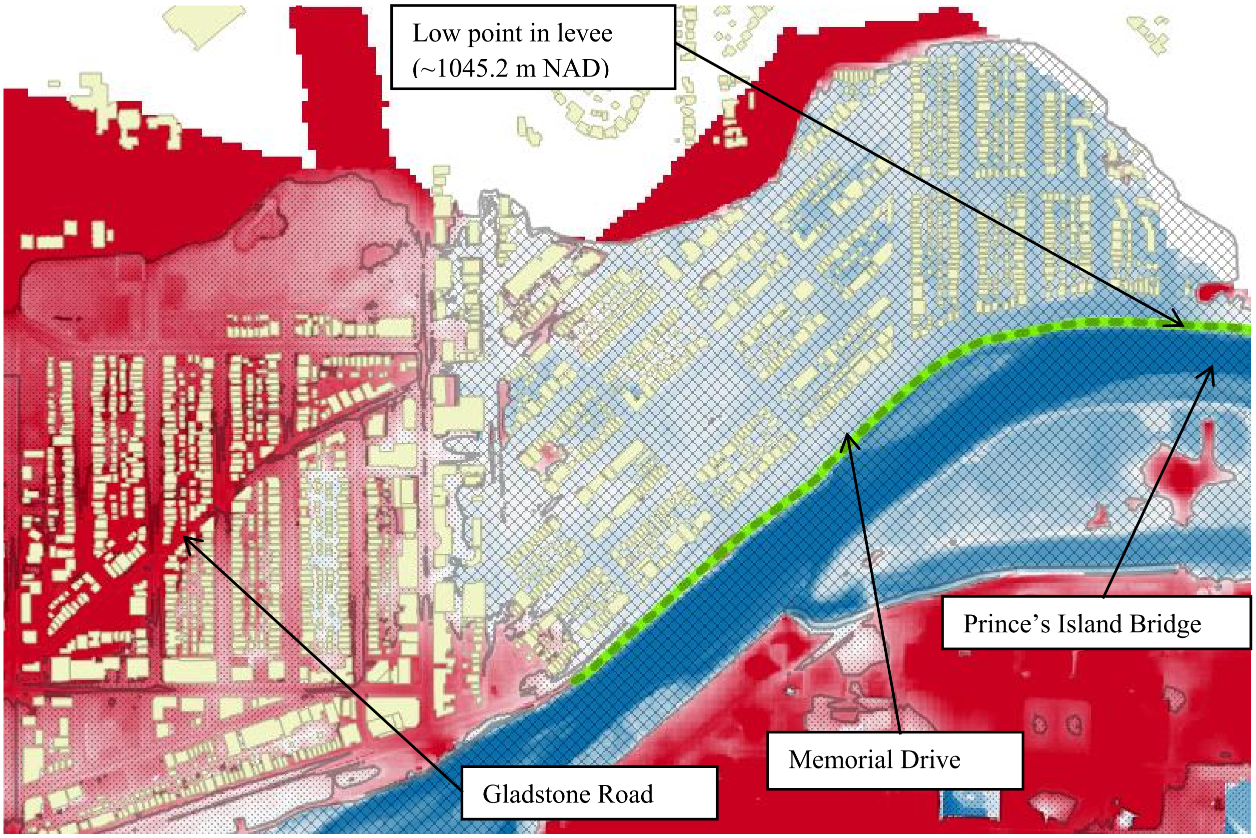

Figure 4-6: Study area 50 ARI flood depths. Surface water depths are shaded blue and groundwater depths red (Appendix G, dataset: 'GLD_2017CoC_WSL_S0_gw'). Inundated areas are cross-hatched while isolated areas are spot-hatched (Appendix G, dataset: 'GLD_2017CoC_WSL_S0_in'). The Sunnyside levee is highlighted in green.

4.4. Vulnerability Characteristics

Sandalack and Nicolai (2006) provide a summary of the history of development in Calgary. The first residents of Hillhurst were mostly Scottish and English, arriving around 1907. Originally, Gladstone Road in Hillhurst was a dirt trail along the north edge of a slough. Eventually, this slough was developed, but suffered frequent flooding until construction of a levee and dredging of the river channel. Sunnyside was a poorer area, initially populated with railroad workers. Today, proximity to downtown, the river, and other amenities make for an attractive upper-middle class neighborhood, with property values 50% higher than the citywide average (City of Calgary 2014). Both neighborhoods are characterized by tree-lined, pedestrian friendly streets and garages rear-oriented towards the alley-ways.

4.4.1. Pre-War Bungalows

The first wave of home construction occurred in the 1910's (Figure 4-10). Many of these pre-WWII bungalows remain, with 45% of the current building stock older than 1945. While the level of upkeep varies, these pre-war bungalows are smaller and less expensive than the more modern homes in the neighborhood.[26] Most were built with a crawlspace-type foundation (Figure 2-2 left). Over their 100-year lifespans, there have been a diversity of renovations within this group including:

- *Basement additions*: Working within the original footprint, crawlspace areas are deepened by excavating near-vertical walls into the ground (Figure 4-7). Such additions can be limited in depth and area to only supply space for utilities (e.g. water heater) or extend to fully-finished basements.
- *Main-floor additions*: Expanding the original footprint or improving porches and decks, the main floor can be expanded to provide additional living area.
- *Second-floor additions*.

Figure 4-8 provides an example of four pre-war bungalows in the study area with varying levels of renovation.

Figure 4-7: Photo of crawlspace during a dug-out basement addition from picswe.com (2018).

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[26] See building class 'C' in Table 5-2.

Figure 4-8: [Top] aerial view and [bottom] street view of four pre-war bungalows in Sunnyside [A, C, D, E] (and one home from 1996 [B]). Building D keeps the original pre-war footprint, while A, C, and E have rear oriented main floor additions. Building D and E have second floor additions. Images obtained from Google Maps on 2018-12-01.

4.4.2. Modern Homes

Following the initial pre-war development, home construction rates were low in Sunnyside/Hillhurst until the 1990's (see Figure 4-10 for year of construction distribution within the study area). Today, Sunnyside and Hillhurst face intense development pressure with contemporary development rates cycling up-and down in response to the economy at an average of 10 new homes per year, as shown on Figure 4-10. Regulating this activity, the current land use bylaw designates the eastern half of Sunnyside as (R-C2), "primarily for single detached, side-by-side and duplex homes;" and the rest of the study area as (M-CG), "multi-residential designation in the developed area that is primarily for townhouses and fourplexes" (City of Calgary 2017). The building typology of the modern homes within this zoning is more diverse (Figure 4-9), and the study survey (Section 5.2.3) suggests most of these have deep finished basements.

Figure 4-9: Street view of three modern homes in Sunnyside. Obtained from Google Maps on 2018-12-01.

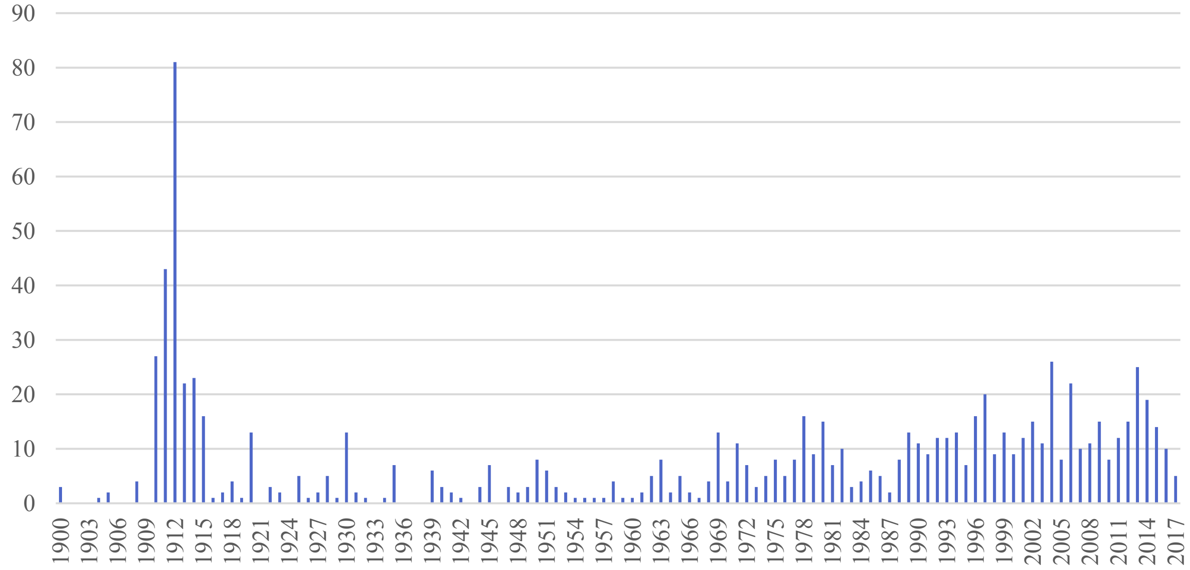

Figure 4-10: Year of construction histogram for the study area as of 2017.[27]

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[27] See Appendix G, dataset: 'CoC_Ass_propass'.

5. Methods

This thesis develops the novel modeling framework SOFDA, conducts data collection and analysis, then applies SOFDA with the data collected on the study area to address the research questions. This chapter seeks to show the reader: 1) how and what inputs were collected; 2) how and why the model framework was developed; 3) how a model of flood risk in the study area was built within this framework; then 4) how this model was used to address the research question. In combination with the Appendices, the information provided in this chapter should be sufficient to reproduce the results presented in Chapter 6.

5.1. Study Boundaries and Limitations

In recognition of the available project resources, methodologies in use by local decision makers, and to keep within the paradigms of the precursor 2017 Study, the boundaries for the thesis work are defined as:

- *The Sunnyside/Hillhurst study area*: As discussed in Section 4.1, this study area is the most favorable for a dynamic flood risk assessment given the project resources. Therefore, the study extents do not match those of a decision maker's constituency. For example, if this study were commissioned by the CoC, the study boundary would extend at least to all floodprone areas within the city limits. With this discrepancy, the benefits calculated here are spatially inadequate for use in decision-making.
- *A financial evaluation of direct, tangible flood damage to buildings*: To build on the accomplishments of the precursor RFDA, this study uses the Alberta Curves which provide a prediction of direct, financial flood damage to buildings. This omits important damage types like indirect and intangible damage and damages to assets other than buildings.
- *Single-family homes:* To simplify the modeling of urban re-development and the door-to-door survey, this study is limited to single-family homes. This limitation means the results presented here do not capture the total benefits of measures.
- *Projections based on current development rates and trends*: To simplify the model, this study assumes contemporary trends (for house typology and re-development rate) provide an accurate prediction of the near-future. To limit the uncertainty from this assumption, a projection horizon of thirty years is seen as reasonable and adopted here. This limitation means the spread of results presented in this study do not capture the full range of results which may be possible (if the modeled system behaves unexpectedly).

- *Period limits*: To improve the reliability of projecting future re-development trends, this study's analysis period was limited to 30 years. This temporal limitation does not capture the total costs and benefits of measures.
- *Effective structural protections*: As no data was available to quantify the reliability of structural protections, this study uses the hazard model results where full performance was assumed. This omits the possibility of premature overtopping or failure of upstream dams, the Sunnyside levee, or the planned temporary barriers.
- *Vulnerability reductions exclusively from FHRs and building typology*: To simplify the modeling of vulnerability dynamics, this study assumes that property owners only make flood vulnerability related modifications (outside the average base rates) if required to do so by FHRs. This omits the influence on property mitigation from flood experience (e.g. installing a backflow valve after being flooded), some future subsidy program, or any other mechanism that may cause a change in the vulnerability of the study area.
- *FHR triggers exclusively from infilling*: To simplify the model, and in consideration of the available data, only the infilling of developed properties is considered to trigger the application of FHRs on a new house. This omits major footprint expansions (i.e. renovations) which should also trigger regulation under Calgary's current FHRs (Appendix B).

Further, this thesis focuses solely on the quantification of flood risk. While quantifying flood risk is an essential element of decision-making methods (such as CBA), the following additional elements must be included before the results of this thesis can directly support decision-making:

- *Costs*: Risk-based decision-making seeks more holistic methods (than the traditional approach), such as CBAs which compare the costs and benefits of options to rank their financial efficiency. To apply such a method to the options considered here, the benefit results from this study would need to be coupled with the costs of the measure to establish its efficiency (relative to other options).
- *Discounting*: CBAs need both costs and benefits to be adjusted to net present values through application of a social discounting rate. For simplicity, discounting was omitted from the results in this study.
- *Broad and numerous options*: A robust risk assessment for decision support should consider a wide range of mitigation options to improve the likelihood of finding the optimal solution. For example, the 2017 Study considered 13 different options and combinations of structural protections, while this thesis only considers a single structural option (P7).

Addressing the above, the methodological advancements made by this thesis can support decision makers within the paradigms of RFDA — expanded to include vulnerability dynamics.

5.2. Model Inputs

5.2.1. Static Risk Data

Like RFDA, SOFDA requires large, granular datasets that describe each asset's vulnerability and hazard under different scenarios. Framed after RFDA, SOFDA uses the same data file formats for the three primary inputs: 1) the building inventory; 2) the flood tables; and 3) the loss functions (see Figure 3-2 for a diagram of RFDA inputs). This allows the work in this thesis to build on the datasets of the 2017 Study, before adding the new dimensions required by the dynamic view of SOFDA. Like in RFDA studies, the loss functions are generally standardized across all SOFDA study areas with the application of the Alberta Curves described in Section 3.1 and their parent damage feature tables. Contrary to this, the building inventory and flood tables are study specific.

Building Inventory

The building inventory contains vulnerability attributes for each asset in the study area, with variables like building type, main floor height, and basement presence. This dataset is meant to describe the study area as it is today in terms that are relevant for flood risk modeling of direct building damages. SOFDA builds a digital model of the study area by spawning a House object (and its nested hierarchy) from the values in each row of this building inventory during model startup (see Appendix D for details).

To create the building inventory for this study, six attributes were extracted from the 2017 Study for the 652 single-family homes in Sunnyside/Hillhurst.[28] To these initial six, three new attributes were appended from CoC property assessment records and the study survey results, as shown in Table 5-1. Table 5-2 summarizes key attributes of this combined building inventory. Appendix A shows a graphical summary of the building inventory (by building type), and a redacted copy of the datafile is provided in Appendix E.

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[28] Within the Sunnyside/Hillhurst area, the 2017 Study's inventory has 1,066 residential assets.

Table 5-1: SOFDA building inventory attribute source and description. Data attributes in gray-shaded columns were obtained from the 2017 Study while those in green-shaded columns were added as part of this thesis work.

Attribute	**Dataset**[a]	**Source**[b]
identifier	IBI_2017CoC_binv_res	Arbitrary
building type	IBI_2017CoC_binv_res	Analyst judgement from field and desktop surveys.
building area	IBI_2017CoC_binv_res	Digital aerial survey (provided by the CoC).
basement	IBI_2017CoC_binv_res	CoC Assessment data.
main floor height	IBI_2017CoC_binv_res	Analyst judgement from field and desktop surveys.
DEM elevation	IBI_2017CoC_binv_res	WR_DEM_2013_20170815[a]
anchor elevation		DEM elevation + main floor height
year of construction	CoC_Ass_propass	CoC Assessment data.
basement finish height		Predictions from statistical model built from survey results.[c]

a) See Appendix G 'dataset' column.

b) For those attributes obtained from IBI_2017CoC_binv_res, the source was provided through personal communication.

c) See Appendix E.

Table 5-2: Study area statistics. Data attributes in grey-shaded columns are not used directly by SOFDA and are provided for context.

Building type	**Count**	**Year of construction**	**Floor area**	**Property value**	**Development-potential-ranking**[a]	**Main floor height**
			m^2	2016 CAD$	rank	m
		median				
AD	19	2004.11	131.24	1,341,105	564.74	0.70
BA	15	1966.33	118.42	769,400	212.87	0.81
BD	303	1972.53	91.07	759,647	409.99	0.72
CA	233	1938.85	85.33	583,910	209.81	0.71
CD	82	1935.07	68.33	572,116	315.13	0.71
all	**652**	**1956.56**	**87.96**	690,429	**326.50**	**0.72**
min		1900	48.09	282,500	1	0.20
max		2017	266.04	2,670,000	652	1.60
dataset[b]		CoC_Ass_propass	IBI_2017CoC_binv_res	CoC_Ass_propass	CoC_Ass_propass	IBI_2017CoC_binv_res

a) See Section 5.3.5. Not passed to SOFDA via the building inventory.

b) See Appendix G, 'dataset' column.

Flood Tables

RFDA flood tables contain hazard attributes for each asset in the study area, with flood WSL provided for each of the flood events considered. These datasets are generated from river model predictions for flood WSL under different scenarios for discharge and structural protections. This thesis developed flood tables from the baseline and most optimistic scenarios of the 2017 Study:

- *Protection option 0 (base; P0)*: "existing improvements and modifications that were initiated after the 2013 flood. This includes historic dykes, new barriers,[29] and stormwater improvements" (IBI Group and Golder Associates 2017, 74).
- *Protection option 7 (enhanced; P7)*: In addition to the above P0 protections, this option includes an upstream reservoir on the Bow River, a local barrier on the north bank at Sunnyside (with crest level 0.6 m above the 200 ARI WSL), and an upgrade to the Sunnyside stormwater pump station.[30] The present value costs of this option were estimated at over $2 billion (IBI Group and Golder Associates 2017).

Table 5-3 supplies a more detailed summary of the collection of mitigations in the 2017 Study's hazard analysis for these two options. This table shows that P0 mostly represents the level of protection afforded Sunnyside/Hillhurst today, except for the recent modification of TransAlta's operating rules for the Ghost Reservoir (see Section 4.3). Further, this base option assumed temporary barriers would be installed and effective at raising the level of protection provided by the Sunnyside levee to the 35 ARI.

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[29] For this option, temporary barriers were included that raised the berm crest level to the 35 ARI WSL.

[30] The Sunnyside sanitary lift station was upgraded in the spring of 2018 to ensure resilience up to a 25 ARI event (City of Calgary 2018c). Construction of an additional lift station is scheduled for Spring 2018 (Harvest Digital Planning 2018).

Table 5-3: Calgary 2017 Flood Mitigation Options Assessment truncated option matrix modified from IBI Group and Golder Associates (2017).

Flood Mitigation Measures		**Option**	
Type	**Brief Description**	**P0**	**P7**
Flood Storage/ Regulation Reservoir	TransAlta's (TA) hydro facilities and reservoirs in the Bow River basin (historical operating rules)	√	▨
	TA's hydro facilities and reservoirs in the Bow River basin - current TA and GoA agreement	▨	√
	One new flood storage facility on the Bow River (between Cochrane and Calgary)	▨	√
Permanent Barriers (ARI of implementation)	Existing barriers (existing conditions without raising dykes)	√	√
	Zoo barrier (designed based on 2820 m^3/s in Bow River)	100	350
	Centre Street bridge lower-deck gates (designed based on 1660 m^3/s in Bow River)	50	350
	Bow River barriers (Bowness North and South, **Sunnyside**) (designed based on 1300m^3/s in Bow River)	▨	200
Stormwater and Drainage Improvements	Existing stormwater outfall gates (e.g. downtown, Mission, Eau Claire, Bowness)	√	√
	Gates and pump stations at planned permanent barriers	√	√
	Sunnyside pump station / Sunnyside stormwater	▨	√
Temporary Barriers	Temporary flood barriers at various locations per the City's flood emergency response plan	√	√

Color legend	
🟩	In progress or complete
🟨	Planned, or waiting for funding, or still being assessed
🟧	No concrete plans to implement
▨	Not included in option

The hazard analysis for both the P0 and P7 options was conducted by Golder Associates with the 1D Hydraulic HEC-RAS model built for the CoC (described in Golder Associates (2015)). The base (P0) discharge-frequency relationship used for the upstream boundary condition was adopted from Golder Associates (2014), and modified for P7 based on assumptions for the recent TransAlta agreement (see Section 4.3). This analysis generated synthetic naturalized hydrographs across some reservoirs using 'the project depletion' method.[31] An 'in-house software package' was then used to find the distribution that best-fit this synthetic dataset, from which the base discharge-frequency relation in Figure 5-1 (blue) was developed.

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[31] The report does not specify which reservoirs were naturalized.

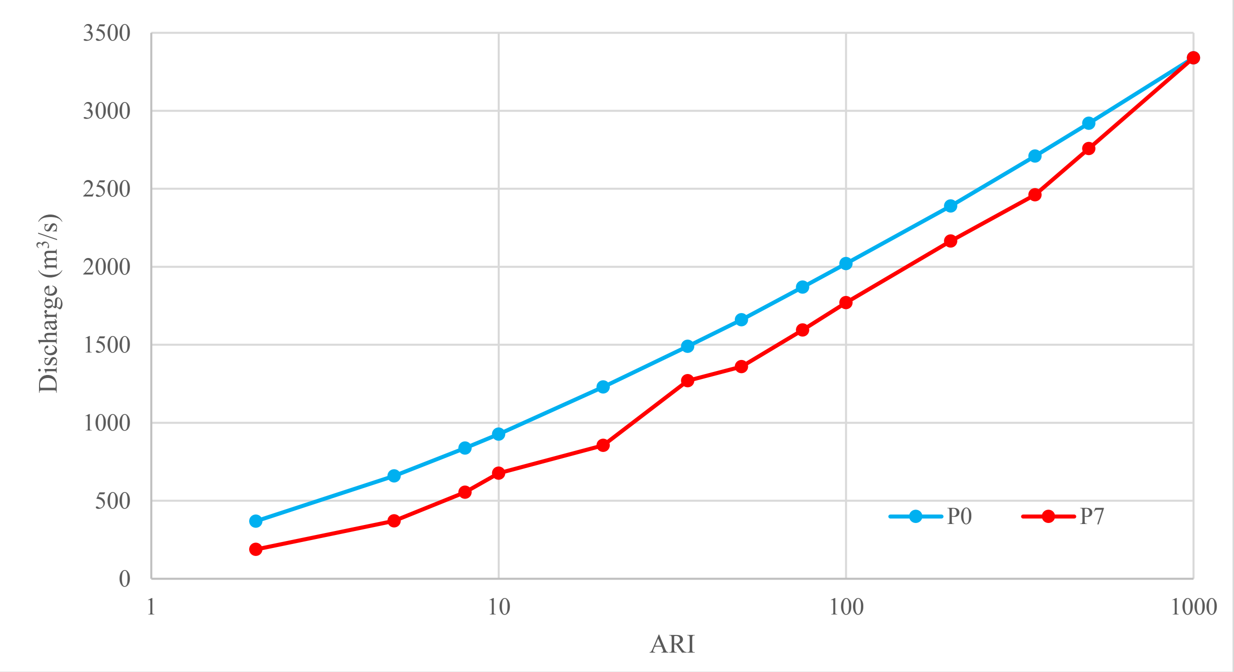

Figure 5-1: Discharge-Frequency curves for the two structural options on the Bow River below Glenmore Dam (Appendix G, dataset: 'IBI_2017CoC_Hyd_ins').

Major updates to the CoC's HEC-RAS model were made following the morphological changes brought about by the 2013 Flood. This work included the construction of a Digital Elevation Model (DEM) from bathymetric, topographic, and aerial surveys. From this, cross-sections for the 1D steady-flow HEC-RAS model were schematized. Roughness and energy loss coefficients were calibrated with the observed 2013 Flood high water marks and validated against observed marks from the flood event in 2005. Next, small modifications were made to generate surface water profiles for the 12 study events[32] for each scenario (p.c.). Profiles were post-processed to build a WSL dataset (i.e. hazard layers; see Figure 5-2 for a sample cross-section). By comparing against the DEM, areas were further segregated into: 1) inundated areas connected to the river channel; and 2) isolated areas disconnected from the river channel. Based on this segregation, ground water surface levels were estimated by projecting from the beach line using a ground water level decay function calibrated to the full 2017 Study area. Figure 5-2 (bottom) shows this beach line in purple and the results of the ground water level decay function for the smallest five events (i.e. those with WSLs below the Sunnyside levee crest). For more detail, refer to IBI Group and Golder Associates (2017), Appendix C.

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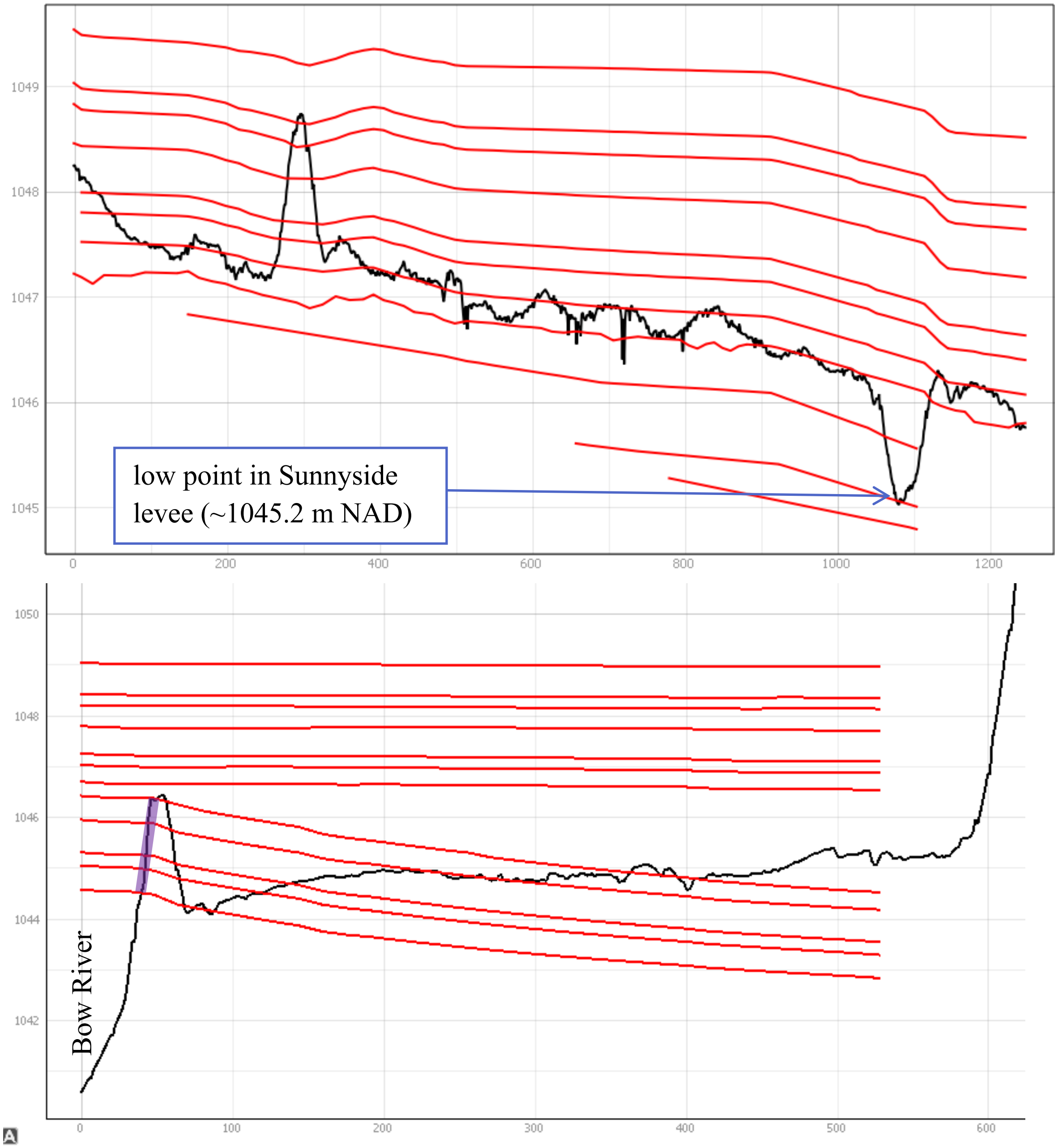
[32] Discharge events corresponding to 5, 8, 10, 20, 50, 75, 100, 200, 350, 500, and 1000 ARI.



low point in Sunnyside levee (~1045.2 m NAD)

Figure 5-2: Surface profiles for structural protection option P0 [top] W-E along Sunnyside Berm and [bottom] S-N in the same area along fourth street. Black line shows the ground elevation (Appendix G, dataset: 'WR_DEM_2013_20170815'), and red lines show the modeled WSL for events: 8, 10, 20, 35, 50, 75, 100, 200, 350,500, and 1000 ARI[33] *(Appendix G, dataset: GLD_2017CoC_WSL_sc0_gw). Groundwater modeling 'beach line' shown in purple. Vertical axis is elevation (m NAD) and horizontal axis is distances in meters.*

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[33] As a result of the groundwater post-processing, some hazard datasets predict 'groundwater' levels above ground.

Table 5-4 supplies a quantitative summary of the flood tables developed for this study from the above described hazard layers for the two structural protection options. Appendix E supplies the complete flood tables for these two scenarios and a detailed description of how these were developed from the 2017 Study's hazard layers.

Table 5-4: Building inventory WSL averages and discharges of the 12 modeled events for the two structural protection options.

ARI	**5**	**8**	**10**	**20**	**35**	**50**
	P0					
WSL (m PWD)	1044.15	1044.55	1044.77	1045.39	1045.82	1046.97
Q (m^3/sec)	659	838	927	1230	1490	1660
	P7					
WSL (m PWD)	1044.53	1044.59	1044.59	1044.66	1044.98	1045.57
Q (m^3/sec)	371	555	677	855	1270	1360
WSL delta	-0.384[a]	-0.034[a]	0.182	0.731	0.831	1.399

ARI	**75**	**100**	**200**	**350**	**500**	**1000**
	P0					
WSL (m PWD)	1046.97	1047.45	1048.12	1048.65	1049.08	1049.35
Q (m^3/sec)	1660	1870	2020	2390	2710	2920
	P7					
WSL (m PWD)	1045.57	1045.63	1045.76	1046.17	1047.02	1047.80
Q (m^3/sec)	1360	1595	1770	2165	2462	2758
WSL delta	1.399	1.816	2.364	2.474	2.068	1.542

a) Higher flood depths from an option with a lower discharge suggest an error in the groundwater flood depths.

5.2.2. Dynamic Vulnerability Data

In addition to the standard inputs of RFDA (borrowed here from the 2017 Study), the dynamic view of SOFDA requires datasets and parameters to describe the dynamic vulnerability of the study area. Considering the project goal to develop a tool tailored for Calgary, and the lack of similar Canadian studies, the survey discussed in Section 5.2.3 was initiated. The remaining data was provided by CoC's Assessment and Planning departments. For a complete discussion of model inputs, see Appendix E.

5.2.3. Study Survey

The objective of the field and web survey was to collect experiences and vulnerability-indicators relevant to the study area. This required interviews with persons who experienced the 2013 Flood.

The study team gained approval to conduct a field and web survey for this purpose from the Research Ethics Board at the University of Alberta (see Appendix C for a copy of the consent form and questionnaires). After four pilot interviews, it was clear that participants had more to share than simple quantitative responses. Therefore, space for additional comment was provided on the web surveys, and many of the field interviews included unstructured dialog.

Survey Methods

The web survey was built and hosted as a Google Form with 37 questions.[34] This survey was promoted on a community Facebook page, the CoC flood newsletter, and the community association's newsletter. The field survey had 28 questions and was conducted door-to-door in April and May of 2018 in Sunnyside. Door-to-door solicitations took place generally between 5 and 8 PM and interviews were designed to take less than 10 mins.[35]

Survey Findings

At the close of the study in June of 2018, there were 27 web and 22 field participants. Comparing responses for home address against the 2013 Flood inundation[36] shows that all the field participants and half of the web participants in Sunnyside lived within 500 m of the 2013 Flood. Thirty-one of 49 indicated they were directly affected by the 2013 Flood. These statistics point to a participation bias from flood vulnerable, and experienced, residents. Results for key qualitative questions are shown in

Table 5-6, and narrative themes are provided in Table 5-5.

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[34] This can be found in the following link: https://goo.gl/forms/k6fhePY9peobZVVm2. A printout is also included in Appendix C.

[35] Field surveys ran as long as 30 minutes, and some were ended prematurely by participants.

[36] See Appendix G, dataset 'WR_flood_201306_inun.'

Table 5-5: Narrative themes from the unstructured part of the survey.

Theme	**Narrative**
Limited salvageability	Following the 2013 Flood, volunteers stripped most flood-affected homes of anything that contacted flood waters. Some participants, with only a few inches of basement flooding, recounted leaving specific instructions to limit cleanup to those items directly damaged by flood waters. Returning hours later, participants found their entire basement stripped and gutted. Few participants could recall salvaging anything more than a few impermeable heirlooms (e.g. porcelain dish sets).
Limited disaster recovery assistance	The survey found only one participant who recalled receiving assistance through the GoA's disaster relief program. Some commented that they started, but later abandoned, this application process.
Limited claims oversight	Some participants indicated that they had received an insurance payment for flood repairs but had not undertaken the repairs.
Evacuation made things worse	All who commented on their evacuation experience indicated that evacuating led to more household damage. One participant explained this by recounting their experience shuttling a pump and generator back and forth between their two properties through the first night of the flood. They concluded that this diligence was the reason their properties had no flood damage, while the next-door neighbor, who evacuated, had considerable damage. This common narrative within the community may explain the response rate to 'would you obey a future evacuation?' (Table 5-6).
Current FHRs are too onerous	While no question was included on the survey directly addressing participant's views on the current FHRs, many chose to share their opinions and experiences. All who did share opinions disapproved of the current FHRs and none expressed support for expanding them. Some felt the FHRs were ineffective and structural protection should be implemented instead. Some felt adherence to the FHRs would negatively alter the character of Sunnyside; particularly that homes elevated above the BFE with furnaces and water heaters on the main floor could not be accommodated by the historical building typology.

Table 5-6: Survey response summary statistics.

Category	**Response result**	
Level of basement finish	Unfinished: Partially finished: Fully finished:	**31%** **22%** **47%**
Backflow valve installed	True:	**68%**
Maintain backflow valve regularly	True:	**0%**
Sump pump installed	True:	**57%**
Generator readily available	True:	**25%**
Basement ceiling height[a]	Min: Max: Median:	**5.9'** **12.0'** **7.9'**
Basement's lowest opening height	Min: Max: Median:	**3.0'** **7.0'** **5.3'**
Bottom of furnace height from basement floor	Min: Max: Median:	**0.0'** **2.0'** **0.5'**
Would obey a similar evacuation order?	True:	**55%**

a) All participants preferred to provide heights and depths in feet rather than meters.

Responses on basement geometry suggest that newer homes have deeper basements (see Appendix E), and that homes built within the past five years have fully finished basements. Further, survey results show that a *minority* of basements are fully finished in the study area.[37] Some participant narratives suggest unique mechanisms behind basement development in Sunnyside:

- *Pre-war bungalow property improvements*: As discussed in Section 4.4.1, some pre-war bungalows have partial and unfinished basement additions.
- *Flood damaged basement, waiting to rebuild*: Some participants indicated they were still intending to rebuild their basements.
- *Flood damaged basement, happy with it empty*: Some participants indicated they had no intention of rebuilding their basements.

PLPM prevalence was significantly higher for the study survey than what has been recorded in other Canadian studies (see Table 2-1). Explanations for this could be: 1) this survey's bias towards more expensive homes; 2) limited number of studies to compare to; 3) bias in other

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[37] CoC property assessment data provides a percentage of finishing in the basement; however, 90% of the entries show 100% of the basement area as finished — including nearly all the survey participants who responded with 'unfinished' basements. Therefore, this property assessment data variable was excluded from the analysis. This model study assumed fully finished basements.

studies; 4) magnitude and recency of flood exposure (i.e. the 2013 Flood); and 5) a difference in prevalence between Calgary and the other study areas.

As was the case in this study, data collection for flood risk research is often resource limited and therefore relies on voluntary homeowner participation to broaden the coverage of the survey. This leads to the following mechanisms which cast doubt on the ability of such voluntary homeowner surveys to accurately sample assets in the study area:

- lack of participant knowledge;[38]
- false identification by the participant; and
- bias towards flood-experienced participants.

Despite these challenges, the study survey provided valuable narratives to guide the development of SOFDA, parameters for asset vulnerability, and contemporary house typology trends.

5.3. SOFDA Description

SOFDA is a model framework developed to simulate flood risk over time using the Alberta Curves and a residential re-development forecast. This section supplies a brief description of how a SOFDA model conceptualizes and simulates flood risk under dynamic vulnerability.

Development Criteria

Model framework development was motivated by a desire to quantify the benefits of FHRs and to help incorporate the dynamics of risk into decision-making. Above all else, a useful model framework was desired; specifically, one that would aid the efforts of decision makers in Alberta to bring about meaningful, lasting, and efficient flood risk reduction. Considering this, the framework criteria are summarized as (the model framework should):

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[38] Many participants of this survey and Winterton's (2017) survey did not know whether they had a backflow valve. During this study's field interviews, the interviewer often had to explain a backflow valve's purpose and function.

1) estimate flood risk within the primary paradigms of RFDA;
    a) provide financial estimates of flood damage using the Alberta Curves;
2) reflect the vulnerability reductions imposed by FHRs;
    a) incorporate the influence of PLPMs;
    b) incorporate the influence of elevating damage-features (e.g. raising water heaters);
3) simulate changes in relevant building typology brought about by re-development (e.g. larger homes with deeper basements);
4) be flexible enough to handle a diversity of FHRs, future trends, and building typologies;
5) provide some quantification of uncertainty (i.e. stochastic modeling);
6) be as simple as possible; and
7) provide detailed outputs to facilitate the analysis of underlying mechanisms.

Guided by these criteria, SOFDA was written in Python 2.7 (see Appendix D for detailed description and source code). Implementation in Python allows the framework to use an extensive library of open-source modules and promotes readability and reusability.

5.3.1. Organization and Hierarchy

To reflect the view that a flood damage prediction should be calculated for each asset in the study area, before summing to obtain the area estimate, SOFDA is object based. This means that during startup, SOFDA spawns objects for each model feature and assigns them a logical hierarchy. For example, for each asset in the building inventory, SOFDA spawns a House object, which in turn spawns five child Damage-Function objects (Dfunc) for each damage type of the Alberta Curves (see Figure 5-6). During simulation, these Dfunc objects are used to make a damage prediction for each of the 12 flood events for each of the 652 assets for each of the three timesteps. The center of Figure 5-3 diagrams a trimmed view of the ten hierarchical objects and three non-hierarchical 'common worker' objects spawned by SOFDA for each simulation. The outside of this figure shows the input requirements for each of these objects. Appendix D supplies a complete description of this hierarchy and each object.

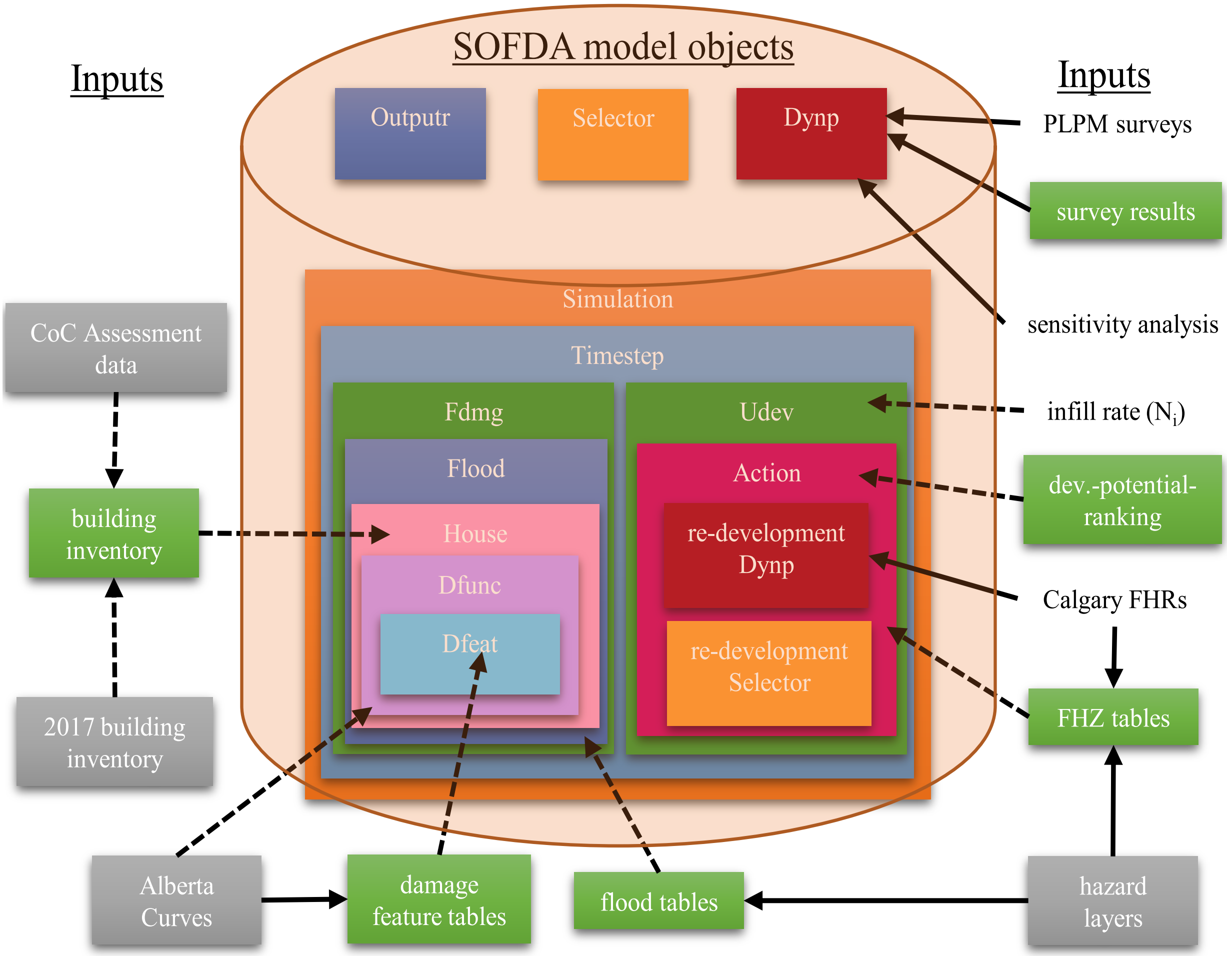

Figure 5-3: SOFDA object simplified hierarchy and input requirements conceptual diagram. Solid arrows denote 'leads' or 'contributes to' while dashed arrows represent information flow. Inputs drawn with boxes represent data sets; with gray boxes sourced from third parties and green boxes generated for this thesis. Some arrows and inputs omitted for clarity. For object descriptions and acronyms, and a more complete description of inputs, refer to Appendix D.

SOFDA's Flood Damage Module (Fdmg) calculates a snapshot of risk from asset vulnerability, while the Urban Re-development Module (Udev) simulates changes in asset vulnerability. Together, these two modules create a dynamic view of risk as shown on Figure 5-4. This figure also shows the top-level hierarchy of SOFDA: within the highest model level (Session object) first Simulation objects, then Timestep objects are nested. These Timestep objects control how Udev updates the building inventory before Fdmg re-calculates EAD.

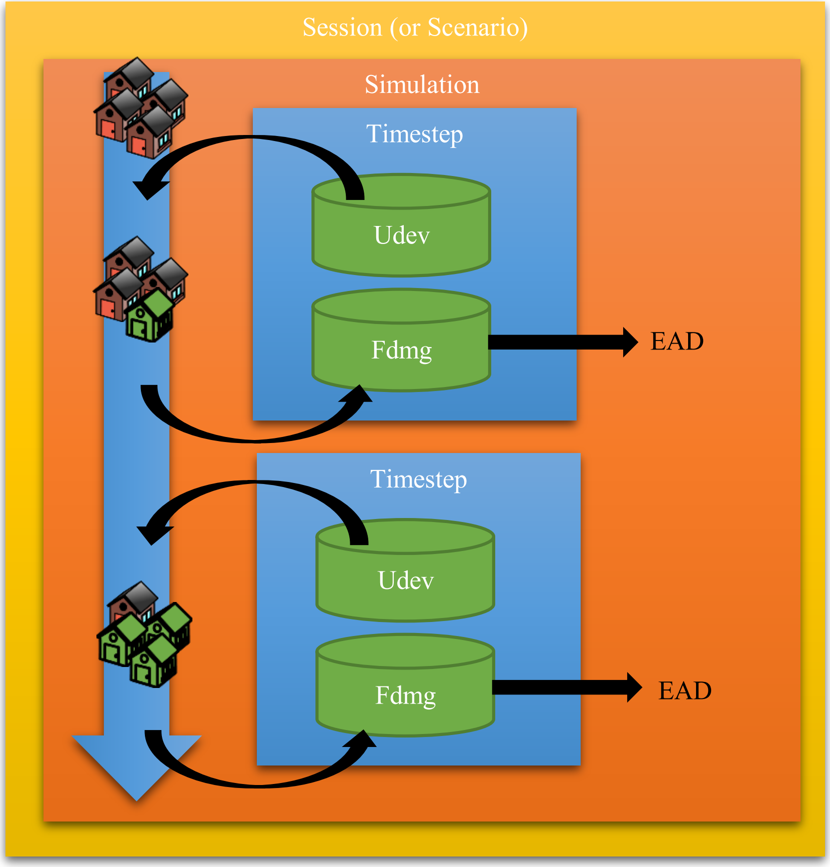

Figure 5-4: SOFDA top-level module hierarchy and simulation process trimmed conceptual diagram.

5.3.2. Flood Risk Simulations

The key capability separating SOFDA from its precursor, RFDA, is the inclusion of time dynamics. In other words, SOFDA represents a shift from the static risk snapshots of RFDA, towards a view of risk that changes through time. SOFDA realizes this new dimension through vulnerability dynamics, conceptualized as the re-development of houses within the study area.[39] To simulate building typology and vulnerability, parameters describing modern houses are used as predictions for the re-developed house typology. This assumes that current building trends will continue.[40] This chain of simplifications allows the model to forecast only those scenarios which are ‘reasonably likely,’ excluding the black swan or surprise events described by Merz et al. (2015) (e.g. another catastrophic flood). In other words, this model study assumes simple extrapolations

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[39] The SOFDA framework can also simulate hazard dynamics (e.g. climate change or phasing of structural protections); however, these dynamics were excluded from the model described in this thesis.

[40] While the parameter medians are held constant throughout the simulation, the stochastic variation of key parameters by SOFDA provides some accounting for the uncertainty of this assumption.

from current trends can supply reasonable and useful forecasts of the future. To increase the reliability of the predications within this limitation, a forecast horizon of 30 years was selected from conversations with decision makers.

The three timesteps shown in Table 5-7 were selected to generate flood risk forecasts at the 30-year horizon and one intermediate timestep (15 years). As the time dimension in SOFDA is realized solely by the infill count (N_i), the intermediate timestep can also be used as a risk forecast at 30-years for a scenario with slower economic and population growth (i.e. less re-development). Like Figure 5-4, Table 5-7 shows that for the t1 and t2 timesteps, first re-development is simulated, then flood damage is estimated. For the first timestep (t0), no re-development is simulated; instead, the starting vulnerability of each asset is estimated to generate the initial conditions for the model.

Table 5-7: Simulation timeline for the SOFDA model showing the basic function of the two main modules on each timestep. See text for module descriptions, acronyms, and details. See Appendix E for a complete description of the model timeline.

Timestep	**Udev module**	**Fdmg module**[c]
t0	Assign initial conditions[a]	Calculate EAD
t1	Re-develop N_i House objects[b]	Calculate EAD
t2	Re-develop N_i House objects[b]	Calculate EAD

a) See Section 5.3.3
b) See Section 5.3.5
c) See Section 5.3.4

5.3.3. Initial Conditions

The initial conditions for this model study are the House object attributes of the first timestep (t0). Except for PLPMs, all these initial conditions are passed to SOFDA as discrete input parameters via the building inventory described in Section 5.2.1.[41] Unlike the easily observable parameters of the building inventory (e.g. floor area, basement finish height), there is limited data on the PLPM status of each house (e.g. which houses have backflow valves). Considering this, and the sensitivity to PLPM status (discussed in Section 5.4), PLPM initial conditions are assigned stochastically based on: 1) results from the study survey; and 2) results from similar surveys (Table

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[41] The SOFDA framework is flexible enough to manipulate all object attributes at any interval internally or maintain parameter values from the input files. Parameters manipulated once, during simulation start-up, are considered here as internal initial conditions (rather than external initial conditions passed from parameter files) as they represent the model state at the start of the simulation — before manipulation during timesteps.

2-1). Table 5-8 provides the stochastic parameters used to assign the PLPM status of each House object during model startup.

Table 5-8: Initial conditions assigned to House objects for each simulation.

Attribute name	Stochastic properties
backflow valve	50% True
sump pump	50% True
generator	25% True

5.3.4. Flood Damage Module (Fdmg)

SOFDA's Flood Damage Module (Fdmg) resembles a traditional flood damage model: combining exposure and vulnerability variables to make damage predictions (similar to Figure 2-11). Figure 5-5 shows how, within Fdmg, first Flood objects, then House objects, then Damage-Function objects (Dfuncs) are nested. The figure also shows how each Flood object controls the evaluation of damages from flood depth using the Dfuncs before summing the damages of all assets to calculate EAD. The following sections elaborate on this Fdmg module.

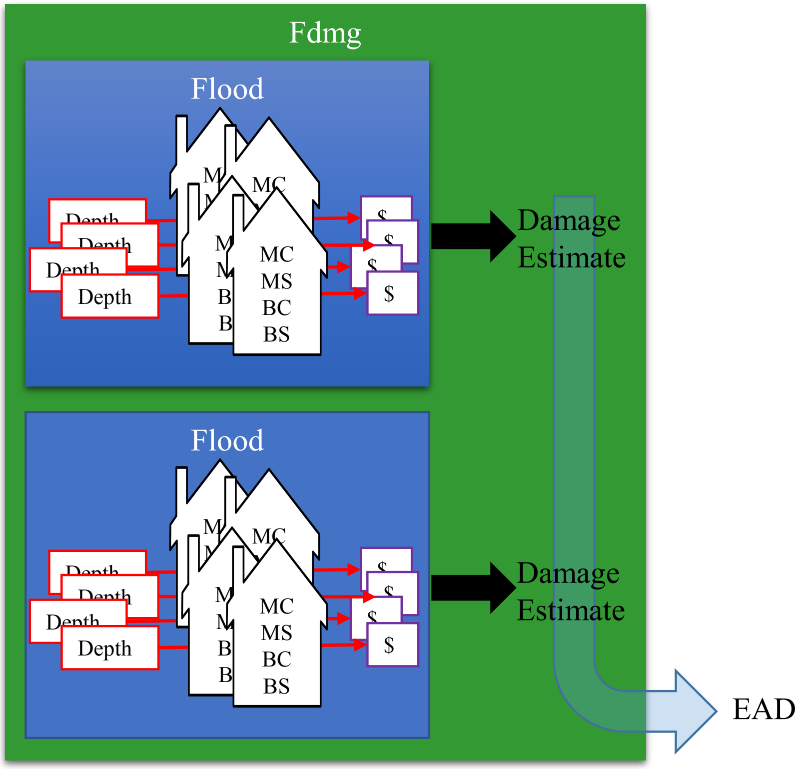

Figure 5-5: Conceptual diagram for the Fdmg module. See Table 5-9 for a description of the Damage-Function objects (Dfuncs) nested within each House object.

Damage-Function Objects (Dfuncs)

As loss function that generates damage predictions from flood depths in consideration of an asset's vulnerability, Damage-Function objects (Dfuncs) lie at the core of SOFDA's Fdmg module. Each Dfunc builds and maintains its own depth-damage relation to quickly estimate damages during the simulation routine. Each House object spawns Dfuncs based on user supplied parameters for place (e.g. garage, basement, or main floor) and damage type (e.g. structural or contents). Parameters used in this study are modeled after the five damage types of the Alberta Curves (discussed in Section 3.1) provided in Table 5-9. As this study did not consider any FHRs that modify building contents, the un-modified Alberta Curves were applied for all contents type Dfuncs (type code 'C'). In contrast, all structural Dfuncs (type code 'S') employed the Damage-Feature Curves discussed below.

Table 5-9: Dfunc [acronyms] and mode by type code (C, S) and place code (M, B, G). See text for a description of curves. See Appendix E for a complete description of Dfunc objects.

Place/Type codes	Contents (C)	Structural (S)
Main Floor (M)	[MC] Alberta Curves	[MS] Damage-Feature Curves
Basements (B)	[BC] Alberta Curves[a]	[BS] Damage-Feature Curves[a]
Garage (G)	N/A	[GS] Damage-Feature Curves

a) The basement vulnerability algorithm (described below) is applied to this Dfunc.

This approach carries forward the assumption of RFDA that, for a given exposure, the main floor for all houses of the same type would be damaged similarly:

- *Contents damages* (C): there is a constant relation between depth and damage scaled by the building's area.
- *Structural damages* (S): there is a constant relation between depth and damage scaled by the relevant building geometry and, for new homes, the requirements of any FHRs.

For basements, the above described mechanisms are similar; however, the basement Dfunc's anchor elevation and vulnerability grade (see below) introduce more heterogeneity between Dfuncs of the same building class (and place code).

To convert WSL values retrieved from the flood tables to a relative depth, each Dfunc calculates an *anchor elevation* as its zero-depth datum as shown in Table 5-10. As the table shows, for basement and garage Dfuncs, this anchor elevation does not correspond to the House object's anchor elevation, which is provided in the building inventory.

Table 5-10: Dfunc anchor elevation formulas used in this study. See Appendix E for a complete description of Dfunc parameters.

Place code	**Anchor elevation formula**
Main Floor (M)	house main floor elevation (HMFE)
Basements (B)	HMFE – basement finish height – joist spacing
Garage (G)	house DEM elevation

Damage-Feature Curves

To facilitate manipulation by FHRs, and allow for more accurate object scaling, SOFDA uses a novel algorithm to generate depth-damage relations directly from damage feature tables. The damage feature tables used by SOFDA are expanded from the damage feature tables developed during the 2015 Study,[42] where each line is considered a 'damage feature' (e.g. 'remove and replace water heater'). This differs from the approach of RFDA, which uses the depth-damage relations of the Alberta Curves. These Alberta Curves are *pre-compiled* from the damage feature tables then scaled by an average house area (for each building class; see Section 3.1). In contrast, SOFDA's Damage-Feature Curve mode compiles the depth-damage relation directly from the damage feature tables for each Dfunc. As shown on Figure 5-6, during model startup Dfuncs (see Table 5-9) spawn a Damage-Feature object for each line on the corresponding damage feature table. For example, from the entry 'remove and replace water heater' on Figure 3-4, a class 'C' House object would spawn a 'BC' Dfunc which would in turn spawn a Damage-Feature object with a depth attribute of 0 m and a price attribute of $1,200. For Damage-Feature objects with geometric units (e.g. m^2), price is calculated from the unit rates provided on the damage feature table and the relevant geometry of the House object. This avoids the assumption in RFDA's implementation of the Alberta Curves that all damage values scale with building area.

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[42] See Figure 3-4 for a sample of the original 2015 Study damage feature tables and Appendix D, Attachment C for the expanded version required by SOFDA.

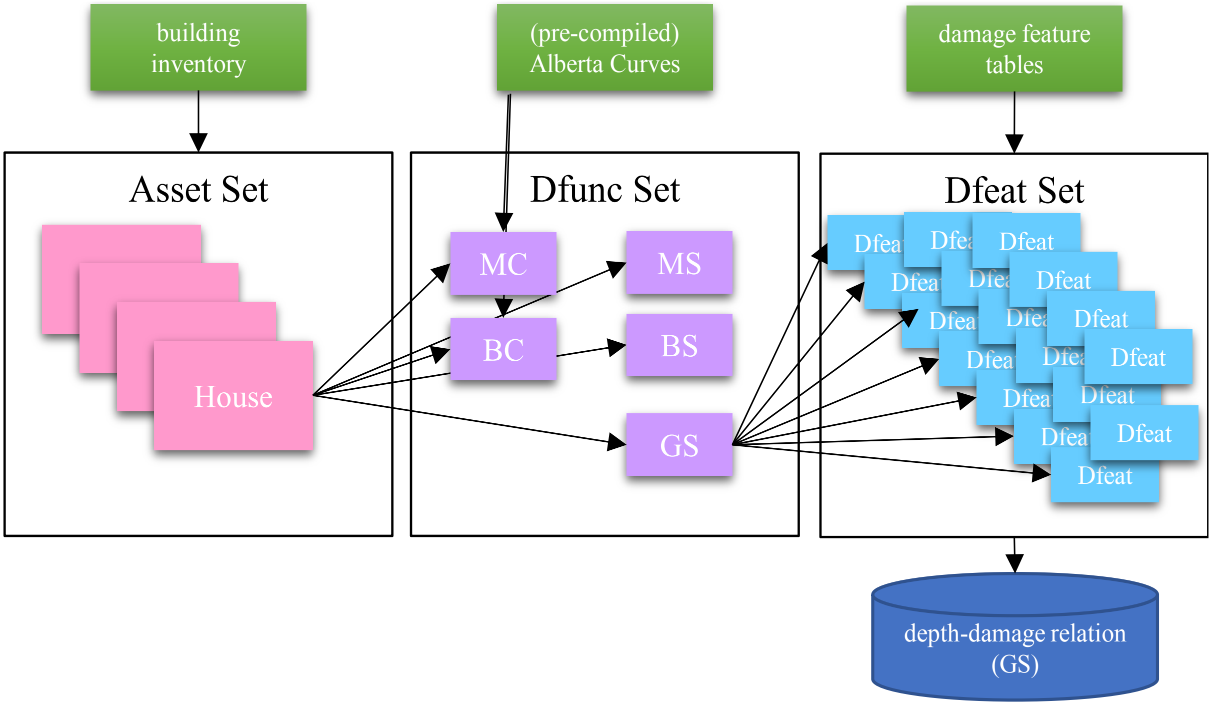

Figure 5-6: SOFDA's House object hierarchy diagram. Arrows clarify the hierarchy relation of one House object and one Dfunc object. Damage-Feature objects shortened to 'Dfeat.' See text for description and other acronyms.

Once the full Damage-Feature object set is spawned,[43] the prices are summed at each depth and a depth-damage relation is generated and made ready for the first damage estimate. A sample collection of the depth-damage relations generated by five Dfuncs for a class 'C' house is provided in Figure 5-7. Comparing this to the four loss functions of Figure 3-5 suggests that SOFDA will predict higher structural (compared to contents) damages than the pre-compiled Alberta Curves.

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[43] For this study, damage features with cost below $490 (roughly 1/3 of damage features) were excluded to improve performance.

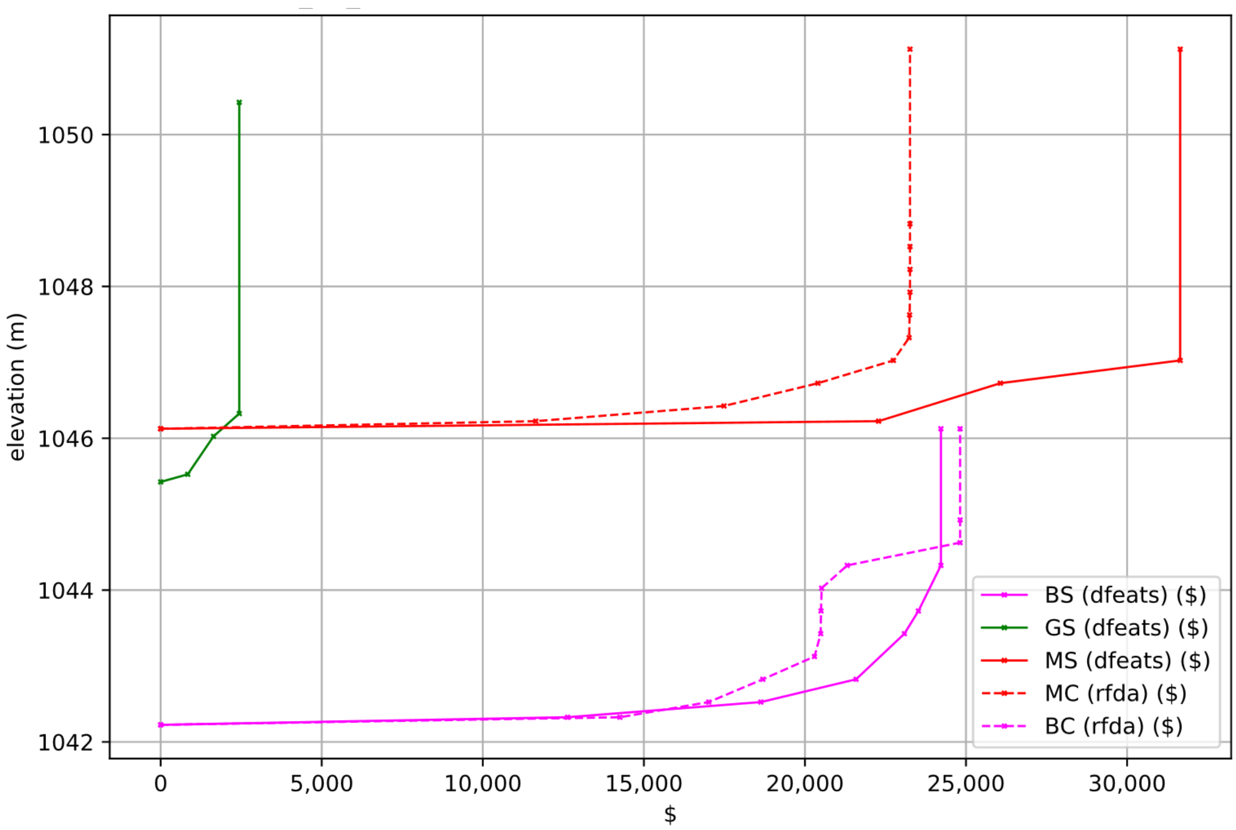

Figure 5-7: Depth-damage relations on five Dfuncs for a typical asset in SOFDA. See Table 5-9 for Dfunc acronym definitions (BS, GS, etc.). Dfuncs marked with '(dfeats)' are generated in mode 'Damage-Feature Curves' while those marked with '(rfda)' are 'Alberta Curves.'

Basement Vulnerability

To model the influence of PLPMs on flood damage vulnerability, SOFDA reduces the exposure to each asset based on its PLPM presence. This reflects the view that, for small basement floods, a house with a backflow valve should be less vulnerable to flood damage than one without. This is accomplished with a simple algorithm that modifies intermediate water depths passed to basement Dfuncs (from the flood tables) as shown in Table 5-11. In other words, for flood events where the groundwater level is between the main and basement floors, SOFDA may reduce the exposure depending on the PLPMs and height-geometry of the House object.

Table 5-11: Basement depth reduction algorithm showing the mitigation of flood exposure.

Condition	**Logic**	**Mitigated depth**
High	flood WSL > HMFE	depth
Intermediate	HMFE > flood WSL > anchor elevation	Table 5-13
Below	flood WSL < anchor elevation	0
Anchor elevation: elevation at which the Dfunc's flood depths are considered zero (i.e. basement floor elevation). *Depth*: raw flood level provided by the flood tables relative to the Dfunc's anchor elevation. *HMFE*: house main floor elevation		

To quantify the efficacy of PLPMs on basement damages from intermediate depths, each house is assigned a basement vulnerability grade of 'dry,' 'damp,' or 'wet' as shown on Table 5-12. Further, the reliance of sump pumps on the city's electrical grid (i.e. grid power) is also considered. To reflect the assumption that extreme events lead to a loss of grid power, the status of grid power is calculated at each time step.[44]

Table 5-12: Basement vulnerability grade calculation logic.

grid power = ON	**grid power = OFF**	**Basement vulnerability grade**
valve & pump	valve & pump & generator	**dry**
valve OR sump	valve OR (pump & generator)	**damp**
otherwise[a]	otherwise[a]	**wet**
a) any combination not included in the above		

After each house is assigned a basement vulnerability grade, SOFDA calculates the mitigated depth to feed to the depth-damage function (for intermediate depths) as shown in Table 5-13. This intermediate depth algorithm also reflects the assumption that any flood depths higher than the lowest opening in a basement (e.g. basement windows) will spill over and flood the basement (to a depth matching the outside WSL) regardless of PLPMs.

Table 5-13: Basement depth reduction algorithm for intermediate basement depth conditions.

Basement vulnerability grade	**Logic**	**Mitigated depth**
dry	depth > basement opening height	depth
dry	depth < basement opening height	0
damp		depth * 0.5
wet		depth
Depth: raw flood level provided by the flood tables relative to the Dfunc's anchor elevation.		

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[44] As described in Appendix E, 'gpwr_ari' is assigned stochastically at each time step from a lognormal distribution centered around 80 ARI.

Estimating Damage

Once the full hierarchy of objects are compiled (and updated), SOFDA is ready to estimate the current risk of the asset set. Figure 5-8 shows the basic program loop undergone by Fdmg for each timestep. This illustrates how each Dfunc's depth-damage relation is queried once for each of the 12 floods, and how raw flood depths are mitigated in consideration of the parent House object's PLPM and grid power status. The last step is the calculation of risk as EAD (described in Section 2.3.1). In short, once the total damage of each simulated flood is plotted against the likelihood of each event, the area under this curve is taken as the present value of the total risk, or EAD.

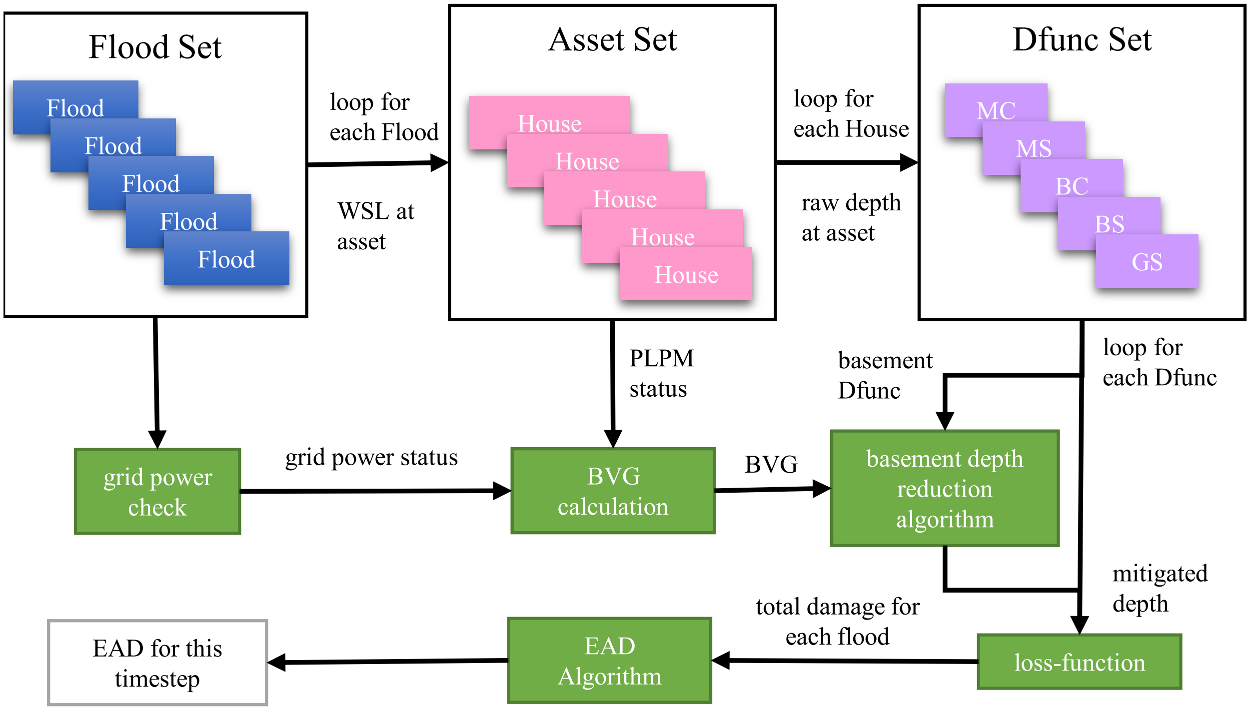

Figure 5-8: SOFDA's Fdmg calculation diagram. Black arrows denote 'leads to;' some omitted for clarity. See text for description and acronym definitions.

5.3.5. Urban Re-Development Module (Udev)

To simulate the effects of urban re-development (i.e. infilling) on the vulnerability of the study area, assets are selected and then assigned new attributes typical of houses built since 2013 in the study area. The Udev module achieves this with four steps: 1) select the count of infills for the timestep (N_i); 2) select House objects for demolition up to this count; 3) assign new attributes to each demolished House object; and 4) re-generate the depth-damage relation of each Dfunc (of that House object). When the scenario under simulation includes FHRs, step #3 is expanded to include attribute assignment per the FHR rules (discussed in Section 5.5.1). Figure 5-9 illustrates these basic steps undergone by Udev in each timestep.

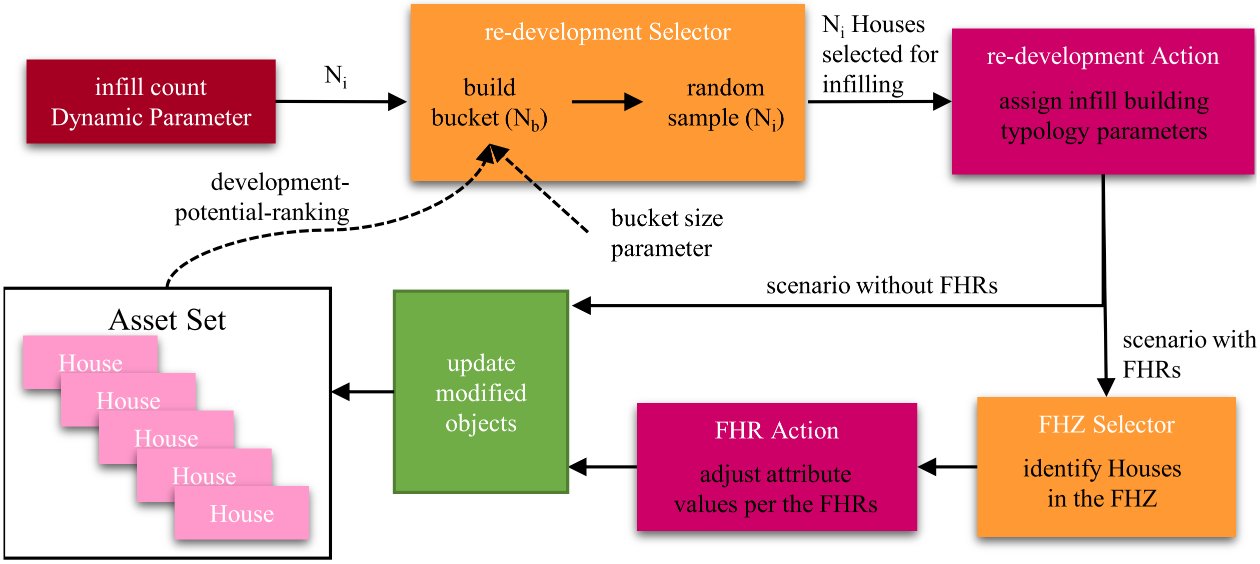

Figure 5-9: SOFDA's urban re-development Action and FHR Action calculation diagram. Solid arrows denote 'leads to' while dashed arrows denote 'contributes to;' some omitted for clarity. See text for description and acronym definitions and Appendix E for details.

Infill Rate (N_i)

For this thesis, a constant median infill rate was assumed based on the average observed in the study area in the past 20 years as shown in Figure 4-10. This rate of 10 houses per year is considered a 'hot market' (D. Sol, p.c.). A 'cooling market' re-development scenario is also explored with a median of five houses re-developed per year (scenarios are discussed further in Section 5.5.1). To better quantify the uncertainty of this infill rate parameter, it is sampled stochastically for each timestep from a normal distribution likelihood function (see Appendix E for details).

Spatial Selection and Downscaling

After N_i is calculated (by sampling the likelihood function), SOFDA selects this number of assets for re-development based on the simple development forecast and some randomized sampling. In this way, SOFDA downscales the infill count prediction to identify the specific houses for re-development, while incorporating some uncertainty through the randomized sampling. For this study, the development potential for each house is assumed to be a direct function of the ratio of the assessed property value ($) to the parcel area ($m^2$). In other words, big lots with cheap homes are predicted to be the most likely to redevelop. This property value-density attribute ($\$/m^2$) is calculated for each asset, then used to rank the assets from most to least likely to develop. Figure 6-11 shows this ranking for a small part of the study area, while Appendix E provides a more detailed discussion of this development-potential-ranking and the random sampling of the downscaling algorithm.

Infill Building Typology

Once a House object is selected for re-development by the downscaling algorithm, the redevelopment action is applied to replace the original parameters with those typical of a new house. The eight dynamic parameters that simulate a re-developed house are provided in Table 5-14.

Table 5-14: House object infill building typology parameters before application of FHRs. See Appendix E for a full description. PLPM parameters shaded in blue.

Attribute name	Unit	New value (mean)	Stochastic properties
floor area	m^2	parcel area*0.45 - 50	normal distribution
anchor elevation	m NAD	DEM elevation + 0.6	normal distribution
year of construction	date	current year	
basement finish height	m	2.8	normal distribution (Figure 5-10)
building type		'AD'	
backflow valve		50% True	
sump pump		50% True	
generator		25% True	

The new floor area parameter is set to the maximum allowable for this single-family home land use designation (less 50 m^2 for the garage). This reflects the assumption that re-development will maximize the profit of the new construction by building the largest allowable footprint.[45] The House object anchor elevation is selected as 0.6 m above grade to reflect typical building practice in the study area. Basement finish height is selected to reflect the data obtained in the study survey for homes built within the past five years, as shown on Figure 5-10. Building type is set to 'AD' to reflect the trend in this study area for new homes to be large, high-value, and two-story. PLPM parameters are assigned using the same parameterization as for the initial conditions discussed in Section 5.3.3. Finally, depending on the scenario and the FHZ status of the House object, the

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[45] This ignores the influence of parcel specific setback requirements that may limit the footprint of the new structure more so than the 45% coverage criteria.

actions described in Section 5.5.1 may be applied to simulate the influence of FHRs on building typology (e.g. main floor above the base flood elevation).

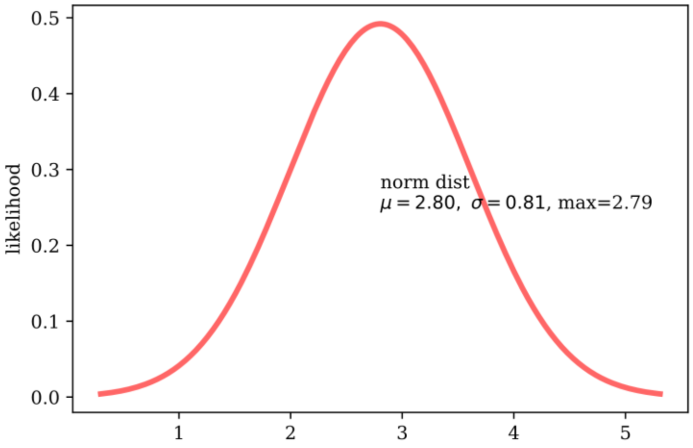

Figure 5-10: Basement finish height (in meters) likelihood function used for this study.

5.4. Sensitivity Analysis

The sensitivity analysis conducted for this model study is a set of special, deterministic model runs on the study area that, instead of seeking a reasonable prediction for flood risk, seeks to quantify the importance of each parameter in making such a prediction. Generally, all parameters are kept at some median or 'best-guess' value, with the exception of the focus parameter; which is toggled between extremes to explore the influence of this parameter on the main results. After completion of the model framework, the sensitivity analysis was conducted to:

- identify parameters for exclusion from the stochastic analysis (those with little influence) to reduce computation time and complexity;
- identify parameters with high uncertainty and sensitivity to help make recommendations on future flood risk modelling and research; and
- build confidence in the model (in other words, does it do what we expect?).

For this study, the sensitivity analysis included 43 such runs to calculate the sensitivity of 25 model parameters. The main findings from the sensitivity analysis are that the damage prediction is:

1. sensitive to the heights (or anchor elevations) of main floors and basements;
2. sensitive to the basement vulnerability grade; and
3. insensitive to parameters that only influence the damage calculation on a small part of the study area (e.g. basement opening height).

Additionally, the sensitivity analysis shows that the change in damage prediction over time (from vulnerability dynamics) is:

- sensitive to the anchor elevation assumption for new houses; and
- sensitive to FHZ (BFE and extents of the current rules).

These sensitivity analysis results suggest that:

- some parameters can be left as deterministic without a significant impact to the damage estimate; and
- future data collection should not limit itself to surveying main floor elevations, but also basement floor elevations (or heights).

A second sensitivity analysis was conducted to explore the EAD prediction sensitivity to the spatial selection algorithm. Three variations of the algorithm for spatial selection from the development-potential-ranking discussed in Section 5.3.5 were tested. Results show that EAD is sensitive to this algorithm, and a higher EAD is correlated to the options most similar to the raw development-potential-ranking (i.e. no randomized sampling). This suggests that those properties with the highest development potential have the highest exposure. The full sensitivity analysis results and discussion are provided in Appendix E.

5.5. Monte-Carlo Simulation Experiment

To implement SOFDA as a stochastic tool, each scenario run includes an ensemble of simulations in a Monte-Carlo style simulation experiment to calculate a range of forecasts. The Monte-Carlo method employed here follows these basic steps:

1) *Parametrize the scenario*: Parameter values (e.g. number of runs) or probability distributions (e.g. normal distribution for infill basement finish height) are defined from the input files for the scenario.
2) *Spawn Simulation object*: Within the scenario parameters, a Simulation object is spawned with discrete parameter values generated as samples from the scenario distributions. This Simulation object is used to simulate one possible forecast for the study area's dynamic flood risk.
3) *Repeat #2*: A new Simulation object is spawned and executed until all simulations are complete.[46]
4) *Post-process*: After the model run is complete, ensemble statistics are calculated from the collection of simulation results to analyze the range of predictions made for the scenario.

5.5.1. Scenarios

Introducing scenarios to model studies can provide valuable context and extend the usefulness of results. Rather than making a single prediction, incorporating scenarios supplies a range of predictions along a range of dimensions. Scenarios acknowledge the uncertainty of predictions and can improve decision support by facilitating observations like: 'model results suggest flood risk is expected to increase *if the current re-development rates continue*,' or 'model results suggest enhancing structural protections will reduce risk *more than imposing new FHRs*.' While the utility of scenarios is clear, selecting which scenarios to evaluate is subjective and challenging. For this study, scenario choice was informed by two considerations:

- those parameters or mechanisms with high uncertainty (e.g. re-development rate); and
- those parameters within the power of perceived audience (i.e. decision makers) to influence (e.g. enhancing structural protections).

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[46] During a trial run of 1,000 simulations, simulations past the 300th influenced the mean ensemble value by less than 1%. Therefore, a run count around 300 was used for this study.

Early discussions with decision makers at the CoC suggested scenario dimensions largely in-line with earlier flood risk studies by the CoC and found elsewhere in the literature:

- *Climate change*: How might climate change influence flood risk?[47]
- *Socio-economic*: How might different socio-economic growth rates influence flood risk?

To these, dimensions for structural protection and FHR options are added to address the research questions. Structural protection options are simulated with alternate flood table inputs obtained from the 2017 Study as discussed in Section 5.2.1. The influence of socio-economic factors on flood risk is incorporated into this study with two infill rates (N_i):

- *a cooling market (U-)*: reduced infill rate (5 houses per year); and
- *a hot market (U+)*: sustained infill rate (10 houses per year).

As the time dimension in SOFDA is driven solely by re-development, intermediate (15-year) timesteps for U+ scenarios are equivalent to the final (30-year) timestep of U- scenarios. In other words, a single simulation run generates outputs for the U- scenario at its mid-timestep ($N_i = 150$), before infilling another 150 houses (on average) to obtain the U+ outputs as shown on Table 5-15. This has the advantage of cutting the number of simulations needed in half, by taking the mid-point results of the normal U+ runs as the end-point results of the U- runs. Therefore, scenarios that capture the socio-economic dimension are excluded from Figure 5-11 as they do not need unique parameters.

Table 5-15: Socio-economic pseudo-scenarios by timestep and infill rate.

Timestep	Mean infill rate (Ni)	Simulated years for U-	Simulated years for U+
t0	N/A	0	0
t1	150	30	15
t2	300	60*	30
*beyond this study's forecast horizon			

On the remaining two dimensions, five scenarios are evaluated as shown in the scenario-matrix of Figure 5-11. For convenience, each of these five scenarios are assigned a 'scenario number' based on their position in the matrix (e.g. S01). In Chapter 6, figure legends concatenate this scenario number, the option codes, and the timestep (Table 5-15) for easy referencing. For example,

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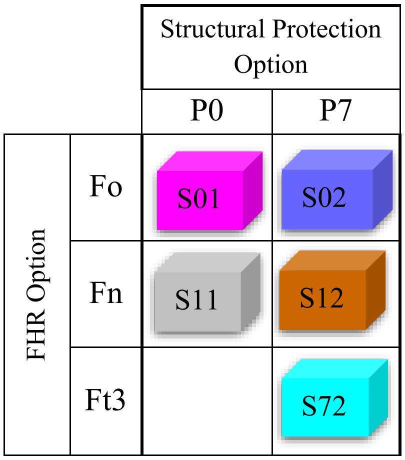
[47] At the time of study, no hazard layers were available for the simulation of climate change. Further, the influence of climate change on flood hazard during the 30-year horizon of the analysis is thought to be minor. See suggestions for future research in Section 7.3.

'S01_FoP0 (t1)' designates results for scenario 'S01' at the first timestep and reminds the reader that S01 was simulated with FHR option 'Fo' and structural protection option 'P0.'



		Structural Protection Option	
		P0	P7
FHR Option	Fo	S01	S02
	Fn	S11	S12
	Ft3		S72

Figure 5-11: Base scenario matrix showing the two scenario dimensions, their option codes, and the scenarios considered in this study (solid cubes with a scenario number). For structural protection options, refer to Section 5.2.1; for FHR options, refer to Section 5.5.1.

Current FHRs (Fo)

This thesis investigated two FHR options and an option without FHRs as summarized in Table 5-16. This table shows: 1) the number of assets included in each FHZ; 2) the base flood elevation (BFE) average in that zone; and 3) the rules that new houses within the FHZ must adhere to.

Table 5-16: FHR option summary statistics.

FHR name	**Code**	**FHZ asset inclusion**	**BFE median**	**Rules**
Current	Fo	Zone 1: 317 (48.6%)	Zone 1: 1046.7	Table 5-17
None	Fn	N/A	N/A	N/A
3-Tier	Ft3	Zone 1: 126 (19.3%) Zone 2: 206 (31.6%) Zone 3: 320 (49.1%)	Zone 1: N/A Zone 2: N/A Zone 3: 1048.2[a]	Figure 5-13

a) BFE taken as the 100 ARI WSL from the 2017 Study's 'unmitigated' scenario (Appendix G, dataset: 'GLD_2017CoC_WSL_um')

Until the major re-write following the 2013 Flood, FHR rules in Calgary's flood fringe centered on three mitigation requirements: 1) design to prevent structural damage; 2) elevate the main floor above the BFE; and 3) elevate mechanical and electrical equipment above the BFE. After the 2013 Flood, Calgary's City Council requested and approved bylaw 11P2014 (Calgary Planning Commission 2014). In the flood fringe, this removed exclusions and replaced them with exceptions based on footprint increases and added a fourth mitigation requirement for backflow valves. The flood fringe rules for the current FHRs are described in Table 5-17 and the FHZ for the study area is shown in Figure 5-12. For a full discussion of FHRs and their history in Calgary, refer to Appendix B.

Table 5-17: Infill typology parameters for houses within the FHZ under the current FHRs (Fo). See Appendix E for a full description.

Attribute name	Unit	New value (mean)	Stochastic properties[b]
backflow valve		100% True	N/A
anchor elevation	m NAD	BFE[a]	N/A
mechanical and electrical feature depths	m	BFE[a]	N/A

a) When applying this parameter, the minimum of the attribute's current elevation and the BFE is taken.

b) FHR rules are applied deterministically.

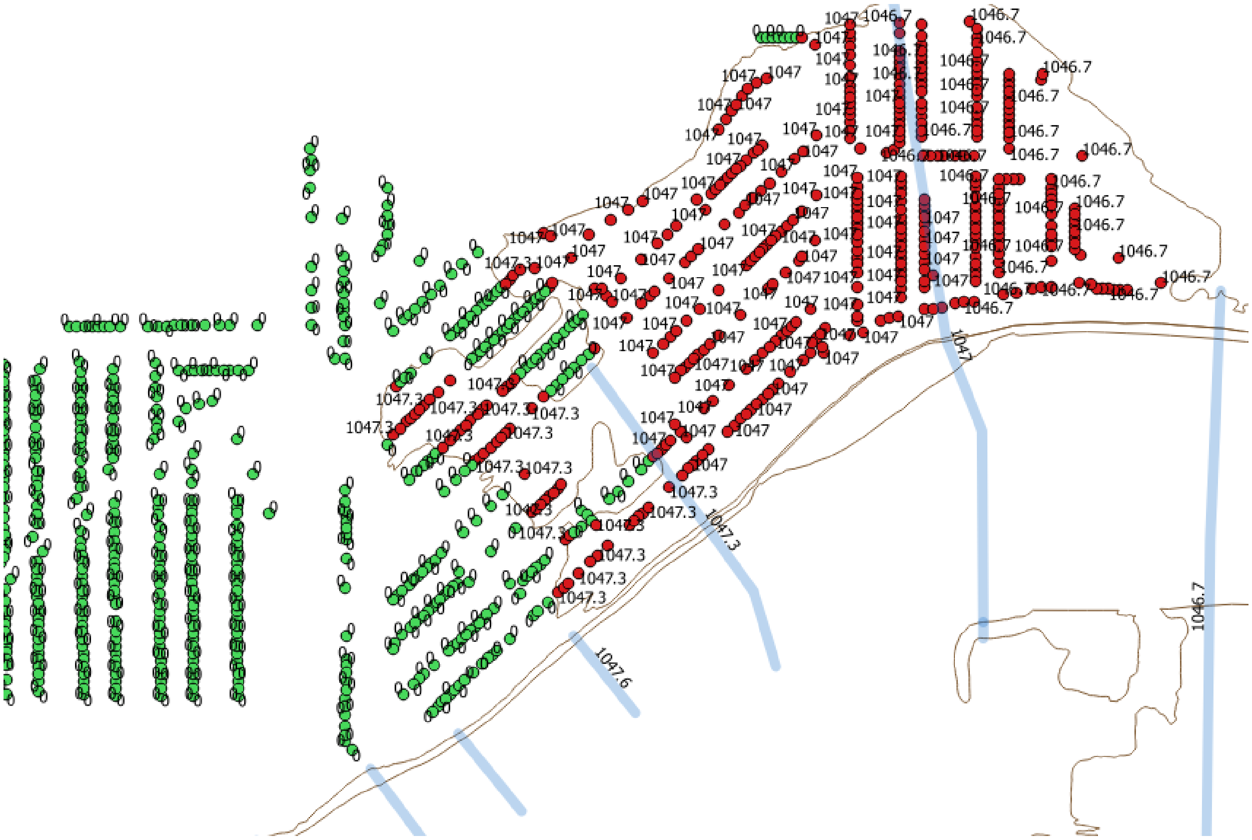
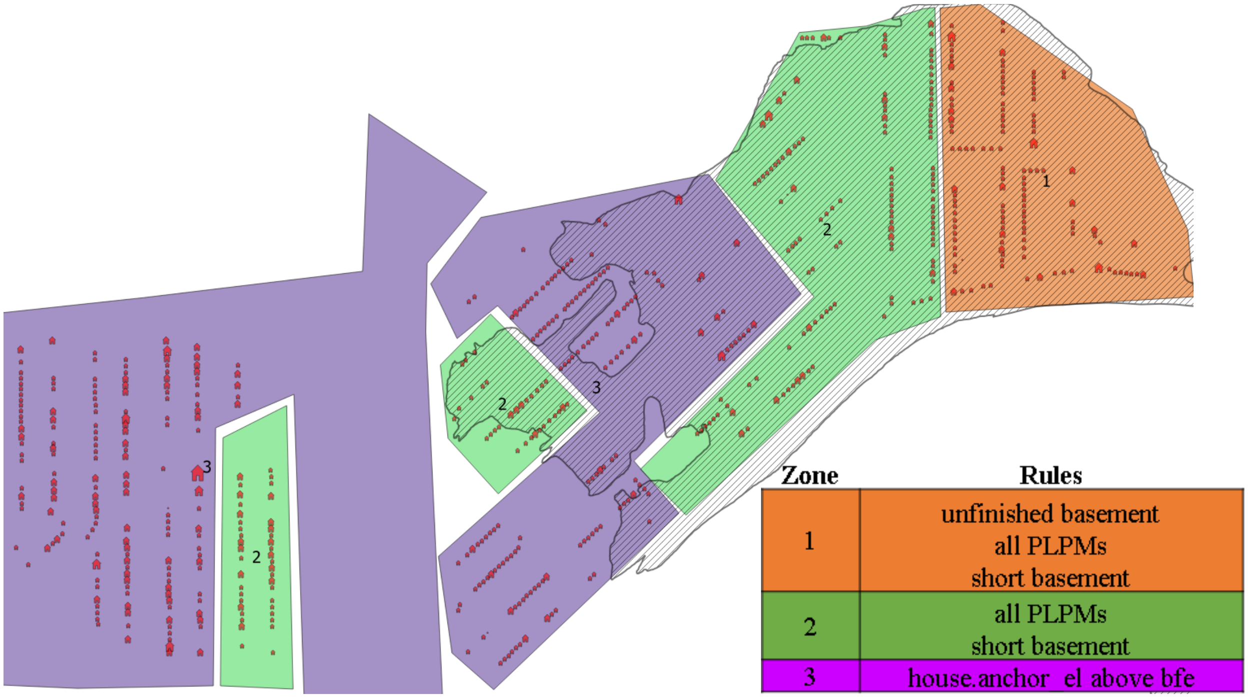


Figure 5-12: Current FHZ in study area showing: houses [green/red] outside/inside the FHZ; and the [blue] base flood elevations (BFE).

3-Tier FHR (Ft3)

An important strength provided by the dynamic view of risk, and a model that structures this view, is the ability to quantify the benefits of policy measures that influence vulnerability gradually, like

FHRs.[48] This limitation on traditional flood risk models hinders the development of robust and efficient FHRs, as policy-makers can only blindly adopt FHRs from intuition, standard practice, and what their constituents consider acceptable. To explore the potential of a dynamic view of risk in facilitating a more methodological evaluation of FHRs, this thesis tests a novel 3-tier FHR on the study area. This hypothetical FHR is developed to optimize the following criteria: 1) simplicity and feasibility for homeowners and city planners; 2) maintenance of the character of the neighborhood; and 3) reduction of flood risk by avoiding the key weaknesses of the current FHRs. From these criteria, the FHR shown in Figure 5-13 was developed. In practice, numerous FHRs could be considered in direct consultation with stakeholders (similar to an options assessment for structural protections).



Zone	Rules
1	unfinished basement all PLPMs short basement
2	all PLPMs short basement
3	house.anchor_el above bfe

Figure 5-13: FHZ for the novel FHR showing the three-tiered areas (orange, green, purple) and corresponding rules. Current FHZ is overlain with a black-hatch.

To address the inefficient, one-size-fits-all, allocation of uniform rules within the FHZ, and the omission of floodprone assets outside the FHZ, the novel FHR divides the study area into three zones based on hazard intensity and likelihood: 1) high (frequent and deep flooding); 2) moderate;

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[48] In contrast to structural protections, which provide an instant vulnerability reduction to the area once complete, retrofit FHRs take time to reduce the vulnerability of a neighborhood as floodproof homes gradually replace floodprone homes.

and 3) minimal, as shown in Figure 5-13. BFE-based rules are avoided for zones one and two, as this WSL is more than 2 m above ground in some areas forcing expensive, out-of-character building typologies. Unfinished basements are mandated in zone one,[49] and short basements (6') in zone one and two. PLPMs are avoided in zone three, as the survey results suggest these are rarely maintained, and therefore should be required sparingly. Accordingly, zone one and two are required to have full PLPMs (backflow valves, generators, and sump pumps). For a detailed description of this FHR option, see Appendix E.

5.6. Practicalities

Early versions of SOFDA were too computationally slow to be useful.[50] This is a common challenge for models built in Python. To remedy this, considerable effort was invested to make the framework faster and less memory intensive. The latest SOFDA version simulating scenario S02, with three time-steps, could perform one simulation in roughly 8 minutes (on the cluster described below), with 1000 Mb of RAM. To evaluate the 1500 simulations desired for this study, model runs were performed on Compute Canada's Cedar cluster located at Simon Fraser University, BC (Compute Canada 2018). These runs were uploaded to the Unix-based cluster using the free software package MobaXterm (https://mobaxterm.mobatek.net/), and queued for execution using the Slurm Workload Manager (https://slurm.schedmd.com/). Single scenarios were typically duplicated on multiple cluster cores to improve run times. Simulations were then re-bundled for post-processing (e.g. ensemble statistics) in custom data analysis modules scripted in Python by the author.

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[49] To simulate this, basement contents damages (BC) were reduced by 50% and all 'electrical' and 'finishing' tagged Damage-Feature objects were excluded.

[50] Even on the small study area, run times in excess of 30 minutes per simulation were not uncommon.

6. Results and Discussion

This chapter presents and discusses the results of the thesis inquiry and elaborating on the significance and limitations of the methodological assumptions. First, some general results reproduced across all scenarios are analyzed. Second, the two research questions are discussed within the paradigms established by RFDA (e.g. direct-flood damage) and the boundaries of the case study. Finally, uncertainties in this risk assessment process are presented and discussed.

6.1. Results Summary

As discussed in Chapter 5, the key metric under evaluation in this thesis is the present value of flood risk, quantified by estimated annual damages (EAD). To address the research questions and investigate the drivers of flood risk, EAD results from the five scenarios discussed in Section 5.5.1 are presented and analyzed. For convenience, this section generally uses the color scheme, scenario number, and option codes illustrated in Figure 5-11.

A total of 1,544 simulations from the 5 scenarios, each with three timesteps (t0, t1, t2), are used in this analysis. Figure 6-1and Figure 6-2 show the spread of EAD ensemble results for the first (t1) and second (t2) timesteps respectively, while Table 6-1 supplies the ensemble statistics for this same simulation set on all three timesteps. These results show the stochastic properties, or level of uncertainty, in the model's EAD predictions. Further, the limited overlap in predictions suggests the scenarios selected represent divergent paths for flood risk, facilitating a clearer exploration of the drivers of this flood risk in the following sections.

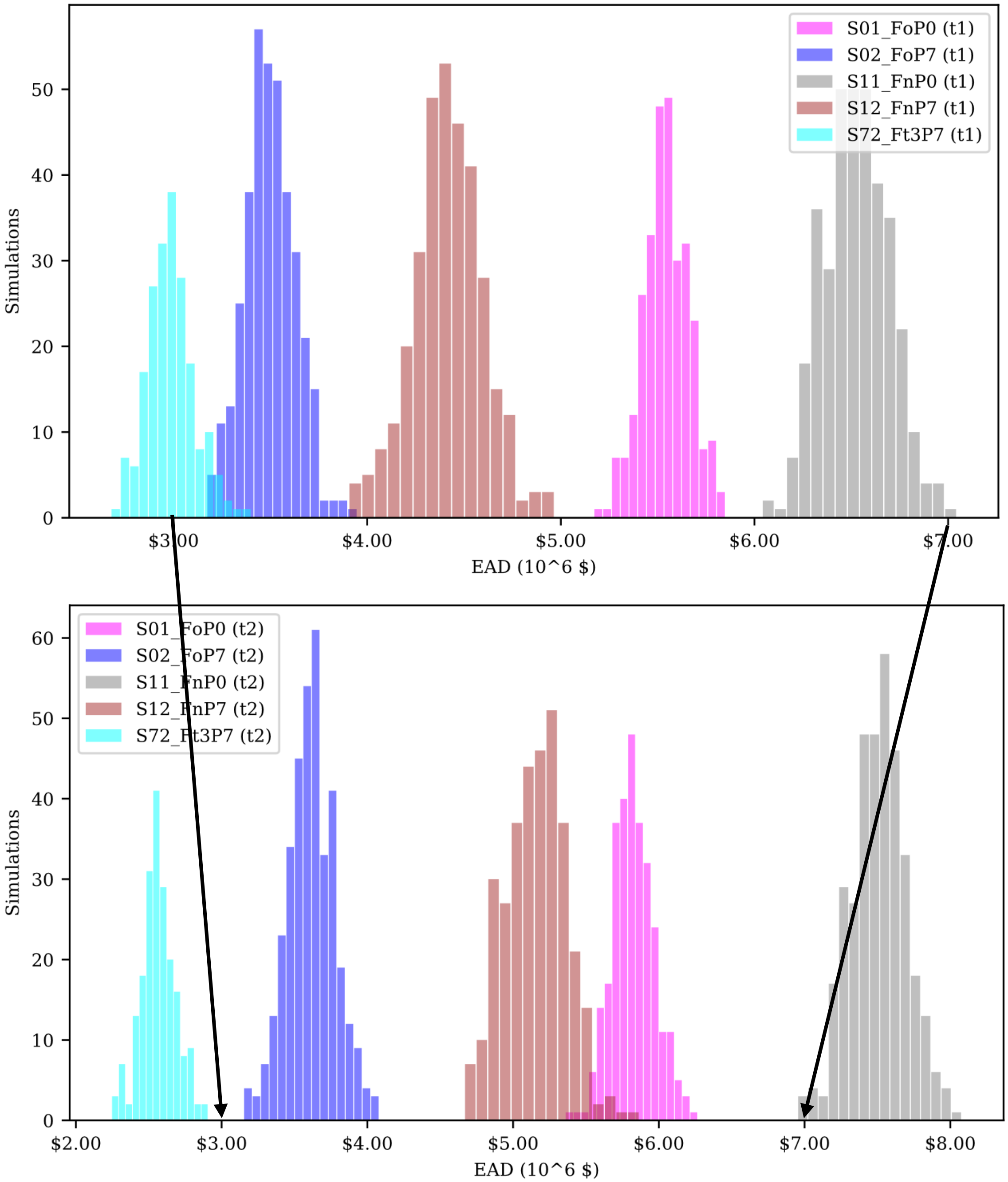

Figure 6-1: Simulation-EAD results histograms for the five scenarios at the[top] first (t1) and [bottom] second timestep (t2). See Figure 5-11 for legend key. Arrows drawn to clarify x-axis relation.

Table 6-1: Scenario timestep-EAD mean and spread results table. See Table 5-7 for a description of timesteps (t0, t1, t2) and Figure 5-11 for a description of scenarios. Arrows added to clarify timestep progression.

Scenario	**Protections**	**FHR**	**Simulations**	**Color**	**EAD (10^6 $)**					
					t0	→	**t1**	→	**t2**	
					med	spread	med	spread	med	spread
S01	P0	Fo	289	Magenta	5.29	0.42	5.54	0.68	5.83	0.91
S02	P7	Fo	365	Blue	3.52	0.60	3.50	0.78	3.61	0.93
S11	P0	Fn	358	Grey	5.29	0.43	6.53	1.00	7.51	1.13
S12	P7	Fn	331	Brown	3.53	0.83	4.42	1.06	5.16	1.20
S72	P7	Ft3	201	Cyan	3.52	0.48	2.99	0.72	2.81	0.66

med: ensemble median of all simulations for that scenario.

spread: difference between the highest and lowest simulated EAD result for that scenario ensemble.

As well as being used to explore the drivers of flood risk, comparing scenarios can provide decision support through quantifying the relative benefits of one option over another. Comparing scenarios to baselines, Table 6-2 supplies the benefits of the two mitigation enhancements considered (P7 and Ft3) as well as the benefits for the current FHRs (Fo) compared to a scenario without any regulations (Fn). The base EAD for the study area (at year 0) is calculated as the mean of all P0 (current level of structural protections) scenario EAD results at the first timestep (t0), which is $5.29 million. To provide more generalizable results, changes in EAD are expressed relative to this base value.

Table 6-2: Mitigation option relative EAD and marginal-dynamic-benefits.

Option code[f]	**Scenario**[f]	**Baseline scenario**[e,f]	**Comparative burden (10^6 $·year)**[a]		**30-year difference (10^6 $)**[b]		**30-year relative difference**[c]		**Marginal-dynamic-benefit**[d]	
			t1	t2	U-	U+	U-	U+	U-	U+
P7 (Fo)	S02	S01	-57.15	-60.53	-1.91	-2.02	-36.0%	-38.1%	-2.6%	-4.7%
P7 (Fn)	S12	S11	-58.20	-62.55	-1.94	-2.09	-36.7%	-39.4%	-3.2%	-6.0%
Fo	S01	S11	-14.85	-27.45	-0.50	-0.92	-9.4%	-17.3%	-9.4%	-17.3%
Ft3	S72	S02	-7.65	-15.45	-0.26	-0.52	-4.8%	-9.7%	-4.8%	-9.7%

a) Cumulative area between the EAD-time ensemble median results for the two scenarios (see Figure 6-14 for an example).

b) Comparative burden divided by the 30-year simulation period.

c) 30-year difference divided by the base EAD ($5.29 million).

d) Difference between EAD at t0 and the 30-year difference (relative to the base EAD).

e) Multiple baseline scenarios are included to isolate risk accumulation to specific mechanisms (i.e. with/without rules). This should not be confused with the base, year-0 EAD value ($5.29 million) which is used to convert all EAD results to relative values.

f) See Figure 5-11.

When comparing the ensemble results between two scenarios, confidence in the trends suggested by the ensemble medians are expressed in the following general terms:

- *low*: inter-quartile ranges of results overlap;
- *medium*: minimum or maximum results overlap; or
- *high*: no results overlap.

6.2. General Results

Before using the model results to explore the two research questions, this section discusses the drivers of flood risk by analyzing the model results. This discussion excludes the 3-tier FHR option (Ft3), which is discussed in Section 6.4.

6.2.1. Small Floods Matter

Figure 6-2 supplies a snapshot of risk, plotting the damage contribution by damage type (BS, MC, etc.) and flood type (groundwater or surface water) for each of the 12 events evaluated (x-axis). From this figure, the EAD can also be visualized as the area under the 'total' damages curve (purple). Comparing this total EAD (dotted line), to the damage value of each event, shows the EAD algorithm's (described in Section 5.3.4) sensitivity to low frequency events. Keeping this sensitivity in mind, Figure 6-2 suggests the following for all simulations:

- *Significant groundwater damage*: The majority of damages from small events (5 to 35 ARI) are generated by groundwater (dmg_gw) and basement (BC and BS) damages. This suggests mitigations that target basement flood damages will provide large benefits.
- *Basement contents (BC) and structural (BS) damages are similar*: Comparing BC and BS depth-damage relations, the sample depth-damage relation in Figure 5-7 (red) shows the maximum relative difference in damage predictions is 12%. However, when applied across all assets and floods as shown in Figure 6-2, this difference decreases — especially for small events (5 to 35 ARI).
- *Negligible garage damages (GS)*.
- *Vulnerable study area*: Under the base structural protections (P0), damage is predicted for all simulated events at all timesteps.[51]

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[51] To complete the EAD calculation, a near-zero damage event is required (intercept with the x-axis). As the smallest event in the hazard set used for this study (5 ARI) was not small enough to provide this, the near-zero damage event was assumed to be 3 ARI. To avoid this assumption, future hazard studies should include events with a lower ARI (also see next footnote).

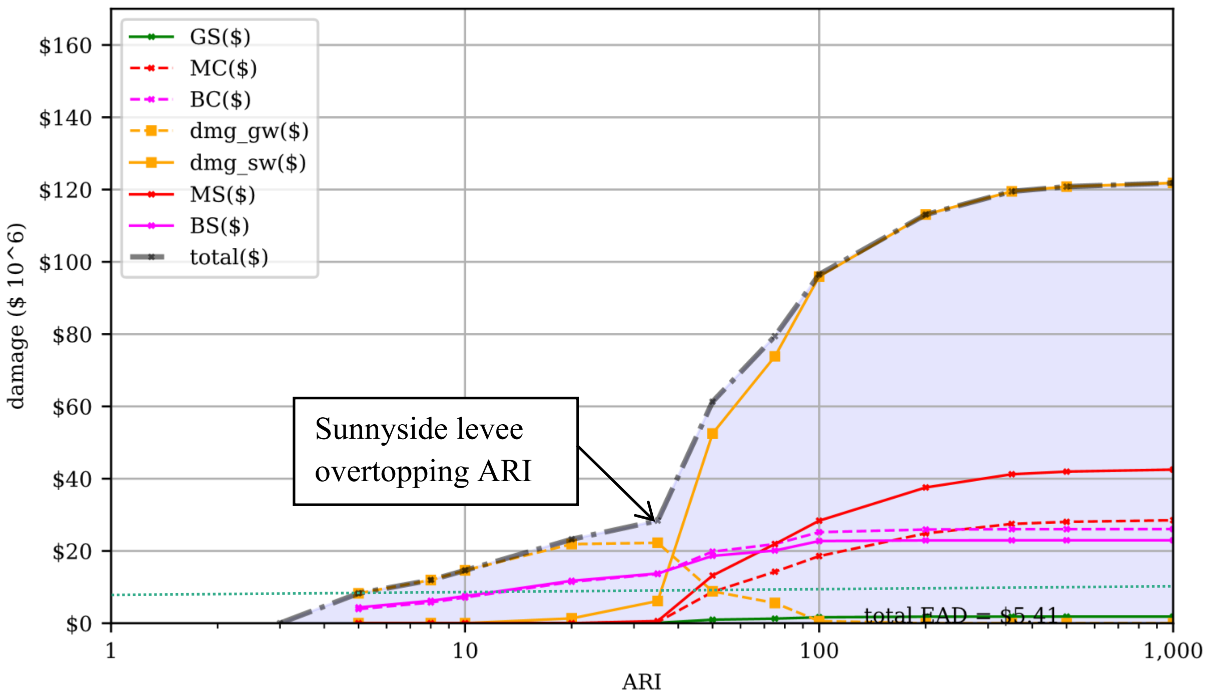

Figure 6-2: Flood damage to ARI plot showing 8 types of damage for a simulation of the S01 scenario at t0. For Dfunc damage codes key (GS, MC, etc.) see Table 5-9. Damages from groundwater (dmg_gw) and surface water (dmg_sw) shown in orange. Area under the total damage curve shaded to illustrate the total EAD calculation (in $ 10^6). Teal dotted line denotes the total EAD for comparison.

The model predictions for damages from small events are counterintuitive and may point towards a positive-bias. If exposure-feedback mechanisms were considered, it is likely that those assets which are frequently exposed would adapt, thereby reducing damages from frequent events. In other words, a homeowner who floods every five years would probably install a backflow valve or keep their basement unfinished. This suggests that groundwater damage is over predicted[52] and that the model will calculate benefits for minor mitigations.

6.2.2. Structural Protections Significantly Reduce Risk

Comparing those scenarios with structural protections (P7: S02, S12, S72), to those without (P0: S01, S11) (Table 6-1) yields a difference in EAD values at year-0 of -33.5%.[53] This negative relative value shows that the selected scenario provides a reduction in flood risk compared to its baseline (i.e. a positive benefit). Comparing the spread of results in Table 6-1 shows that the

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[52] The 2017 Study accounted for these “unrealistically high damage values” by manually adjusting “damages for the 5, 8, and 10 year return floods to reflect more reasonable anticipated damage values” (IBI Group and Golder Associates 2017, 85). Future research should establish this near-zero damage event empirically from damage claims.

[53] The error in WSLs for frequent events discussed in the footnote of Table 5-4decreases these benefits.

influence of the structural protection dimension on the EAD result outweighs the other socio-economic and FHR dimensions considered.

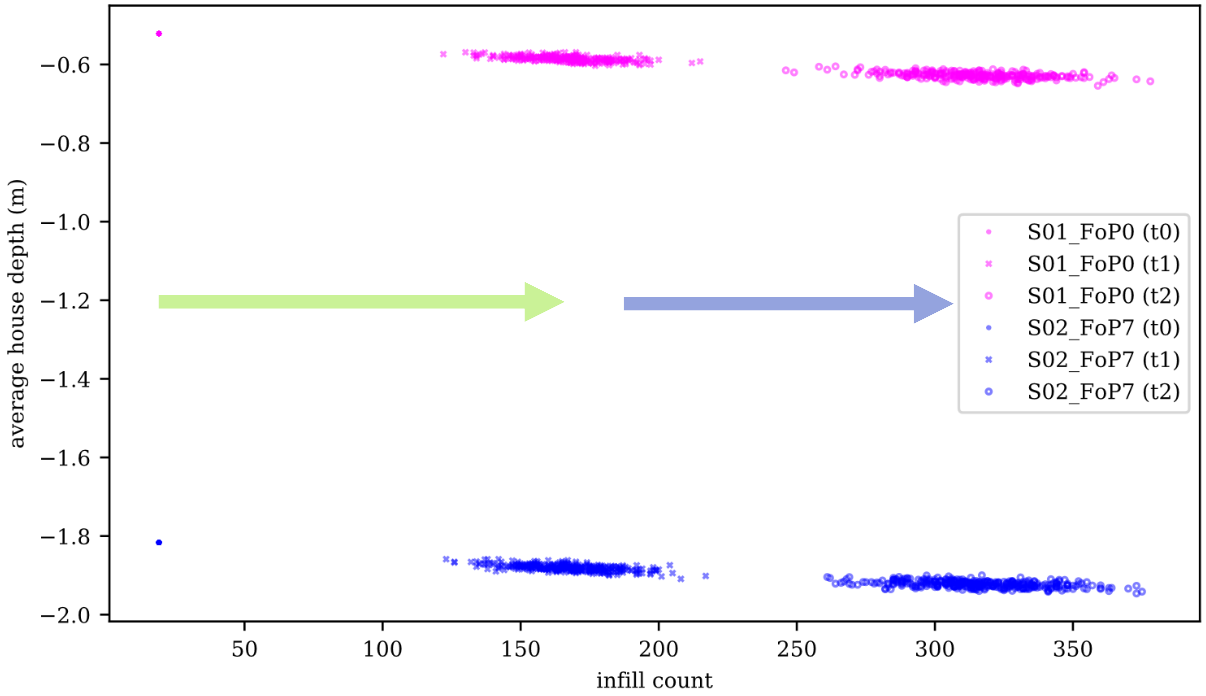

Figure 6-3: Average house depth vs. infill count simulation results scatter plot for the two Fo scenarios at each timestep. Arrows added to clarify timestep progression. See text for details and Figure 5-11 for legend key.

The magnitude of these benefits is unsurprising considering the difference in discharge-frequency relations (Figure 5-1) and the corresponding drop in simulated WSLs (Table 5-4) and extents (Figure 6-4) used to model these enhancements. Looking at the simulation ensemble results, Figure 6-3 shows the reduced flood depths (taken relative to each House object's anchor elevation) of enhanced structural protections (S02; bottom) compared to the baseline (S01; top) and the spread of total infills at each time step (from the stochasticity of this parameter). As well, this figure shows the slight downward trend of house flood depths as the FHRs mandate higher main floor elevations for infills.

Figure 6-4: Exposure comparison for the [top] base (P0) and [bottom] enhanced (P7) structural protections in the study area showing: [yellow] building footprints; [green] existing levee; [black hatch] current FHZ; and [blue] 50 ARI surface water inundation extents.

6.2.3. Without FHRs, Risk Is Increasing

Looking solely at the scenarios without FHRs (S11 and S12) on Figure 6-5, the model predicts an increase in EAD as houses are redeveloped. Further, the statistical summary of the ensemble results provided by the box plots (minimum, maximum, median, and inter-quartile range) shows that this trend holds for the full range of stochastic parameters considered (i.e. high confidence). This unsurprising result is driven by the infilling of cheaper smaller homes (generally class ‘C’) with larger, more expensive (class ‘A’) homes with deeper basements. This progression of increasing floor area and deeper basements is shown on Figure 6-6.

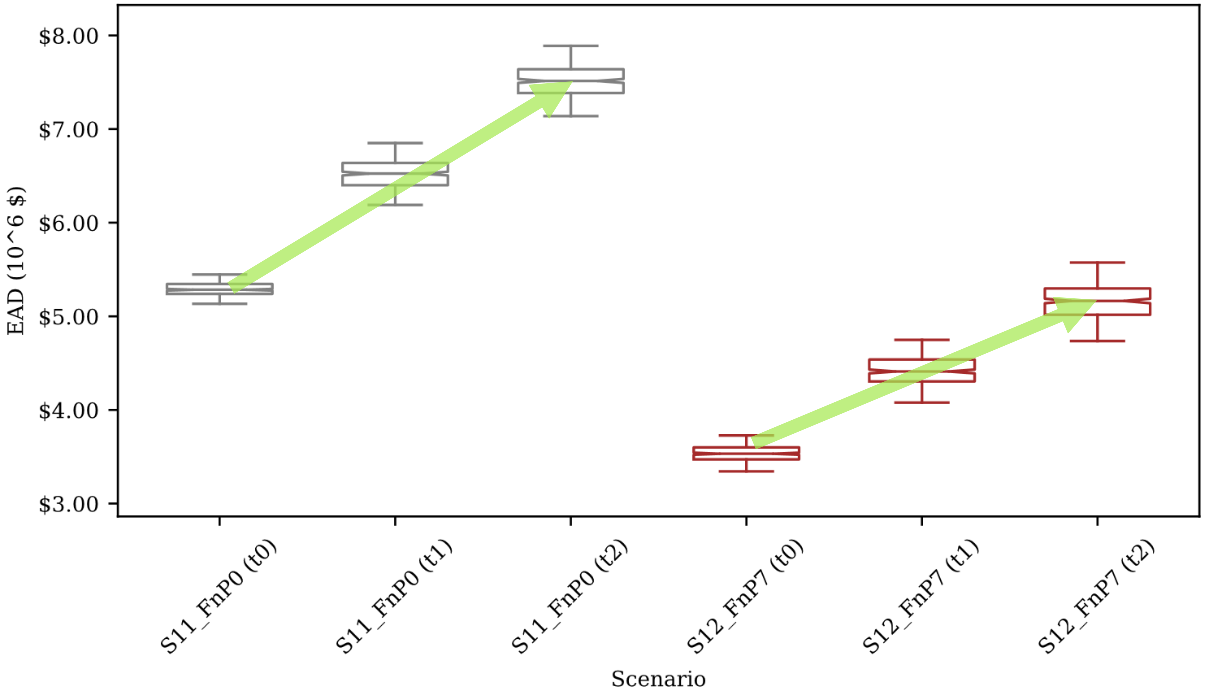

Figure 6-5: EAD-timestep results boxplot for the two Fn scenarios. See text for details and Figure 5-11 for scenario key. Arrows added to clarify timestep progression.

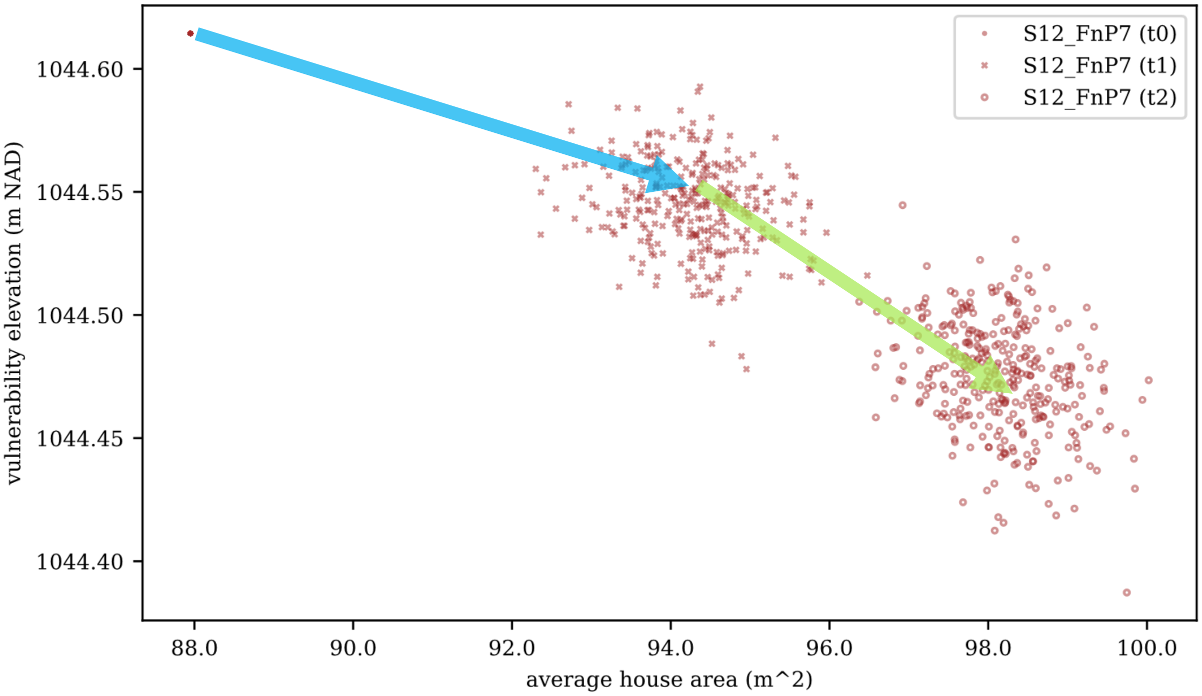

Figure 6-6: Vulnerability elevation vs. average house area simulation results scatter plot on three timesteps for the no FHRs (Fn) and the baseline structural protections scenario (S11). See text for details and Figure 5-11 for legend key. Arrows added to clarify timestep progression.

6.2.4. Without Structural Protections, Risk Is Increasing

Focusing on the scenarios with base structural protections (P0), the model predicts an increase in EAD as houses are redeveloped (Figure 6-7). The drivers of this increase for the scenario without regulations (S11) are discussed above. With regulations (S01), the rate of risk accumulation is less; however, the model predicts that the factors increasing vulnerability (larger area, deeper basements) still outweigh the vulnerability reductions mandated by the current FHRs (PLPMs, higher vulnerability elevations) when the full study area is considered. While on average, the results indicate an accumulation of risk under the current regulations (without protection enhancements), the ensemble spread suggests medium confidence, as there is an overlap in results outside the inter-quartile range. Further, Section 6.2.6 shows that when only those assets within the FHZ are considered, risk decreases. In summary, absent intervention, risk may accumulate in Sunnyside/Hillhurst.

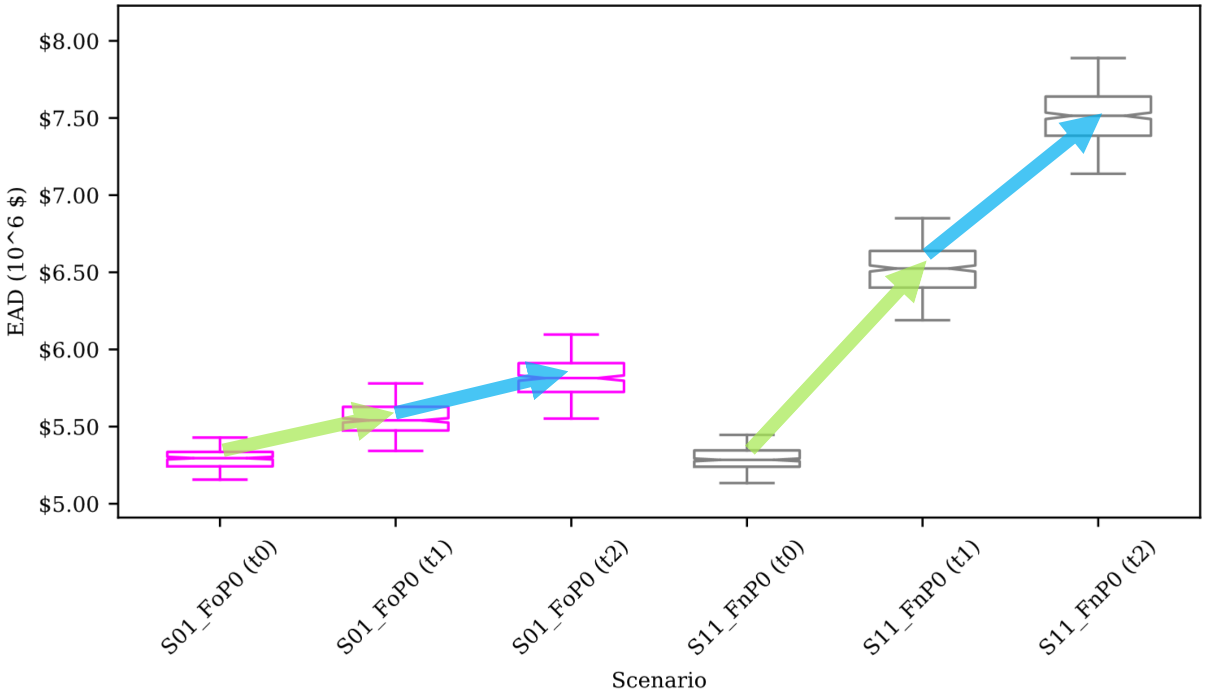

Figure 6-7: EAD-timestep results boxplot for the two P0 scenarios. See text for details and Figure 5-11 for scenario key. Arrows added to clarify timestep progression.

6.2.5. Together, Risk Is Steady

Table 6-1 shows the relatively constant EAD forecast in the scenario with enhanced structural protections and the current FHRs (S02). In other words, the model predicts that, with enhanced structural protections, vulnerability increasing factors roughly balance the vulnerability reductions imposed by the current FHRs. This stands in contrast to the imbalances described in the previous two sections. To elucidate why the model calculates this, Figure 6-8 supplies two indicators for the focus scenario (S02) compared against the scenarios sharing structural protection and FHR dimensions (S01, S12). With FHRs alone (S01), the number of damaged houses is progressively driven down by the regulations; however, flood depths remain high. These deeper, more extensive floods expose vulnerable infills outside the FHZ to more frequent and severe flooding, thereby causing progressively more damage. With structural protection enhancements alone (S12), the trend towards deeper basements leads to more houses being damaged more severely as the simulation progresses. Together (S02), structural protections reduce the exposure of vulnerable infills outside the FHZ, allowing the vulnerability reductions realized inside the FHZ to dominate the results. Put simply, the larger floods of the P0 scenarios expose more assets outside the FHZ which become progressively more vulnerable.

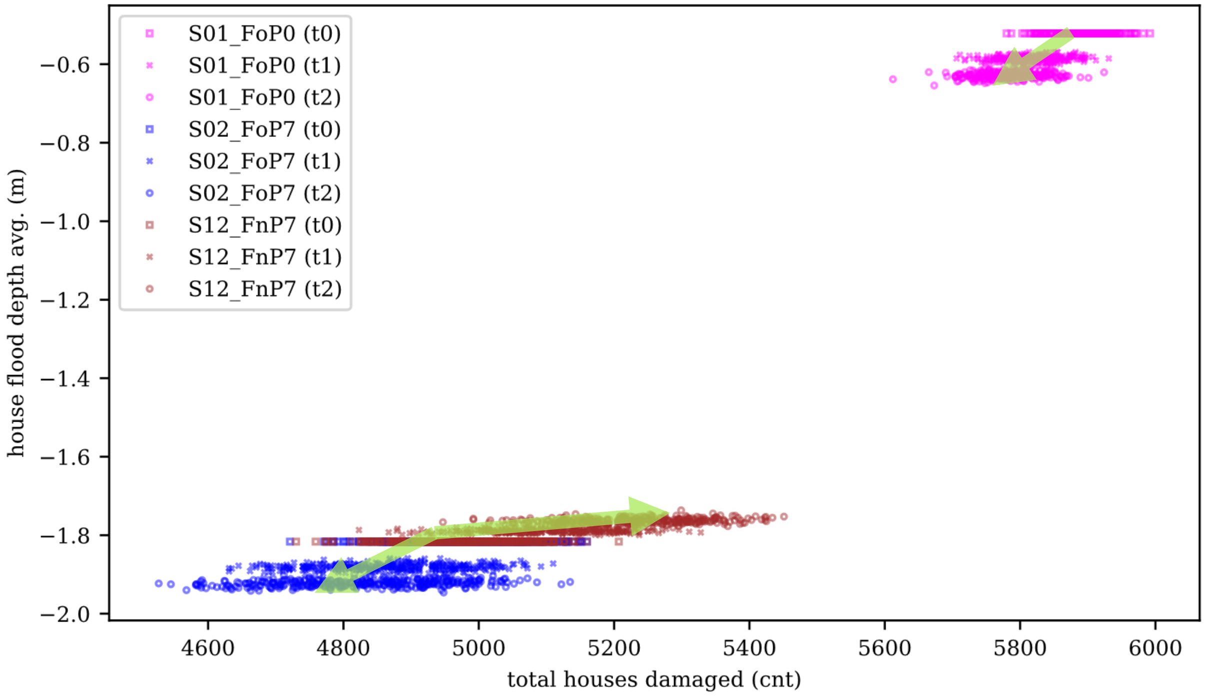

Figure 6-8: Average house flood depth vs. total houses damaged[54] *simulation results scatter plot on three timesteps for three scenarios (S01, S02, S12). See text for details and Figure 5-11 for legend key. Arrows added to clarify timestep progression.*

6.2.6. Inside the FHZ, Risk Is Decreasing

Under the current FHRs (Fo), 51.4% of the study assets fall outside the FHZ (Table 5-16) and therefore redevelop without restrictions. Figure 6-9 shows the progression of EAD for two scenarios, each divided by contributions from assets inside (top) and outside (bottom) the FHZ. The top half of the figure provides two forecasts for EAD inside the FHZ: 1) a future with regulations (S01; magenta) where EAD is declining; 2) and a future without regulations (S11; grey) where EAD is increasing. The bottom half of the figure shows that in both futures, EAD growth outside the FHZ is positive and equivalent.[55]

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[54] Number of houses calculated with non-zero flood damage summed across all simulated flood events for that timestep.

[55] Because this figure provides the results of a single stochastic simulation for each scenario, there is a small variation in the results.

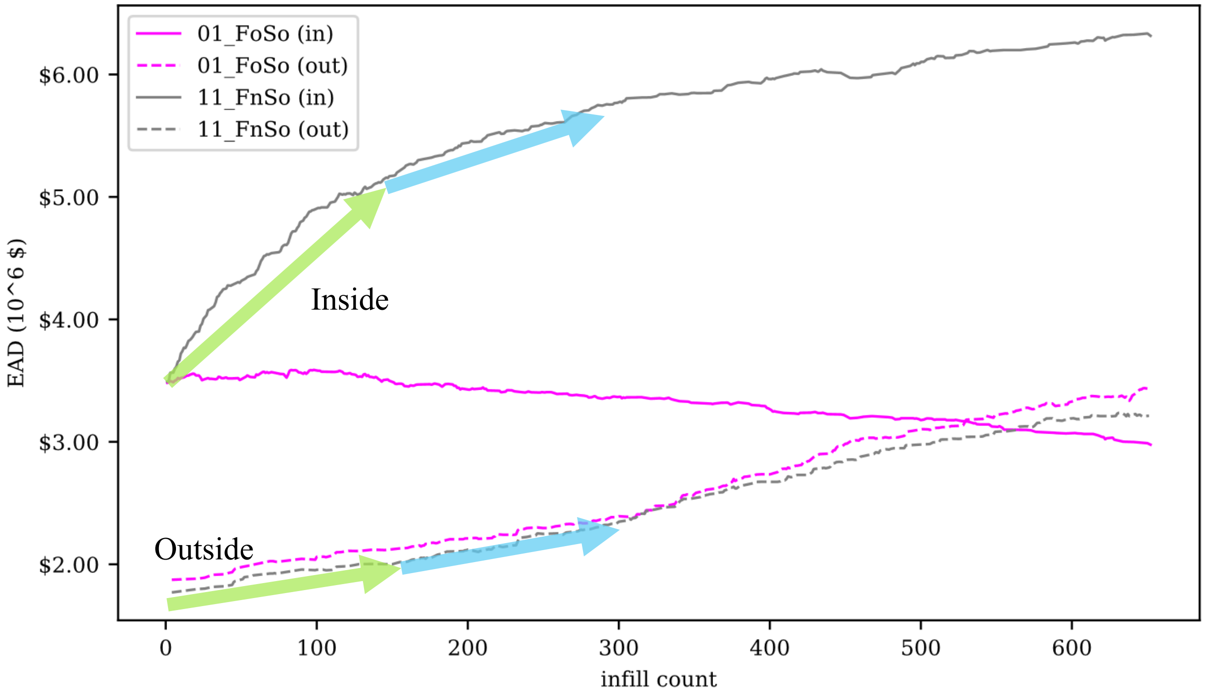

Figure 6-9: EAD vs. infill count single simulation results plot by FHZ inclusion for two scenarios on the full inventory. See text for details and Figure 5-11 for legend key. Arrows added to clarify timestep progression.

To elucidate the drivers of vulnerability inside vs. outside the FHZ, Figure 6-10 shows the progression of vulnerability elevation and the number of backflow valves inside the FHZ. When rules are applied (S01), the backflow valve prevalence increases, and redevelopment raises the average elevation of the assets.[56] Both these mechanisms reduce vulnerability. Further, this demonstrates that the current BFE is higher than many existing main floor elevations in the study area. This supports the view, expressed by some study participants (Table 5-5), that the current FHRs mandate house typologies not conforming to the neighborhood (i.e. high main floors).

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[56] The progression of vulnerability elevation in the S11 results shows that the parameter selected for the anchor elevation of infills in this study (Table 5-14; DEM elevation + 0.6) simulates lower main floor heights than the initial conditions provided in the building inventory (Table 5-2; median for all assets = 0.72).

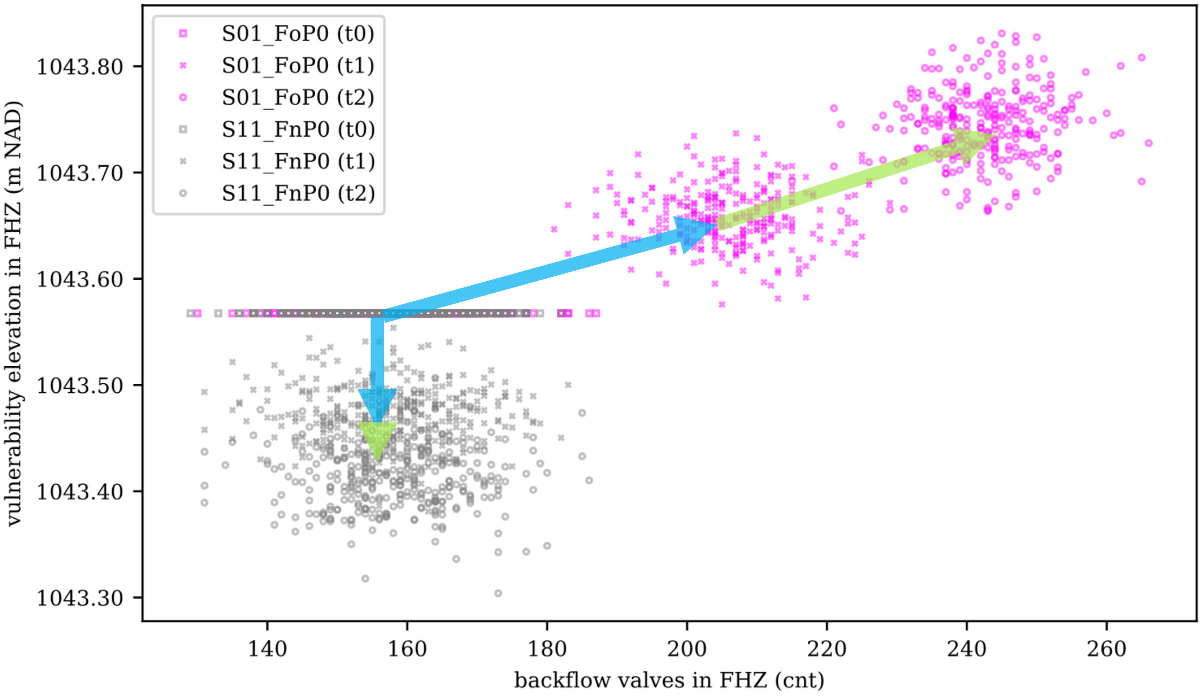

Figure 6-10: Number of backflow valves vs. average vulnerability elevation inside the FHZ simulation results scatter plot on three timesteps for two scenarios. See text for details and Figure 5-11 for legend key. Arrows added to clarify timestep progression.

This difference in behavior also illustrates the significance of the study boundaries on the results. For example, had the study area been limited to the current FHZ, the model results would show that the current FHRs substantially reduce risk through time, rather than the accumulation of risk simulated here. Similarly, had the study area been extended to include more assets outside the FHZ (but still vulnerable to the most extreme event considered), the performance prediction of the current FHRs would likely be reduced. This provides a clear demonstration of the utility of a risk-based framework. Under the traditional, standards-based approach, the study extents would be defined by the design-event (i.e. the FHZ). Such a study would conclude that the FHRs perform as expected, and flood damage is mitigated. In contrast, the risk-based approach employed here considers all possible events — including those events flooding beyond the FHZ. This more holistic view paints a picture of underperforming FHRs and an accumulation of risk as infills outside the FHZ drive up the community's vulnerability.

6.2.7. It Is the First Few Years That Count

Figure 6-11 shows the development-potential-rankings used for the spatial downscaling of the Udev module (described in Section 5.3.5) for a part of the study area along Memorial Drive.

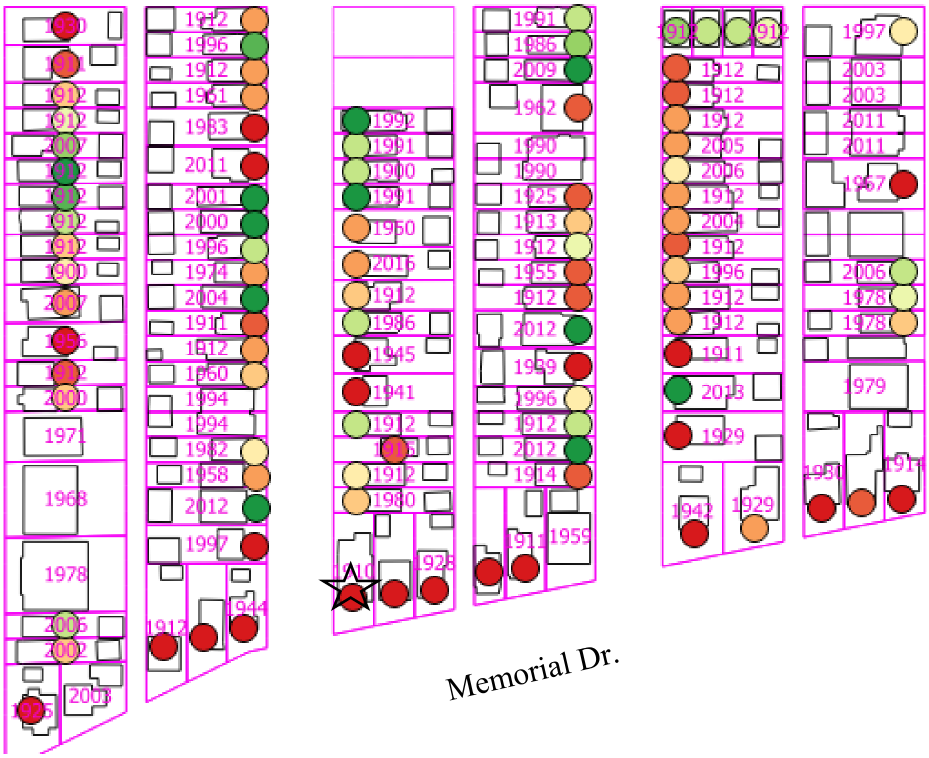

Figure 6-11: Development-potential-ranking for a portion of the study area showing: potential rank from high [red] to low [green]; [black] digital area survey building outlines (Appendix G, dataset: 'CoC_ISS_bldgs_das2017'); [magenta] property boundaries and year of construction (Appendix G, dataset: 'CoC_Ass_propass').

The local context of this study area is such that the properties with the highest development potential are also those with the most exposure. This can be seen on Figure 6-11, which shows those homes along Memorial Drive, which itself abuts the River, have a high development potential (large lots with cheap homes). As shown on Figure 4-6, this area is low-lying and vulnerable to frequent flooding (see Figure 4-2 for a photo from the 2013 Flood in this area). While proximity to the busy Memorial Drive seems to have discouraged the re-development of this corridor, the simple value-density ranking applied here forecasts a high-likelihood of redevelopment. In fact, during the field survey, the starred house on Figure 6-11 was torn down and replaced by a larger home with a 10 foot[57] basement. Similarly, assets in the more expensive, less exposed Hillhurst are generally assigned a lower likelihood of redevelopment. This context was explored further with the sensitivity analysis described in Section 5.4.

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[57] Height from basement floor to ceiling in units commonly used by study participants.

The schematization of this local context (via the development-potential-rankings) results in a high rate of vulnerability change early in the simulations as the over-exposed, small, cheap homes are quickly replaced with larger ones. This disparity can be seen in the curvature of the top half of Figure 6-9. This effect is lessened by the presence of FHRs, which impose vulnerability reductions on the infills here.

6.2.8. Hot Markets Matter More Without FHRs

The significance of the first 100 infills, described above, also influences the model sensitivity to the socio-economic pseudo scenarios (described in Table 5-15), which are parameterized by the infill rate (N_i).[58] For example, Table 6-1 shows that results for scenarios under the current FHRs (Fo; S01 and S02) have a difference between t1 and t2 of 5% and 3% respectively, while scenarios without FHRs (Fn; S11 and S12) have a difference of 18% and 21% respectively (Figure 6-12 shows this graphically). Put simply, more development leads to more vulnerability — especially without FHRs regulating re-development. As a result, when considering the 30-year EAD,[59] the socio-economic scenario dimension (U+/U-) only has significance in the absence of FHRs. In other words, under the current FHRs, the risk accumulation between t1 and t2 is minor compared to other parameter uncertainties.

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[58] This can also be considered an artifact of the coarse timesteps (15/30 years) of this study. For example, if we examined the risk accumulation after five years, the relative disparity between U+ and U- scenarios would be more significant.

[59] For the simple marginal-dynamic-benefits discussed in Section 6.3, the coarse timesteps are adequate considering the objectives and uncertainty of the study. When discounting is applied, future studies should explore the sensitivity of the timestep resolution on the present value benefits.

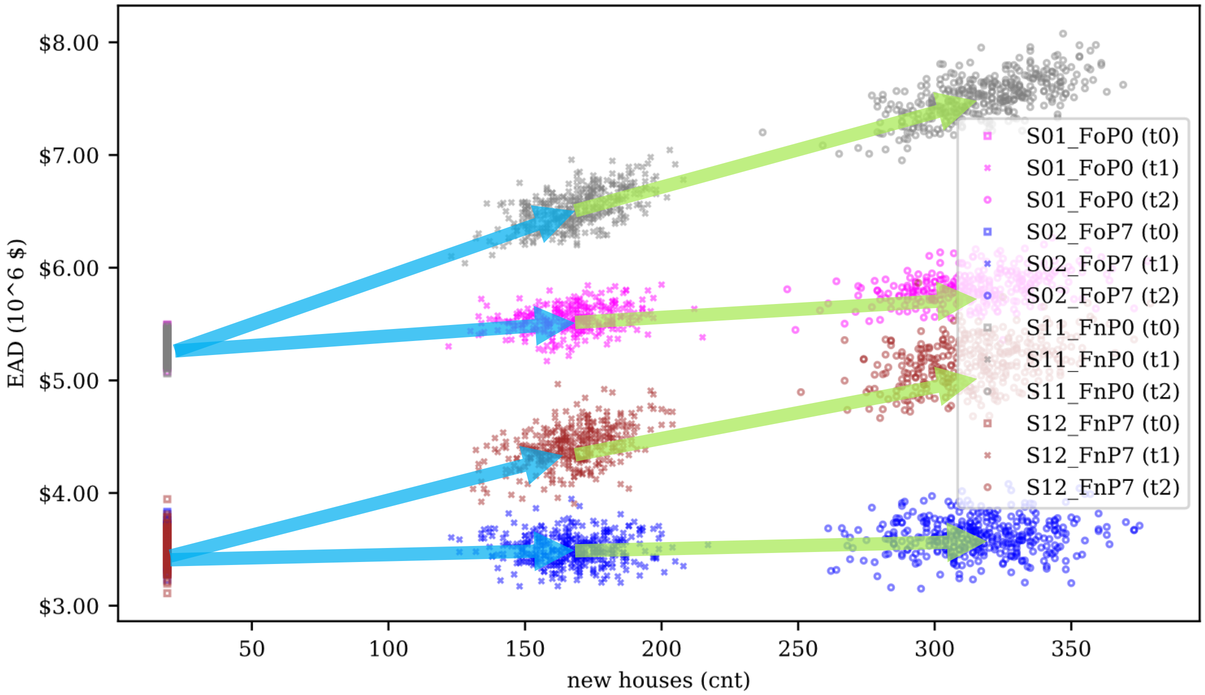

Figure 6-12: EAD vs. new houses simulation results scatter plot for four scenarios at each timestep. Arrows added to clarify timestep progression. See text for details and Figure 5-11 for legend key.

6.3. Analysis of Vulnerability Dynamics

The progression from standards-based to risk-based decision-making in Alberta (via RFDA) has significantly improved the transparency and efficiency of FRM. However, RFDA takes a static view of risk. This inhibits the quantification of FHR benefits and a more robust accounting of risk in dynamic societies. To show the limitations of this static view, SOFDA was applied to the study area to address the first research question: *how does the incorporation of vulnerability dynamics change the assessment of benefits for traditional flood mitigation approaches?*

To evaluate the marginal benefits of a dynamic view over a static view, the term *marginal-dynamic-benefits* is introduced to describe those benefits that a static view of risk fails to quantify (see footnote on Table 6-2). This assumes the perspective of a risk-analyst seeking to understand the value of a dynamic view (i.e. all timesteps), compared to the more traditional static view of risk (i.e. first timestep), in their evaluation of mitigation options.

6.3.1. Enhanced Structural Protections

To explore the first research question, scenarios with/without structural protections (P7/P0) are compared across timesteps (t0, t1, t2) and the hot market (U+) scenario is assumed.

Static Benefits

Figure 6-13 supplies the ensemble results for the current FHRs (Fo) with/without structural protections (P0/P7) on the three timesteps simulated (t0, t1, and t2). The traditional static assessment for the benefits of the P7 protections is estimated by comparing the initial EAD with and without these protections (i.e. P7 minus P0 at t0). This yields a benefit of -33.5% (Figure 6-14; orange arrow).

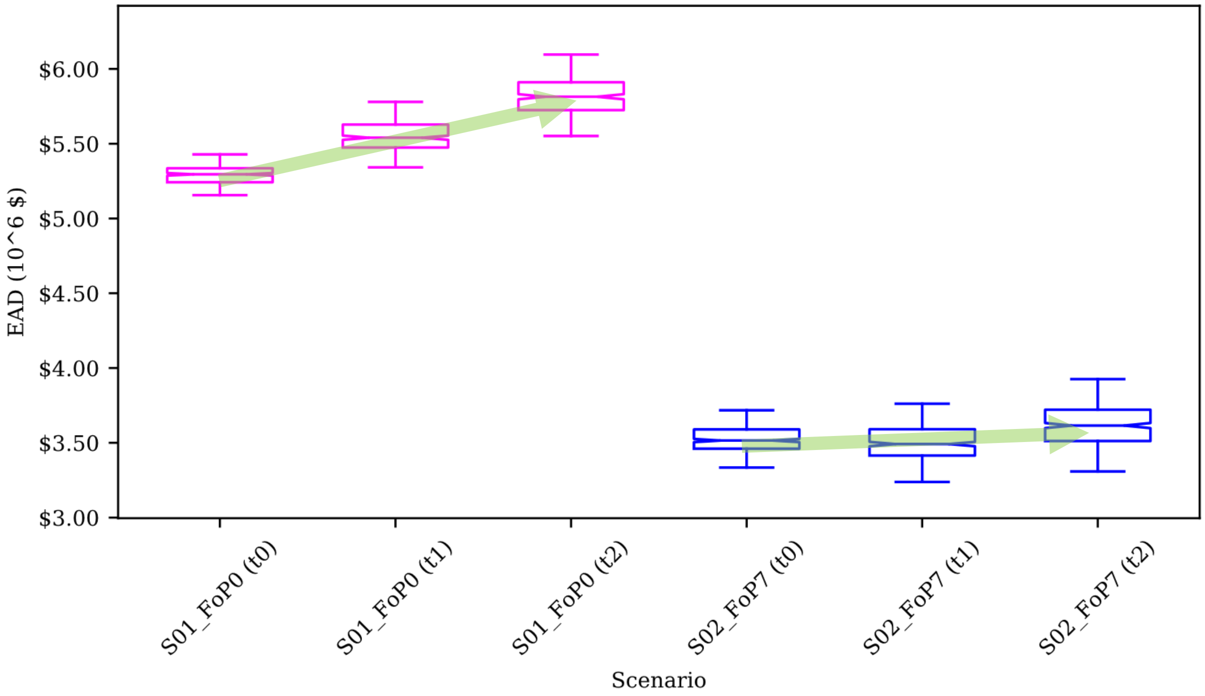

Figure 6-13: EAD-timestep results boxplots for the two Fo scenarios. See text for details and Figure 5-11 for scenario key. Arrows added to clarify timestep progression.

Considering the $2 billion price tag for these mitigations (IBI Group and Golder Associates 2017), this magnitude of initial benefit is not surprising. However, because P7 is itself a collection of levee improvements and enhanced operating rules for the Ghost reservoir, the scenarios from this study do not provide enough granularity to disentangle the dynamic behavior of these individually. To explain this, recall that the flood tables, which parameterize structural protection scenarios, hold two pieces of information for each asset: 1) flood event WSLs; and 2) event frequency. Once overtopped, levees supply no mitigation. This is schematized with identical WSLs (for ARIs larger than the overtopping event) for the base and enhanced scenario. On the other hand, the discharge-frequency manipulations (Figure 5-1) that simulate the modified operating rules, in effect, only modify the event frequency, but do this for 11 of the 12 flood events simulated. The interplay of these two exposure reductions obfuscates any broad conclusions between specific measures (i.e. levees vs. upstream reservoirs) and their performance under dynamic vulnerability.

Dynamic Benefits

A dynamic view of risk accepts that the benefits of mitigation are not fixed, and that the efficiency of a measure may change through time as a protected community redevelops and grows. A dynamic assessment for the benefits of the P7 protections is estimated by comparing the EAD for scenarios with and without protections (P7 minus P0) averaged across all timesteps (t0, t1, t2). Plotting the ensemble medians from Table 6-1 against time, for a hot-market socio-economic scenario (U+), yields an average EAD change of -38.1%, as calculated in Figure 6-14. Comparing this to the static benefit yields a marginal-dynamic-benefit of -4.6% (purple area). This marginal-dynamic-benefit is a result of the differences in vulnerability dynamics, with and without structural protections, described in Section 6.2.4. In short, this result provides a simple caveated answer to the research question: a static view underestimates the benefits of structural protections.

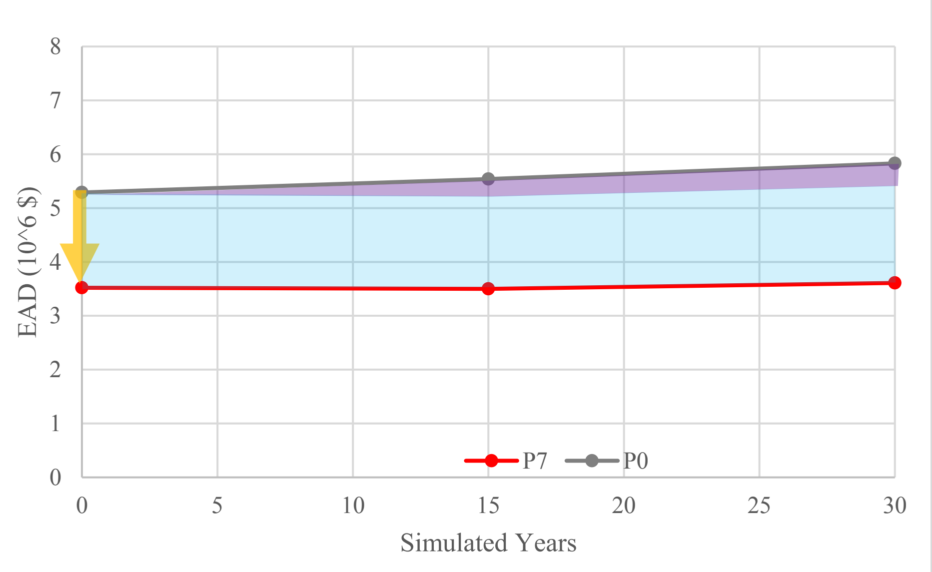

Figure 6-14: EAD-time ensemble median results (for a U+ socio-economic scenario) comparing scenarios with and without structural protections under the current FHRs (Fo). To obtain the average EAD difference between the two scenarios, the shaded areas (60.53 x 10^6 \$•years) are divided by the 30-year simulation period. Arrow denotes the orientation of the static-benefit. Marginal-dynamic-benefits are shaded in purple for clarity.

Risk-Growth Rates

Fundamentally, the marginal benefit of including vulnerability dynamics in the analysis comes from a difference in risk-growth rates between the two scenarios considered. For example, if the scenario with enhancements (P7) had the same rate of risk growth as the scenario without (P0), a dynamic model would estimate the same benefits as a static model, and therefore zero marginal-dynamic-benefit. Only because the presence of walls slows the growth of risk, do we see a difference in EAD. This result is best illustrated by comparing the arrow slopes on Figure 6-13. These show a medium confidence for risk accumulation in a scenario *without* protection enhancements (S01), and no accumulation in a scenario *with* protection enhancements (S02).

Using the secondary outputs provided by SOFDA, we can explore the drivers of this rate disparity. The two exposure metrics shown on Figure 6-8, for the with/without enhancement scenarios (S02/S01), quantify the simulated exposure reduction provided by the enhancements. From this, we can hypothesize that the difference in risk growth is driven by the magnitude and frequency of exposure simulated on the high vulnerability growth zones (houses outside the FHZ). The base protections (P0), having higher exposure, are therefore more sensitive to this vulnerability growth than the scenario with enhancements and lower exposure (P7). In other words, the greater the vulnerability growth, the greater the marginal-dynamic-benefit of the enhancements.

To demonstrate the relation between vulnerability growth and marginal-dynamic-benefit, Table 6-2 calculates the benefits of the enhancements (P7) in a scenario with unregulated vulnerability growth (Fn) as -39.4%. This risk reduction is slightly better than the -38.1% with FHRs (Fo) and the -33.5% calculated for a static view. Put simply, the benefits of walls are progressively magnified when high vulnerability re-development is allowed. However, the reader should not submit to the fallacy that structural protections perform just as well without rules (see Section 6.3.3).

Links and Feedbacks

The aforementioned difference in *risk* growth should not be conflated with a difference in *vulnerability* growth. SOFDA does not incorporate a link between exposure experience and vulnerability dynamics — despite the wealth of evidence for such a link. For example, Di Baldassarre et al. (2013) documented (and then developed a conceptual system dynamics model of) the ‘levee-effect,’ a phenomena where the perceived security of structural protections encourages development. Similarly, numerous studies have demonstrated a link between flood experience and the adoption of PLPMs (Bubeck et al. 2012; Merz et al. 2013; Winterton 2017; Thistlethwaite et al. 2018). To minimize the effect of this shortcoming of SOFDA, this thesis selected a simulation period of 30 years. Further, this implies that when predicting risk based on projections of future trends, confidence decreases as the simulation progresses.

Generalizability

Using the insights gained from the model study, a few inferences can be made about the marginal-dynamic-benefits of structural enhancements in general:

1. *Far-reaching protections*: The larger the protected area, the greater the likelihood sub-areas of high vulnerability growth will be protected from flood waters. In the absence of enhancements, these sub-areas will accumulate risk faster thereby increasing the marginal-dynamic-benefit of the enhancements.
2. *Community age and condition*: The marginal-dynamic-benefit of an option is dependent on the rate of vulnerability growth of the affected assets. Older, or higher land-value communities (Sunnyside/Hillhurst are both), face more development pressure than newer, or lower land-value, communities. In the absence of strong FHRs, this pressure can drive high vulnerability growth, thereby increasing the marginal-dynamic-benefit of any structural protection enhancements considered for that area.
3. *Groundwater and basements*: Like #2, permeable areas with increasing basement development (without PLPMs) will experience high vulnerability growth (under the current FHRs). A structural protection enhancement option that mitigates groundwater flooding for such an area would protect many of those assets driving up vulnerability, thereby increasing the marginal-dynamic-benefits of the option.

6.3.2. The Current FHRs

Unlike the evaluation of structural protections, evaluating the benefits of the current FHRs is complicated by their active enforcement status (i.e. that they are already in the bylaw). Because the current FHRs are indeed current, they should be considered as a baseline, like in the previous section (rather than evaluated as an option). However, quantifying a hypothetical option to remove the current FHRs, and allow unrestricted development, can supply a means to better understand: 1) how structural protections and FHRs interact; and 2) deficiencies of the current FHRs. Adopting this perspective yields an average benefit of -17.3% (i.e. the current FHRs reduce risk by 17.3%)

as shown in Figure 6-15. These benefits are driven by the vulnerability reductions imposed by the current FHRs, discussed in Section 6.2.3.

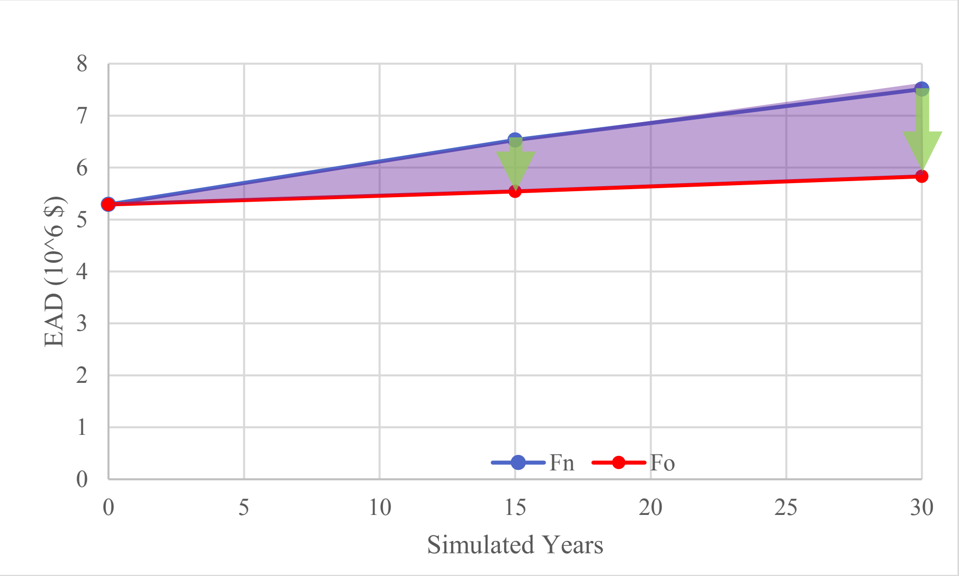

Figure 6-15: EAD-time ensemble median results (for a U+ socio-economic scenario) comparing scenarios with/without the current FHRs (Fo/Fn) under the current structural protections (P0). To obtain the average EAD difference between the two scenarios, the shaded area (27.45 x 10^6 \$•years) is divided by the 30-year simulation period. No discounting is applied. Green arrows denote the dynamic benefits.

Damage by Source

To explore the relative contribution of damages by type and source, Figure 6-16 presents four graphs illustrating the damages from different flood events for a scenario without FHRs (S11; left) and with FHRs (S01; right) at the beginning (t0; top) and end (t2; bottom) of a typical simulation. From this, the following observations can be made about the current FHRs (Fo):

- most damages from small events (5 to 35 ARI) are generated by groundwater and basement damages;
- the current FHRs are effective at inhibiting the growth of risk for small events (5 to 35 ARI) (compare the left tails of the bottom two plots);
- FHR mandated PLPMs, which for this study only mitigate against groundwater damage, are ineffective for large events (> 75 ARI) (large events are exclusively surface water damages);
- the current FHRs are ineffective for extreme events (> 100 ARI) (compare the right tails of the bottom two plots);
- the ratio of basement contents and structural damages is unaffected by FHRs (compare magenta lines).

This last point suggests the requirement to elevate mechanical and electrical features does not substantially mitigate damages.

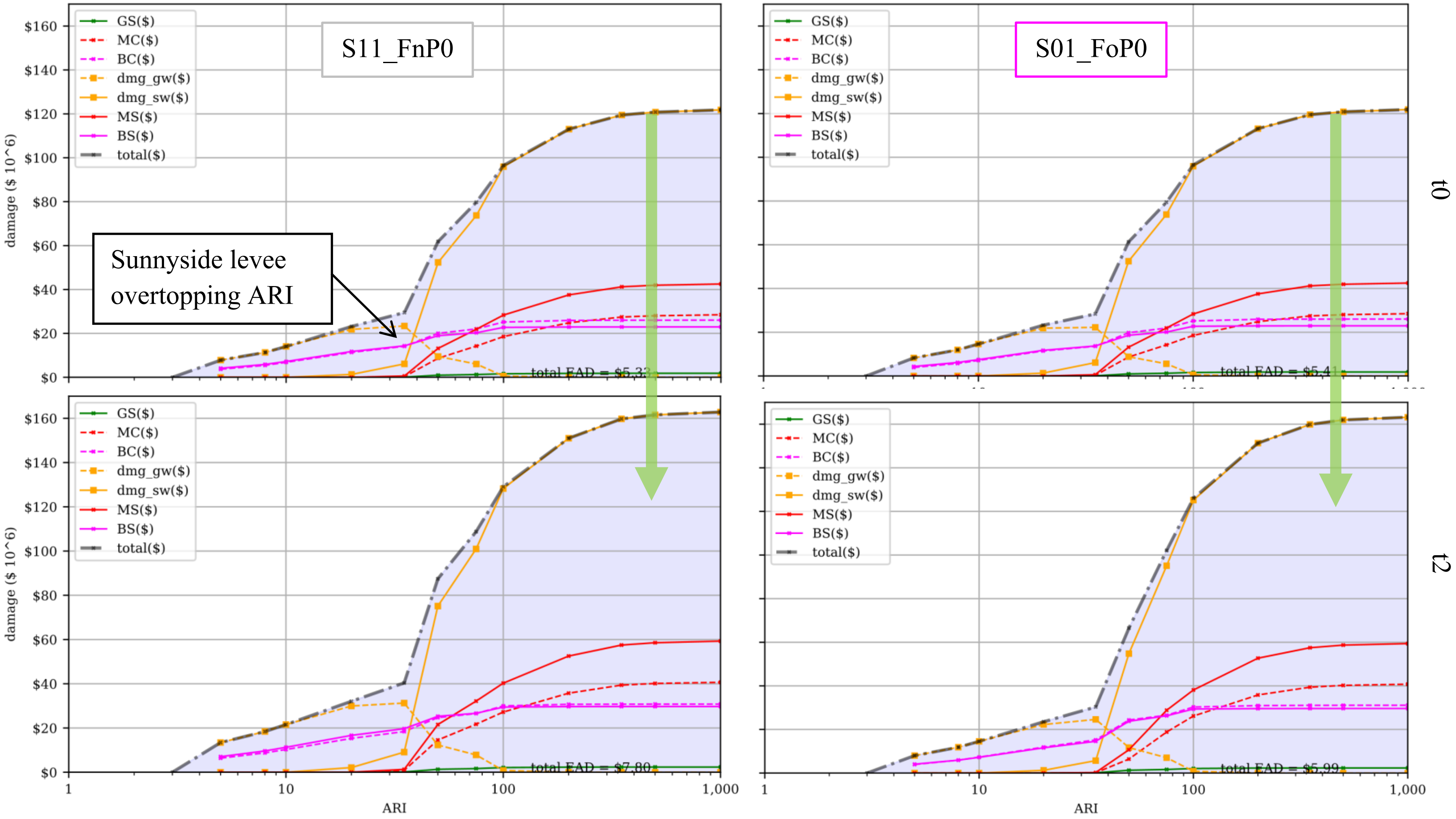

Figure 6-16: Flood damage to ARI matrix plot showing 8 different types of damage for a simulation at [top] t0 and [bottom] t2 for the [left] S11 and [right] S01 scenarios. For Dfunc damage codes key (GS, MC, etc.) see Table 5-9. Portion of damages from groundwater (dmg_gw) or surface water (dmg_sw) shown in orange. The area under the total damage curve is shaded to illustrate the total EAD calculation (in $ 10^6). Green arrows clarify the time progression.

Like structural protections, the design of FHRs must balance a community's values against efforts to reduce flood risk. In the context of FHRs, this generally requires allowing human land use and development to continue in the floodplain, but under selective restrictions targeted to limit vulnerability increases. For retrofit FHRs, applied in communities like Sunnyside/Hillhurst, this can mean allowing the replacement of older (smaller) homes by newer (larger, more expensive) homes, but requiring backflow valves and elevating above the BFE. In theory, this FHR helps to optimize the use of the floodplain by balancing the desire to grow property values against the desire to prevent future flood damage.[60]

Weaknesses

Taking this framing of objectives, key functional weaknesses of the current FHRs are:

1. all assets within the FHZ have similar restrictions, thereby reducing the efficiency of the FHR (i.e. higher-risk homes have the same restrictions as lower-risk homes);[61]
2. some older, low-lying, developed areas (like Sunnyside) have BFEs as much as 2 m above ground, making any new buildings adhering to the FHRs out of character with the rest of the neighborhood;
3. existing buildings, small additions, and accessory residential buildings are exempt;
4. assets outside the FHZ have no restrictions, despite being vulnerable to damage from extreme surface water floods (i.e. greater than the design event) and more frequent groundwater floods damage; and
5. except for mechanical and electrical equipment, no restrictions are placed on basements, allowing the current trend of deep, finished, basements in floodprone areas to continue unrestricted.

In particular, current infilling trends in the study area seem to exploit the loopholes of #4 and #5. While limiting FHRs to the FHZ was clearly by-design (#4), the exclusion of basements (#5) may have been unintentional, considering that developed basements are a modern trend (see Section 4.4). Regardless of intent, the model results show that (in the absence of structural protection enhancements) risk is increasing under the current FHRs (Figure 6-7; left half). However, as intuition suggests, Figure 6-15 shows the current FHRs (Fo) still provide substantial mitigation

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[60] Expanding the discussion to the floodway, maintaining hydraulic conveyance for flood flows is also an objective of the FHRs that reduces flood damage. More recent and holistic management approaches also consider recreational and environmental uses of the floodplain.

[61] Inclusion of a BFE in FHRs does provide some scaling of mitigation-effort to risk; however, not all rules are tied to the BFE.

when compared to a scenario with no FHRs (Fn). In other words, while the standards-based paradigm that created the current FHRs has supplied some benefit, enhancements are needed to ensure risk does not accumulate further and a disaster like the 2013 Flood is not repeated or exceeded.

Enhancements

Section 6.2.6 shows that, under the current FHRs, the accumulation of risk is driven by assets *outside* the FHZ. Considering this, and functional weaknesses #4 and #5 from above, two (non-exclusive) spatially-derived avenues are presented to improve the current FHRs:

- *Enhance flood rules inside the FHZ*: Flood rules applied within the FHZ could be enhanced such that flood risk is so substantially reduced that the risk accumulated from assets outside the FHZ is negated or overcome.
- *Expand the FHZ*: The FHZ could be extended to increase the number of regulated assets, thereby directly reducing the risk contributions from assets currently outside the FHZ.

Pursuing the former, the simplest solution (from a risk-analyst's perspective) would be to reduce the number of exclusions, forcing more assets to reduce vulnerability. While this study may underestimate the rate of vulnerability reduction inside the FHZ,[62] FHRs are certainly more effective when more assets adhere to them. However, dropping exclusions would likely be politically challenging. An alternative could be a city-wide retrofit program where PLPMs are implemented without regulatory trigger, such as the backflow valve subsidy program in St. Thomas, ON (Kamerman 2018) or Edmonton, AB (Epcor 2018).

Another approach to improving the flood rules could be to enhance the requirements themselves:

- *PLPMs*: The current FHRs mandate a single PLPM — backflow valves — not addressing PLPMs such as sump pumps (and their power supplies). To simulate this, all infills within the FHZ were equipped with backflow valves, while base rates were applied for sump pumps and generators (50% and 25% respectively). Applying the basement vulnerability grade logic (shown on Table 5-13) to these parameters leaves many infills inside the FHZ with residual vulnerability (to intermediate groundwater depths). In other words, backflow valves alone are not enough to protect from groundwater flooding (especially without working sump pumps). FHRs could be enhanced by requiring more PLPMs (like sump pumps and backup power supplies).

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[62] By only considering FHR triggers from infilling and ignoring the additions/expansions trigger some underestimation is likely.

- *Elevating:* The current FHRs only require elevating main floors and some equipment above the BFE. Results suggest the latter has a negligible influence on EAD. Alternatively, these requirements could be modified to restrict basement development altogether. In particular, tighter restrictions should be considered for improvements below the BFE which may lead to vulnerable bedrooms — like the one Lorraine Gerlitz drowned in during the 2013 Flood (Southwick 2014). However, increasing the BFE to which main floors are elevated, may not be an efficient approach. Considering how low Sunnyside is compared to this flood level, a higher BFE could make redevelopment cost-prohibitive.
- *Graduated FHRs:* For an efficient policy, investment in a mitigation needs to be proportional to the damages avoidance it contributes. The current FHRs have a single set of blanket rules which are applied to all properties within the FHZ. To improve efficiency, more equal and targeted FHRs should be considered (like the one in Section 6.4).
- *Other actions*: a plethora of regulatory measures and PLPMs are available as mitigation measures mandated by FHRs. For example, the novel 3-tier FHR described in Section 5.5.1 restricts basement development and height and mandates generators, sump pumps, and backflow valves. More creative greenfield and retrofit options are also available (e.g. sealants, wraps, shields, micro-barriers).
- *More realistic hazard mapping:* Despite the intention for the BFE of the current FHRs to be a 100 ARI design event, the elevation in the bylaw roughly corresponds to the WSL of a 75 ARI event.[63] This discrepancy prompted the GoA's recent re-mapping study (results originally expected December 2017 (Frohlich 2018)). However, this revision will only be an update of the FHZ that applies the same paradigms and procedures to update the hazard map to reflect the changes in boundary conditions accumulated over the past 30 years (p.c.). This update will not address the methodological shortcomings which lead to inaccuracies in the flood WSL to ARI prediction (e.g. naturalized flows, exclusion of levees, exclusion of groundwater) used to map the FHZ. Even within the design-based paradigm of FHZs, such shortcomings lead to a spatially heterogeneous patchwork of regulatory requirements that reduce the efficiency of the policy.

For a simple example illustrating this last point, consider Sunnyside and another Calgarian community to the north: Elbow Park. Like Sunnyside, Elbow Park is an older, expensive, neighborhood with extensive development in the flood fringe that suffered substantially during the 2013 Flood. However, unlike Sunnyside, Elbow Park has no historical levees and, being on the Elbow River, has less mitigation. Therefore, an updated flood risk map of Elbow Park should map

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[63] Under the base protections P0 scenario.

closer to the real 1% annual chance flood hazard. On the other hand, an updated flood risk map of Sunnyside (which naturalizes flows per Alberta's current mapping policies and assumes levee failure) would map a hazard greater than the real 1% annual chance flood hazard. Such discrepancies place unequal regulatory burdens on communities like Sunnyside (when the current level of protection is considered) and facilitate a disproportionate accumulation of flood risk in communities like Elbow Park.

In summary, the amount of vulnerability reduction enhancing flood rules alone (without extending FHZs) can provide is limited. For any substantial improvements, flood rules must behave like flood waters, and extend beyond the FHZ.

6.3.3. Walls and Rules

Despite a tendency to dichotomize FHRs and structural protections, from an FRM perspective, these are both simply tools to reduce flood risk. Therefore, to reduce any bias that may lead to a less-favorable investment, robust FRM should evaluate both tools on equal footing. This obvious view has, until now, been held back in Alberta in part by the technical limitations of RFDA. With SOFDA, it is now possible to evaluate the benefits of both measures. Expanding on the siloed analysis of structural protections in Section 6.3.1, and the current FHRs in Section 6.3.2, this section takes a comparative view of FHRs and structural protections to explore how both work to reduce risk. Further, this comparative approach serves to address those stakeholders who view structural protections as a replacement for FHRs by exploring the harmony achieved when both are applied in concert.

Apart

To understand the strengths of dual-mitigation (with FHRs and structural protections), the following key political or non-technical differences should be considered first:

1. *Protected feelings*: Structural protections are typically visible structures — often large and made from concrete — whose completion is celebrated by politicians and local news media (CBC News 2016). In contrast, FHRs only exist on paper. Further, resident interaction with FHRs is typically negative and in the context of the regulator imposing some prohibition on their private property rights. These disparities may contribute to a feeling of 'being protected' by structural measures in contrast to a feeling of 'being burdened' by FHRs.

2. *Timing*: Structural protections reduce risk immediately, while FHRs supply gradual risk reduction. The orange arrow in Figure 6-14 shows that, conceptually, enhancing structural protections provides benefit at year 0, while Figure 6-15 shows that enhanced FHRs take time to provide benefit. This observation is, in essence, a re-framing of the motivating premise for this thesis: a dynamic view of risk is required to evaluate FHRs. This reflected result can be explained intuitively: the moment structural protection enhancements are operational, the community is protected, and their risk lowered. In contrast, no physical change is manifested the moment new FHRs are legislated.
3. *Who pays*: Structural protections are typically financed by all tax-payers, while FHRs have negligible up-front monetary costs. Further, this tax base for structural protections generally does not align with those standing to benefit from the protection. For example, the proposed stormwater lift stations in Sunnyside are financed in part by a $10 million grant from the GoA (Alberta Government 2017b). Contrary to this, any costs associated with FHRs are borne primarily by property owners through the restriction of some future use.[64]
4. *Who benefits*: Structural protections reduce the risk of all assets behind the protection, while FHRs only reduce the risk of those assets which trigger regulatory action (i.e. new buildings and additions). Therefore, in developed communities, retrofit FHRs leave a patchwork of vulnerability reduction.

Combining #3 and #4 suggests that the relation between those who stand to benefit, and those who stand to pay, differs between structural protections and FHRs. Considering all the above, policy development and implementation for structural protections and FHRs has traditionally been siloed. For example, within the GoA, authority for FHRs falls under the department of Municipal Affairs, while structural protections are the purview of Alberta Environment and Parks[65] (the CoC is similar). There is also some evidence that private citizens think of these two mitigations as not only separate, but interchangeable. For example, some participants in our survey expressed the view that policy makers should exclusively pursue investment in structural protections and not consider additional FHRs — a view shared by local advocacy groups (CRCAG 2016). Kreutzwiser et al. (1994) and Shrubsole et al. (1997) had similar findings in their Canadian surveys. A further example of this siloed thinking can be found in the flood hazard mapping

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[64] However, the evidence suggests these costs are not reflected in property values (Shrubsole et al. 1997; Babcock and Mitchell 1980).

[65] Alberta Environment and Parks conduct the hazard mapping studies from which FHZs are developed, and typically provide funding support for non-provincial projects and decision support and feasibility design for major provincial works. Responsibility for the later stages of development and construction of major provincial works are typically passed to Alberta Infrastructure (p.c.).

policies of the GoA that require FHZ mapping to ignore the influence of structural protections (i.e. assume levee failure) (Alberta Environment 2011).

Adopting this siloed (either-or) view, the concrete, immediate, and tangible nature of structural protections provides some obvious advantages over FHRs. However, structural protections lack resilience. In other words, once a levee is overtopped (or fails) its utility dissolves exposing assets to the full unmitigated flood waters. In contrast, FHR mandated wet floodproofing PLPMs and elevating can reduce damage from nearly all flood magnitudes, regardless of the performance of structural protections. The major shortcomings of structural protections related to their lack of resilience are:

- *Premature structure failure:* While structural protections are typically designed (and modeled) to provide protection up to a certain WSL, there remains some residual risk that these mitigations will fail during a flood. These failures obviously reduce the level of safety (and efficiency) originally calculated for the mitigation.
- *Dynamic hazards*: Assuming satisfactory performance to the design WSL, a structural protection measure can still fail to achieve its intended efficiency if the likelihood of a given flood WSL changes. Forces such as climate change, land use change, and channel restrictions can all distort this WSL-likelihood relation causing protected assets to be exposed more than expected.

Further, levees are typically designed and modeled to only mitigate surface water flooding. The bottom half of Figure 5-2 shows that the hazard analysis for this study modeled the Sunnyside levee in this way (the bottom five WSLs extend beyond the levee, rather than stopping). This groundwater often leads to damage from relatively small events in developed alluvial floodplains. For example, in this study, under the base structural protections (P0) the Sunnyside levee overtops near the Prince’s Island Bridge (Figure 4-6) for floods larger than the 35 ARI event (with temporary barriers). However, Figure 6-16 shows that damages are generated for (all considered) floods below this ARI, despite an assumption of 100% performance by the structural protection. In other words, even though the levee ‘works,’ damage from groundwater flooding still occurs. Well-designed FHRs can serve to reduce the residual risk left by this groundwater seepage and the lack of resilience from structural protections.

Together

The results shown on Figure 6-17 suggest that alone, neither structural protections (P7) nor the current FHRs (Fo) are sufficient to halt an accumulation of risk; only the joint scenario (S02) was successful in this. As was explained above, while the scenario with solely the current FHRs (S01) realizes the same vulnerability growth as the joint scenario (S02), only under the enhanced protections is the exposure limited to those assets within the FHZ, stabilizing risk for the full study area. From this, three conclusions can be drawn: 1) structural protections do not halt the accumulation of risk in the long-term (Section 6.3.1); 2) the current FHRs (Fo) are inadequate (Section 6.3.2); and 3) combining these is the most effective option.

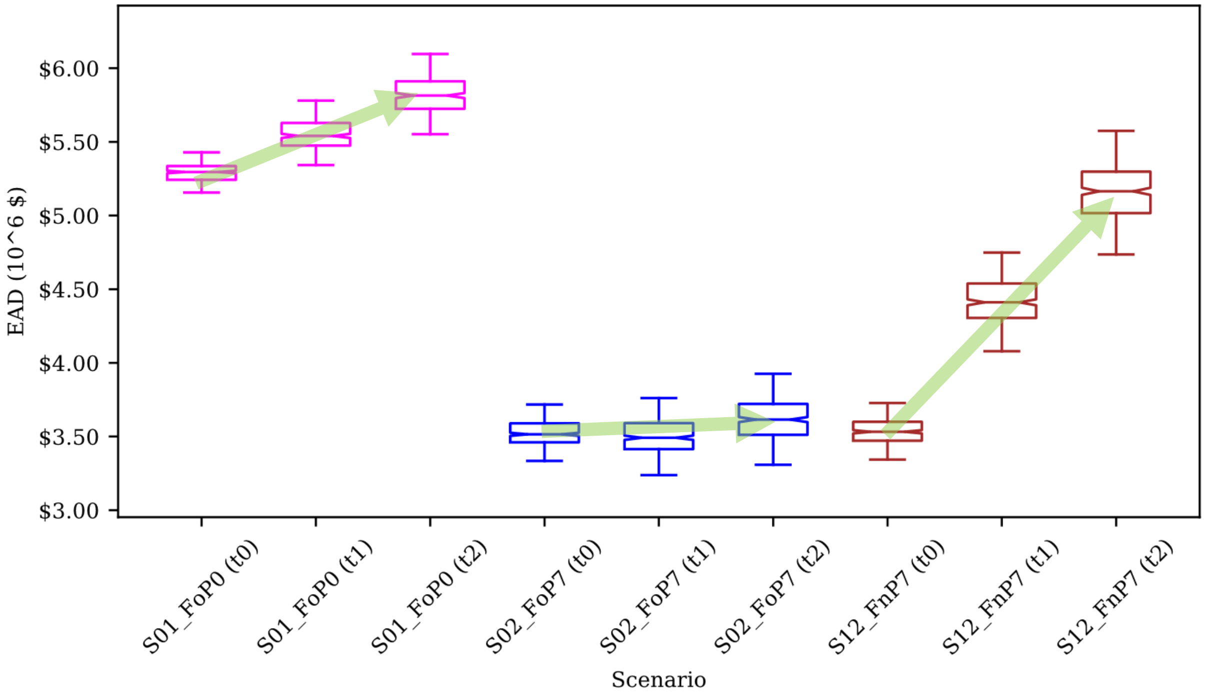

Figure 6-17: EAD-timestep results boxplots for the three scenarios. See text for details and Figure 5-11 for legend key. Arrows added to clarify timestep progression.

The role groundwater mitigation plays in the harmony between FHRs and structural protections like levees is less generalizable because it depends on the specifics of the structural protection and the groundwater characteristics of the study area. For example, one scenario considered in the 2017 Study included a measure to install a groundwater interception trench along the Sunnyside levee to reduce groundwater flooding exposure. When considering an option like this, or in area with low permeability, groundwater would not reach the asset, stifling the utility of groundwater

PLPMs. However, in an area like Sunnyside, FHR mandated PLPMs supply a valuable stopgap for levees installed without groundwater mitigation (like in P7).

In summary, a multi-layered approach uses the social and political advantages of structural protections, while correcting for their lack of resilience through imposing FHRs. This is particularly important given the highly uncertain future suggested by climate change and urban development in Chapter 1. To improve FRM further, all layers of such a combined strategy should be optimized, including FHRs.

6.4. Analysis of Enhanced FHRs

To explore the second research question — *are there more favorable FHRs that provide as much or more flood damage mitigation than the current FHRs, while avoiding the more onerous restrictions?* — scenarios for the current (Fo), a novel 3-tier scheme (Ft3), and no regulations (Fn) are compared (all with the P7 enhanced structural protections).

Motivation

As discussed in Section 5.5.1, a novel 3-tier FHR was developed to optimize the risk-reduction and regulatory burden by:

- *Removing the burden to elevate in low-lying areas*: While elevating is an effective measure to mitigate flood risk, it can be cost-prohibitive (see Section 2.2.1) — especially in low-lying areas like Sunnyside. Therefore, elevating requirements are minimized in this novel FHR to reduce the overall burden, increasing efficiency and the likelihood of political acceptance.
- *Restricting the development of basements*: As discussed in 6.3.2, the dangerous trend of deeper finished basements is not addressed by the current FHRs.[66] Assuming that basement height restrictions would impose a negligible burden, and that basement furnishing/occupancy restrictions would impose a small burden, basement restrictions for new developments are used in the novel FHR as a high efficiency mitigation measure.

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[66] However, Section 6.2.6 shows that the requirement for PLPMs has inhibited this from increasing vulnerability.

- *Regulating the whole community:* The current FHZ paradigm leaves many residents just outside the FHZ, with the mistaken view that they are *not* susceptible to riverine flood damage. Similarly, these homes are left unprepared and unprotected, having been built free of regulations. This is especially significant considering more than 30% of assets outside the FHZ in the study area are vulnerable to basement damage from the 5 ARI base event (P0). Therefore, this novel FHR expands regulations to all assets within the study area to reduce flood risk.
- *Applying a graduated FHZ:* All houses face some riverine flood risk. Fortunately, as one moves up and away from rivers, this risk gradually and continuously decreases from high to negligible. The current FHZ paradigm does not recognize this, instead devising three zones: 1) high exposure (floodway); 2) some risk (flood fringe); and 3) no flood requirements. In Calgary, few homes are still in the floodway, leaving nearly all assets within the FHZ to be regulated equally. While elevating requirements tied to BFEs do provide some proportionality to the current FHRs, FHRs generally blanket all assets with the same mitigation requirements. This divorcing of reduction-efforts from the thing that they are trying to reduce — local flood risk — impairs the efficiency of the policy. Therefore, a graduated, 3-tier FHZ is pursued to improve efficiency by providing a closer link between flood risk and mitigation effort.

Results

Figure 6-18 shows that this 3-tier FHR (Ft3) is the only scenario considered in this study that progressively reduces EAD. Two model indicators driving this result are provided in Figure 6-19. As the figure shows, before re-development, all scenarios start at t0 with an average groundwater damage ratio[67] near 0.45 and an average vulnerability elevation of 1044.62 m NAD. Without rules (S12), this vulnerability elevation progressively *worsens*, and there is a slight *increase* in the portion of damages coming from groundwater (as a result of the deeper basements). Under the current rules (S02), there is a slight *improvement* in vulnerability elevation, and a *reduction* in the share of damages coming from groundwater. Contrary to this, the 3-tier scheme (S72) shows a significant reduction in the portion of damages coming from groundwater because of the combined influences of: 1) unfinished basements in zone one; 2) shallower basements; 3) more PLPMs; and 4) elevating assets in zone three.

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[67] The sum of groundwater damages from all 12 flood events considered divided by the sum of total damages for the full inventory.

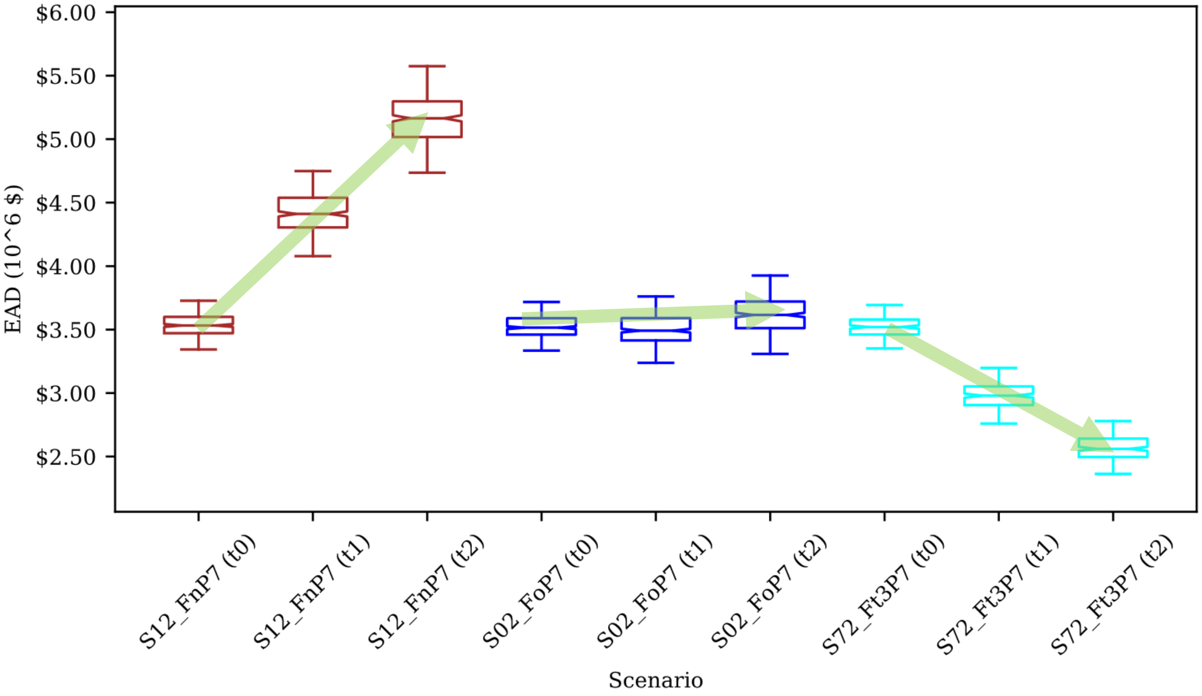

Figure 6-18: EAD-timestep results boxplots for the three P7 scenarios. See text for details and Figure 5-11 for scenario key. Arrows added to clarify timestep progression.

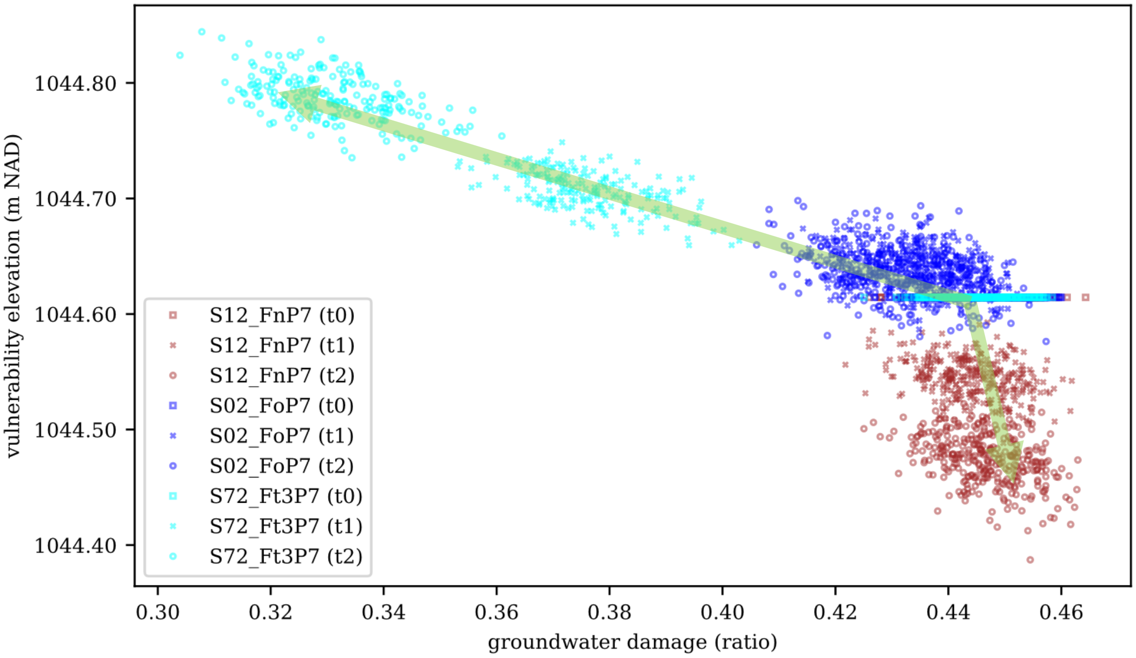

Figure 6-19: Number of backflow valves vs. the ratio of total damage from groundwater results scatter plot on three timesteps for three scenarios. See text for details and Figure 5-11 for legend key. Arrows added to clarify timestep progression.

Taking the perspective of a risk analyst evaluating the benefits of the 3-tier FHRs (Ft3) over the current FHRs (Fo) yields a benefit of -9.7% (i.e. the enhanced FHRs reduce flood risk by 9.7%). Figure 6-20 shows the contributions to the total EAD at simulation's end from the 5 Dfuncs. From this figure, the following observations can be made about the performance of Ft3 over Fo:

- *More damage from large floods*: For the 350 and 500 ARI events, the Ft3 scenario predicted 10% and 35% more damage respectively (than the Fo scenario). However, equivalent performance was predicted between the two scenarios for the most extreme event (1000 ARI). This result is driven by the unique exposure of the 350 and 500 ARI events, which substantially inundate Sunnyside's zone one and two while Hillhurst's zone three remains protected (with the P7 structural enhancements). Therefore, the elevating that would be imposed by the current FHRs (Fo), in the zone one and two areas, outperforms the basement mitigations imposed by the 3-tier FHRs (Ft3). However, because the likelihood of these events is small, their influence on the total EAD calculation is countered by the mitigation performance of the more frequent events.
- *Less damage from small floods*: Combining the smallest five events (5 to 35 ARI), the Ft3 scenario mitigated 27% more damage than the Fo scenario.
- *Negligible change in basement contents damages*: Despite simulating zero basement contents damages (BC) in zone one, their proportional contribution was similar between the two scenarios. This suggests that the influence of the prohibition of basement contents on the 19.3% of assets within zone one (Table 5-16) is countered by the reduction in vulnerability realized from the PLPMs under the Fo scenario.

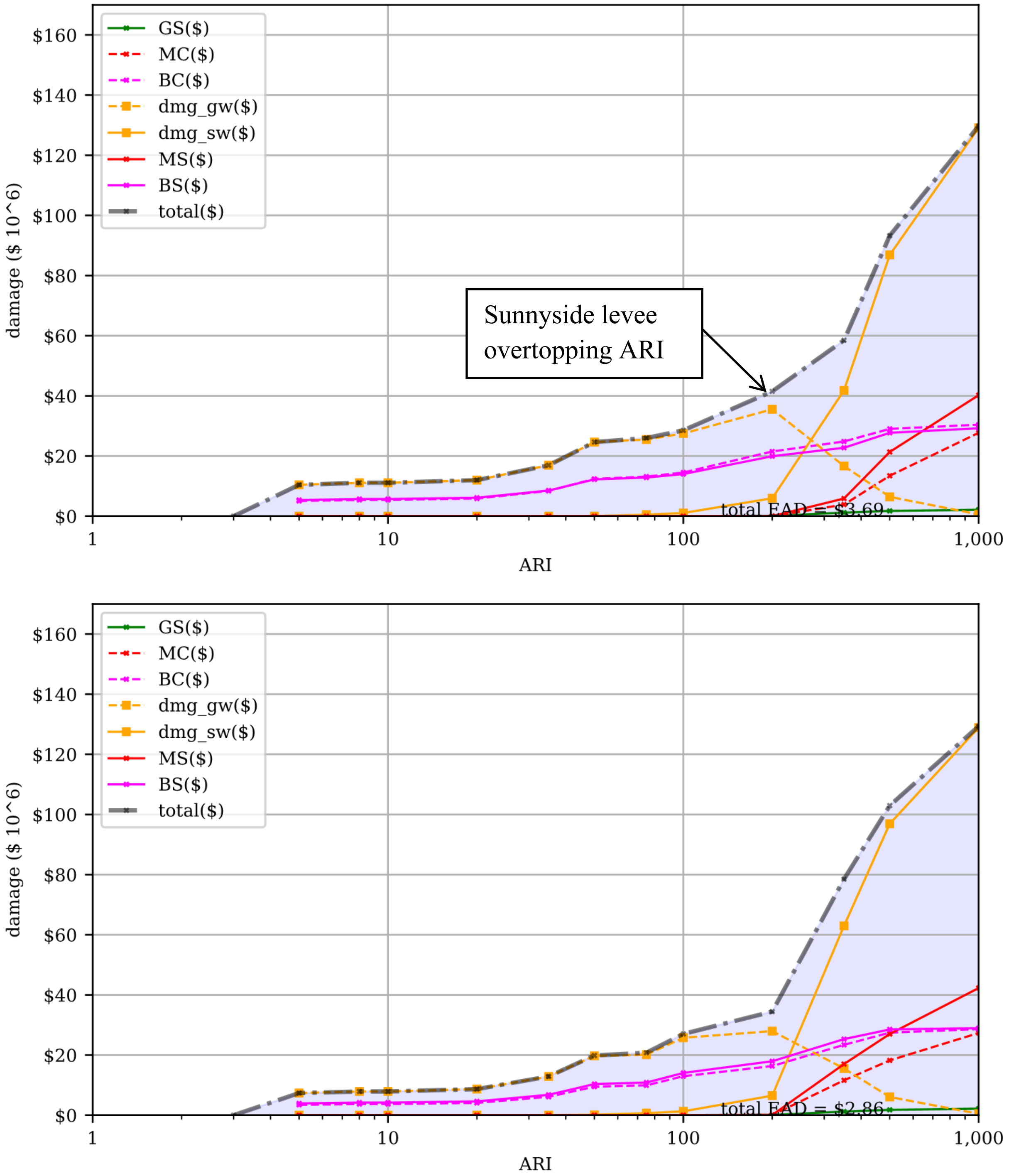

Figure 6-20: Flood damage to ARI plot showing 8 different types of flood damage for a simulation at t2 for the [top] S02 and [bottom] S72 scenarios. For Dfunc damage codes key (GS, MC, etc.) see Table 5-9. Damage from groundwater (dmg_gw) and surface water (dmg_sw) shown in orange. Area under the total damage curve shaded to illustrate the total EAD calculation (in $ 10^6).

Challenges

While these results suggest enhancing FHRs can reduce flood risk, transitioning away from design-based, blanket FHRs towards a risk-based paradigm will likely face obstacles:

1. *Political challenges*: Any change to FHRs will create winners and losers — with the latter incentivized to oppose. Further, being an early adopter of creative solutions (like novel FHRs) may lead to surprise costs and extra resistance from skeptics.
2. *Complicated enforcement*: The current blanket FHRs cover three pages in the CoC's land use bylaw, making enforcement by city planners and code-enforcers relatively simple. A graduated, or more spatially heterogenous scheme (like Ft3), would complicate enforcement. However, the complete land use bylaw is over 1000 pages, and the CoC already enforces spatially complex regulations for the purposes of preserving and enhancing a community's image, fabric, and social environment (e.g. area redevelopment plans). Considering this precedent, and the adoption of modern mobile GIS tools, enforcing more spatially heterogenous FHRs seems well within the capabilities of the CoC.
3. *Confusion and opacity*: Like #2, a more complex FHR would likely confuse and frustrate property owners, reducing their support for the policy.
4. *Computational complexity*: Unlike the current FHRs, which can be developed by city staff largely from provincial flood hazard maps, standard practice, and precedents — risk-based FHRs need more advanced and computationally intensive analytical tools (like SOFDA). To use such tools would require more training of city staff or outsourcing, both of which would require more up-front investment in planning for hazards.

While the omission of cost and other options from this analysis prohibits a real optimization, simulating benefits supplies a useful first step towards identifying more efficient FHRs by demonstrating how they may reduce risk. Assuming efforts to quantify the costs of FHRs are successful, an assessment like the one applied here could be used to identify an optimized FHR from a set of alternatives. Enabled by the dynamic view of SOFDA, such FHR optimization efforts bring the power of risk-based decision-making to FHR policy.

6.5. Risk Prediction Uncertainties

Like RFDA, SOFDA represents a substantial improvement in FRM decision support tools, and an incremental step towards more holistic and robust decisions. Importantly, development has revealed methodological uncertainties for future research to address (discussed in Section 7.3), while still producing a useful tool. Expanding on these opportunities, this section describes some of the major uncertainties of this thesis, and their corresponding assumptions in calculating risk estimates. The discussion focuses on those activities under the purview of the risk analyst, as diagramed in Figure 3-2.

6.5.1. Initial Conditions

Establishing the initial conditions (discussed in Section 5.3.3) proved challenging given the limited resources available for the field survey of this study. In particular, few analogous studies were available for those variables which were newly required by SOFDA (e.g. PLPM presence, basement height). Further, the voluntary format of the field surveys limited the confidence and applicability of the survey results. While enough data was available to develop a crude statistical model for basement height from the survey data, simple (stochastic) flat-rates for PLPM status were used. If this parameterization underestimates the real PLPM prevalence, the results for this study would positively bias the performance of FHRs. This bias would cause the model to predict less risk accumulation than would otherwise be realized (for all scenarios). Some accounting for this uncertainty was provided through assigning PLPMs stochastically. However, the limited number of simulations, and that PLPM parameters were sampled for each asset, led to a small range of average PLPM prevalence in the simulation ensembles. For example, the simulated range of total backflow valve prevalence was 46% – 53% (Figure 6-21), while the range reported in the literature was 24% – 39% (Table 2-1) and the value for this study survey was 68%. Considering this, and the significance of PLPMs on asset vulnerability, future studies should invest more effort into mapping and parameterizing PLPM prevalence.

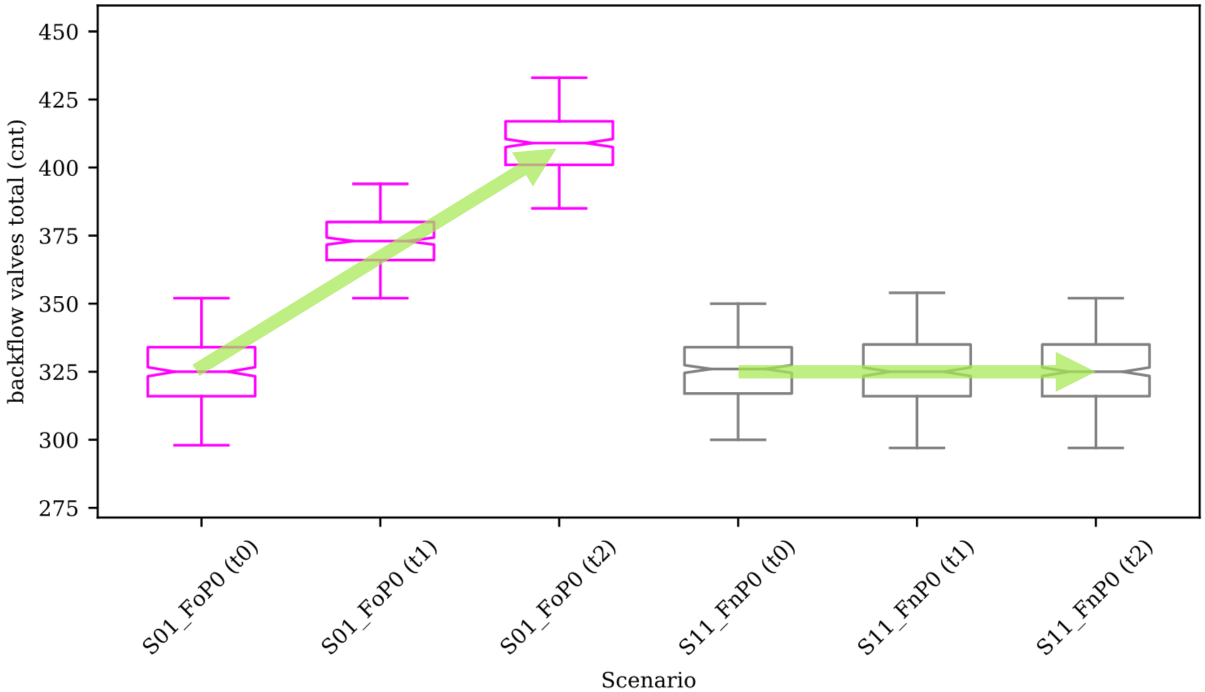

Figure 6-21: Backflow valve vs. timestep results boxplot for the two P0 scenarios. See text for details and Figure 5-11 for scenario key. Arrows added to clarify timestep progression.

6.5.2. Urban Re-Development

Exogeneous Infill Rate (N_i)

In SOFDA, the number of infills simulated for each timestep (N_i) is assumed exogenous or not influenced by the local context of the study area. While this modeling choice was made primarily to avoid complexity, it does reflect the view that re-development is driven by macro-economic factors beyond the study area (e.g. immigration, job-growth). In other words, the number of infills in Calgary each year is independent of the happenings within Sunnyside/Hillhurst, and Sunnyside/Hillhurst will receive a similar portion of those infills each year. This view omits observed trends like the increase in the share of developed area growth vs. greenfield growth in Calgary (Section 1.1). Further, this view assumes no inter-neighborhood dynamics on the spatial allocation of redevelopment. In other words, re-developers will not be dissuaded from the study area towards some other, cheaper, or more attractive neighborhood.

To communicate this uncertainty, the infill rate (N_i) parameter was presented with the two socio-economic scenarios, U+ and U-, described in Table 5-15. Surprisingly, such a treatment revealed that, for this study area, only those scenarios without FHRs (Fn) were sensitive to the infill rate (N_i), and therefore the economic scenario.

However, this sensitivity to infill rate depends on the study boundaries, as discussed in Section 6.2.8. Were the study boundaries expanded to include more heterogenous sub-areas, some partitioning algorithm should be employed to distribute the total infill rate (N_i) to each sub-area. This algorithm could be built empirically from development permit records and historical socio-economic indicators (e.g. GDP and population growth rates).[68] Alternatively, an agent based modeling method, like the one developed by de Koning et al. (2017), could be used to mimic the interactions of agents (e.g. sellers, buyers, and financiers) for a more realistic simulation of property transfers. However, more choice-algorithms would need to be included to further segregate these transfers into the actions of a typical home buyer (e.g. tear-down, additions, renovations). Such a sophisticated approach would need extensive data collection and model development, likely reducing its usefulness in decision support.

Spatial Selection and Downscaling

After the infill count (N_i) is sampled for a timestep, SOFDA downscales this prediction to the individual assets with the stochastically applied development-potential-ranking described in Section 5.3.5. The significance of this spatial downscaling was demonstrated with the sensitivity analysis described in Section 5.4. Further, Figure 6-9 (S11) shows that when development occurs under the high-exposure found in the FHZ, EAD increases more so than outside the FHZ. As intuition suggests, in the context of spatial hazards (like floods) where and how development occurs is highly relevant.

This poses a significant challenge for flood risk modeling as the necessary granular development models are under-studied and sensitive to local context. Figure 6-22 shows that, for the simple value-density ranking employed here, of the 50 parcels that would have been predicted to redevelop from 2014 to 2018, only 10 would have done so. This suggests a more robust downscaling sub-model is worth pursuing.

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[68] Alternatively, each sub-area could have an independent rate.

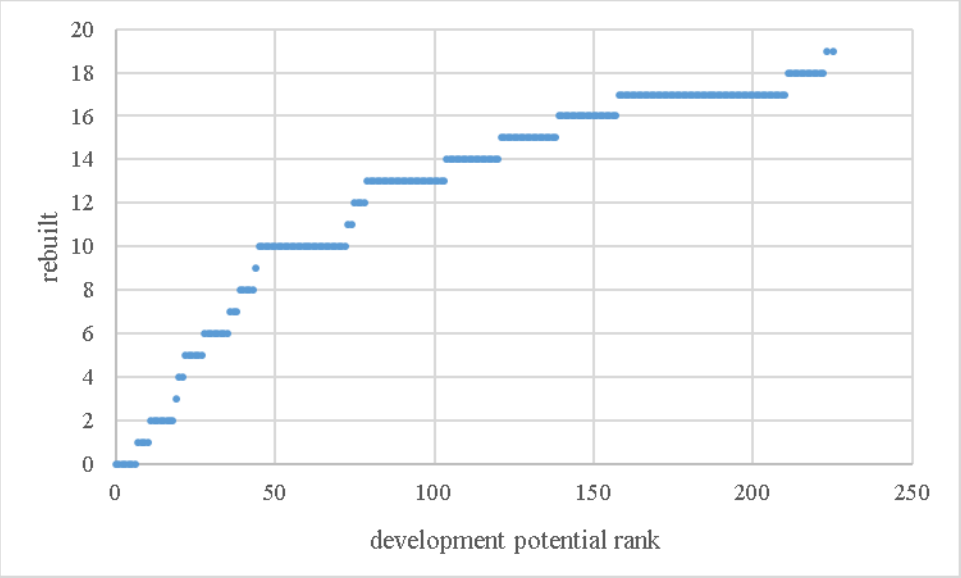

Figure 6-22: development potential rank vs. number of observed rebuilds between 2014-2018 for flood affected parcels in the study area.

Home Additions

This study took the simplifying assumption that FHRs are triggered only when a house is demolished, and the property infilled. This omits the retrofitting requirement for major additions included in the current regulations (Appendix B). Conversations with development experts and survey participants suggested that, in practice, such requirements were often either wholly or partially waived (or contravened). This complexity poses a challenge for modeling. If major additions were included, simulated vulnerability indicators (e.g. PLPM presence, vulnerability elevation) would decrease; however, asset areas would increase. These counter acting forces leave the significance of the major additions trigger on flood risk accumulation in Calgary unclear. Additional research should be conducted to: 1) establish the rate of home additions that trigger some FHR requirements (rather than FHR required); then 2) include this trigger with the infill trigger (of this model study) for a more robust exploration of the accumulation of flood risk.

Complex Re-development: Lot Joins

After a parcel is identified for infilling, SOFDA applies the infilling actions described in Table 5-14 to simulate replacement of the old house with the new. The parameterization of these actions matches a typical infill, where a lot with a single old house is sold, demolished, then replaced with a contemporary house. However, within the areas zoned for multi-residential (M-CG) development, such single lots can be joined, cleared, and replaced with multi-story apartment buildings. An example of this happened in 2013 on the 800 block of 5th Avenue which abuts the northern boundary of the study area (Figure 6-23). Modeling such re-development would require logic for the spatial relation of parcels. Incorporating this would significantly complicate any downscaling or infill typology algorithms. However, without such complex mechanisms, predictions on the future vulnerability of neighborhoods (like Sunnyside/Hillhurst) are incomplete.

Figure 6-23: [left] before and [right] after aerial image of the 800 block of 5th avenue in Sunnyside. Obtained from Google Earth on 2018-12-01.

7. Conclusions and Recommendations

In the aftermath of the 2013 Flood, communities in Alberta recognized the need to improve decision-making around flood mitigation. This led to the development of the Alberta-specific Rapid Flood Damage Model (RFDA). Building on the accomplishments of RFDA, this risk-based evaluation of floods is extended here to incorporate the dynamics of vulnerability. This was accomplished by developing the novel Stochastic Object-based Flood damage Dynamic Assessment model framework (SOFDA). SOFDA represents an incremental step towards more holistic flood risk management (FRM), by progressing past the static view of risk underlying RFDA, towards a dynamic view that recognizes changes in vulnerability and hazard. Moving into this paradigm, two research questions emerged that explore the utility of this new view in: 1) the evaluation of *traditional* mitigation measures; and 2) the development and evaluation of *novel* mitigation measures. With SOFDA, a simplified case study was used to explore these questions and demonstrate the value of the dynamic view of risk. The rest of this chapter provides conclusions and recommendations targeted at different audiences: 1) FRM decision makers; 2) future users of RFDA and SOFDA; and 3) future flood risk researchers. This siloing is provided for convenience only; readers from all groups may find value in each section, regardless of identity.

7.1. For Decision Makers

From the exploration of risk-dynamics in this thesis, two conclusions emerged directly relevant to decisions on flood risk management (FRM):

- The traditional, static assessment of structural protections may underestimate benefits;
- Under the current standards-based FHRs, re-development trends in floodprone communities in Calgary are likely increasing the city's flood risk.

From these conclusions, two recommendations for FRM are presented:

- Future risk assessments should incorporate vulnerability dynamics; and
- A risk-based framework should be applied to optimize and improve the current FHRs.

As this study demonstrated for Sunnyside/Hillhurst, Calgary's current FHRs leave substantial room for improvement. Further, the much anticipated provincial updates to the FHZ and the political momentum from the 2013 Flood, provide a once-in-a-lifetime opportunity to amend the land use bylaw and ease Calgary off its current trajectory of increasing flood damage. To start this process, alternate FHRs should be evaluated with a robust and complete analysis of the costs and benefits using a dynamic risk-based tool like SOFDA. This dynamic risk assessment should engage stakeholders, especially homeowners, to develop FHRs that each community can be proud of. Such an approach may circumvent local opposition — and supplant it with support. Towards this, Table 7-1 presents some conceptual improvements to the current FHRs that could be considered during such an assessment.

Fundamentally, these recommendations seek to make FRM more holistic and equitable by improving efficiency and reducing long-term harm from floods. However, it must be emphasized that flood risk modeling is still in its infancy, and the advancements of this thesis are a very small step down a very long road.

Table 7-1: Elements suggested for consideration to improve the efficiency of Calgary's current FHRs. Cons are in addition to the inherent challenges that will likely accompany any regulatory change.

Element	**Description**	**Pros**	**Cons**
Prohibit development below the BFE	Adding a rule to the current FHRs, occupancy or finishing restrictions could be placed on enclosed spaces below the BFE.	Reduce the accumulation of risk	Reduced use of the floodplain
Require sump pumps with backup power	Adding a rule to the current FHRs, sump pumps and backup power supplies (portable or otherwise) could be required for all properties with enclosed space below the BFE.	Reduce the accumulation of risk	Additional cost to property owners
Eliminate FHZs (not BFEs)	Maintaining a design-based framework, more robust hydraulic and groundwater hazard studies could establish a design-event BFE for FHRs. Rather than stopping at some arbitrary surface water inundation line, this BFE should extend as a groundwater level to all floodprone areas. In other words, flood rules must behave like flood waters, and extend beyond the FHZ.	Reduce the accumulation of risk, reduce confusion and surprise of residents, more equitable	Enforcement complexity, reduced use of the floodplain
Make FHZs realistic	Maintaining the philosophy of the current FHRs, the simplifying methodologies of Alberta's current Flood Hazard Identification Program Guidelines (2011) could be improved to provide a more spatially consistent representation of riverine flood hazard (e.g. the levee failure assumption, naturalized flows).	Improve the efficiency of FHRs, reflect and encourage investment in local mitigation	Hazard study complexity
Graduated FHZs	Adopting a risk-based framework, the severity of FHR requirements could be spatially graduated based on the level of exposure.	Reduce the accumulation of risk, improve the efficiency of FHRs	Enforcement complexity
Tailor FHRs to the community	FHRs could be developed that reflect the diversity of building typologies, flood regimes, and residents in different areas.	Improve the efficiency of FHRs	Enforcement complexity, development complexity
Require insurance	Those homes within the FHZ could be required to purchase insurance (initially subsidized) where cost accurately reflects the risk of that property.	Reduce the accumulation of risk	Liability uncertainty, enforcement complexity, development complexity, added cost to property owners

7.2. For Flood Risk Modelers (and Modellers)

The flood risk assessment in this thesis likely represents the most narrow and focused risk model study to date in Alberta. Unlike the risk modeling of the precursor 2017 Study, which greatly surpassed the work of this thesis in terms of breadth (in area, assets, damage types and scenarios), this thesis focused solely on the 652 single-family homes in Sunnyside/Calgary using: 1) the enhancements afforded by SOFDA; 2) 2013 Flood damage data; and 3) field survey results. From this work, the recommendations in Table 7-2 are presented to improve future flood risk modeling studies employing either RFDA or SOFDA.

Table 7-2: Recommendations to improve future flood risk modeling studies employing either RFDA or SOFDA.

Recommendation	Description
Lower the ARI of the smallest event considered	To avoid extrapolating risk estimates to calculate the zero-damage event (i.e. x-axis intercept on the EAD curve) — a process which may considerably influence the risk assessment — hazard layers should include a high-likelihood event (e.g. 2 or 3 ARI; see Section 6.2.1).
Survey and include heterogenous basement heights	In alluvial floodplains, like Calgary, basement damages from groundwater flooding can substantially contribute to flood risk. Obviously, this contribution depends on the depth of basements below ground, as was confirmed by the sensitivity analysis (Section 5.4). This study's survey suggests these basement depths vary significantly between houses (Section 5.2.3). Therefore, building inventory development should also include some survey of this parameter, especially in areas predicted to experience frequent basement flood damage.
Survey and include basement finish level	Like the previous recommendation, this study's survey showed that not all houses with basements are fully finished (Section 5.4). Therefore, building inventory development should also include some survey of this parameter.
Develop realistic hazard layers	To make robust decisions, and maintain the confidence of their constituents, decision makers require accurate predictions of risk and transparent accounting for uncertainty. For the hazard analysis, this requires the flood WSL-frequency relation (predicted for each asset) be as accurate as possible. Like damage modeling, future hazard models should work to reduce assumptions that distort this flood WSL-frequency relation (see Section 6.3.3).
Consider structural protection reliability	Like the previous recommendation, the reliability of structural protections (e.g. levees) influences the WSL-frequency relation and should therefore be incorporated into risk analyses. This would likely require a survey of existing structural protections, and some quantification of their failure likelihood as a function of flood depth. The hazard analysis would then need to consider cascading, joint, and independent failure of each protection. While this would substantially complicate the hazard analysis, such mechanisms are significant, and may alter the model conclusions passed on to decision makers.

Similar to the above, Table 7-3 supplies more recommendations that future SOFDA modeling studies should consider. While both sets of recommendations must be weighed against their added financial and time burdens, the sensitivity analysis presented in Section 5.4 shows that some of these parameters may influence damage predictions by as much as 35%. Considering the billions of dollars under consideration for mitigation investment in Alberta, the improvements suggested by these tables seem well worth it.

Table 7-3: Recommendations to improve future dynamic flood risk modeling studies employing SOFDA. See Table 7-2 for more recommendations.

Recommendation	Description
Invest in a robust survey of asset PLPMs	The presence of PLPMs significantly influences model risk predictions in areas with basements and groundwater flooding (see Section 5.4). Future models should strive to map the prevalence of PLPMs for a large portion of the study area, especially in those areas predicted to experience frequent basement flood damage.
Consider more variation in base rates	Parameters that describe a study area average (base rate) of some object parameter (e.g. backflow valve prevalence on each House object) should reflect the range of averages reported in the literature (see Section 6.5.1).
Divide the study area into more homogenous sub-areas	To improve predictions for urban re-development, the study area should be divided into homogenous sub-areas (similar to how a home-buyer may perceive them). Urban re-development in each sub-area should then be modeled separately to avoid simulations where the infill rate (N_i) is disproportionally downscaled between the sub-areas (see Section 6.5.2).
Use large study areas	To minimize the influence of the study area boundaries on the results, they should be extended to just beyond the inundation of the largest modeled flood event.
Include more timesteps	To better understand the drivers of flood risk, more timesteps should be included to provide intermediate results.
Include FHR triggers from additions	For a more robust prediction of vulnerability dynamics under FHRs, all triggers should be included (see Section 6.5.2).
Use hazard layers with more granular structural protection options	To better understand the drivers of flood risk under structural protections, each measure should be investigated independently (e.g. hazard layers for just the levee improvements), rather than the ensemble of measures investigated here (see Section 6.3.3).
Include hazard dynamics (e.g. climate change)	To provide a full accounting for the benefits of a measure over its lifetime, forces that change the hazard must also be evaluated. This includes regulation by upstream reservoirs, channel modifications, land use changes, and climate change. While downscaling of global climate models, to provide projections for future discharge relations, holds promise, these results are not yet available for Calgary. Once available, such hazard dynamics should be incorporated, with the vulnerability dynamics explored in this thesis, to provide better direction for flood mitigation investments.

7.3. For Flood Risk Researchers

A primary criterion for SOFDA's development was to improve decision support within the paradigms of the current tool, RFDA. This, and limited resources, left many components of the flood risk cycle unaddressed. Regardless, SOFDA can still improve decisions if these omissions are respected. Table 7-4 provides a summary of some such omissions from the SOFDA framework that future research should consider.

With models expanded to include some of the elements discussed in Table 7-4, future flood risk research would be capable of exploring some of the key uncertainties blocking FRM from more robust and resilient flood risk reduction, like:

- What is the optimum FHR for an area?
- What is the actual adherence rate to FHRs, and how does this influence the accumulation of risk?
- What benefits might a PLPM subsidy program provide?
- What is the effect on risk accumulation of assuming levee failure and naturalizing flows in FHZ mapping?
- What are the optimum FRM policies considering the uncertainty of climate change?
- How might the inclusion of mitigation reliability (i.e. levee failure) influence investment decisions?

Such technical questions should be tackled concurrently with the more important philosophical and cultural questions of the environmental sustainability and social equity of FRM investments.

Finally, real, granular, flood damage data is desperately needed. For this thesis, months of effort were invested to solicit damage data from: 1) the CoC; 2) the GoA; 3) insurance companies; 4) other field surveys; and 5) residents. Only data from #1 and #5 provided the asset-level granular data necessary to validate the loss functions of this study — but both were partial and incomplete. Without long-term, standardized, granular flood damage data in Canada, decisions around FRM carry considerable uncertainty. This decision uncertainty costs tax payers' untold sums in inefficient investments and increases the likelihood they will suffer another catastrophe — like the 2013 Flood.

Table 7-4: Recommendations to improve the SOFDA framework for more robust decision support.

Recommendation	**Description**
Expand beyond single-family homes	To capture the full benefits of an option, all assets affected by that option must be evaluated. This would require not only the incorporation of other land use types into the analysis (commercial, industrial), but improvements to the urban re-development sub-module.
Improve the Urban Re-development module	See Section 6.5.2
Make the infill rate (N_i) endogenous	To allow the expansion of SOFDA studies beyond a single, small, homogenous, neighborhood, the simulated infill rate (N_i) should incorporate some inter-neighborhood dynamics to predict the development rates between heterogeneous sub-areas.
Improve downscaling	The simple development-potential-ranking employed for this study should be replaced in SOFDA by an algorithm with greater predictive power.
Include lot joins	The simple one-to-one asset re-development employed by SOFDA should be improved to handle more complex re-development phenomena, such as lot joins.
Improve basement loss functions	The simple depth reduction algorithm employed by SOFDA (Table 5-11) should be replaced by a sub-model that incorporates mechanisms to consider the flood pathway (e.g. did it come through the windows or the sump pump?), the quality of the basement (e.g. are there foundation cracks?), the occupants of the house (e.g. are they likely to remove contents from the basement before damages?), and the vulnerability of the basement (e.g. is the basement finished?). Empirical basement flood damage data should be used to inform and validate this sub-model.
Expand to a fully stochastic integrated hazard-vulnerability model	The simple EAD algorithm employed in this study provides a reasonable risk metric from which to evaluate changes in vulnerability. However, this ignores much of the randomness that occurs in hazard phenomena (e.g. levee failure) and disconnects those processes from vulnerability. A more robust approach would be to fully integrate the hazard and the vulnerability model. This would facilitate the simulation of nuances like the combined timing of flood events with development.
Include intangible damages	The direct-damages to single-family homes considered in this study represent a small portion of the harm poorly-managed floods can cause society. Under RFDA, the 2017 Study evaluated three intangible dimensions for flood harm, with metrics like ‘population vulnerability’ and ‘water quality.’ While these dimensions are often more complex and difficult to quantify, they too should be evaluated under a dynamic view.
Include indirect damages	A complete accounting of damage must consider all elements in the economy. This includes the knock-on effects of flood damage, such as lost-pay and hotel costs. Further, financial assessments (like the ones developed in this thesis) fail to capture the indirect benefits of flood damage. For example, omitting wages earned through cleanup activities from a loss assessment over estimates the economic damage.
Expand the analysis to include all hazards	Riverine floods are not the only peril facing society. To find the most efficient investments, all opportunities must be considered. Similarly, to reduce harm more efficiently, mitigations for all types of hazard must be considered. In particular, synergies between riverine and pluvial flood mitigation should be explored.
Incorporate interconnectivity	It is well established that the intersection of floods and society creates a complex and dynamic system (see Section 2.3.4). While such interconnections and feedbacks pose challenges for data collection and modeling, absent these complexities, model predictions will remain incomplete and short-sighted.

7.4. Closing

Damage trends and population and climate change projections suggest urbanized societies face a choice between: 1) massive increases in hazard and exposure; or 2) regulating for, and investing in, mitigation. As of writing, eight development permits are pending for the study area (City of Calgary 2018b). Under the current FHRs, these will likely be larger, more expensive homes with deep, finished basements. Such irreversible vulnerability increases are humbling considering this was one of the communities most impacted by the 2013 Flood and, five years later, the levee is only high enough to protect from a 10 ARI event. Extrapolating these trends out to cities without the flood experience and expertise of Calgary, in regions without the economic base of Alberta, under the uncertainty of climate change, suggests urbanized societies desperately need to move past the static view of risk — and towards a dynamic view that prepares for tomorrow.

Bibliography

Abboud, J.M., M.C. Ryan, ., and G.D. Osborn. 2018. "Groundwater Flooding in a River-Connected Alluvial Aquifer." *Journal of Flood Risk Management*, January, e12334. https://doi.org/10.1111/jfr3.12334.

Aerts, J. C. J. H., W. J. Botzen, K. C. Clarke, S. L. Cutter, J. W. Hall, B. Merz, E. Michel-Kerjan, J. Mysiak, S. Surminski, and H. Kunreuther. 2018. "Integrating Human Behaviour Dynamics into Flood Disaster Risk Assessment." *Nature Climate Change* 8 (3): 193–99. https://doi.org/10.1038/s41558-018-0085-1.

Aerts, J. C. J. H., W. J. W. Botzen, K. Emanuel, N. Lin, H. de Moel, and E. O. Michel-Kerjan. 2014. "Evaluating Flood Resilience Strategies for Coastal Megacities." *Science* 344 (6183): 473–75. https://doi.org/10.1126/science.1248222.

Alam, Rafat, and Shahidul Islam. 2017. "Quantifying Disaster." 2017. http://www.macewan.ca/wcm/MacEwanNews/STORY_FT_MAC_ECON_RESEARCH_2.

Alberta Environment. 2011. "Flood Hazard Identification Program Guidelines."

Alberta Government. 2014. "Respecting Our Rivers."

———. 2016. "Province, TransAlta Reach Agreement to Protect Calgary and Other Bow River Communities from Flood and Drought | Alberta.Ca." April 27, 2016. https://www.alberta.ca/release.cfm?xID=416497AD8E5AF-C609-3404-6A349ADE5BB730BD.

———. 2017a. "Flood Hazard Identification Program." 2017. http://aep.alberta.ca/water/programs-and-services/flood-hazard-identification-program/.

———. 2017b. "Alberta Community Resilience Program – Fact Sheet." https://open.alberta.ca/publications/alberta-community-resilience-program-fact-sheet.

Babcock, Marion, and Bruce Mitchell. 1980. "Impact of Flood Hazard on Residential Property Values In Galt (Cambridge), Ontario." *Journal of the American Water Resources Association* 16 (3): 532–37. https://doi.org/10.1111/j.1752-1688.1980.tb03908.x.

Barendrecht, Marlies H., Alberto Viglione, ., and Gunter Bloschl. 2017. "A Dynamic Framework for Flood Risk." *Water Security*, March. https://doi.org/10.1016/j.wasec.2017.02.001.

Becker, Andrea B., William M. Johnstone, ., and Barbara J. Lence. 2011. "Wood Frame Building Response to Rapid-Onset Flooding." *Natural Hazards Review* 12 (2): 85–95. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000029.

Bin, Okmyung, and Craig E. Landry. 2013. "Changes in Implicit Flood Risk Premiums: Empirical Evidence from the Housing Market." *Journal of Environmental Economics and Management* 65 (3): 361–76. https://doi.org/10.1016/j.jeem.2012.12.002.

Bryant, Seth P., and Evan Davies. 2017. "Living with Rivers." KIAS. https://www.researchgate.net/publication/322582161_Living_with_Rivers_Flood_management_in_Alberta.

Bubeck, P., Jeroen C. J. H. Aerts, Hans de Moel, and Heidi Kreibich. 2016. "Preface: Flood-Risk Analysis and Integrated Management." *Natural Hazards and Earth System Sciences* 16 (4): 1005–10. https://doi.org/10.5194/nhess-16-1005-2016.

Bubeck, P., W. J. W. Botzen, J. C. J. H. Aerts, and others. 2012. "A Review of Risk Perceptions and Other Factors That Influence Flood Mitigation Behavior: Review of Flood Risk Perceptions." *Risk Analysis* 32 (9): 1481–95. https://doi.org/10.1111/j.1539-6924.2011.01783.x.

Burby, Raymond J., Robert E. Deyle, David R. Godschalk, and Robert B. Olshansky. 2000. "Creating Hazard Resilient Communities through Land-Use Planning." *Natural Hazards Review* 1 (2): 99–106.

Burn, Donald H., and Paul H. Whitfield. 2016. "Changes in Floods and Flood Regimes in Canada." *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques* 41 (1–2): 139–50. https://doi.org/10.1080/07011784.2015.1026844.

Calgary Planning Commission. 2014. “Report to Council - Floodway, Flood Fringe and Overland Flow Bylaws 11p2014 & 12p2014.”

Cammerer, H., A. H. Thieken, ., and J. Lammel. 2013. “Adaptability and Transferability of Flood Loss Functions in Residential Areas.” *Natural Hazards and Earth System Sciences* 13 (11): 3063–81. https://doi.org/10.5194/nhess-13-3063-2013.

CBC News. 2016. “$33M Earmarked for Sunnyside Pump Station, Bonnybrook Berm after 2013 Flood | CBC News.” CBC. November 10, 2016. https://www.cbc.ca/news/canada/calgary/flood-mitigation-calgary-ottawa-bonnybrook-sunnyside-stormwater-wastewater-funding-1.3845340.

City of Calgary. 2012. “Calgary Watershed Report. A Summary of Surface Water Quality in the Bow and Elbow Watersheds, 2010-2012.”

———. 2014. “Assessment Roll Highlights.” January 3, 2014. http://www.calgary.ca/PDA/Assessment/Pages/Assessment-Roll-Highlights.aspx.

———. 2015. “Municipal Development Plan.”

———. 2016. “Developed Areas Growth & Change 2016 (DRAFT).” 2016–0993.

———. 2017. *Land Use Bylaw 1P2007*.

———. 2018a. “Calgary and Region Economic Outlook 2018-2023. Fall 2018.”

———. 2018b. “Planning & Development Map.” 04 2018. https://developmentmap.calgary.ca/#map.

———. 2018c. “Sunnyside Sanitary Lift Station Replacement.” 2018. http://www.calgary.ca/UEP/Water/Pages/construction-projects/Construction-projects-and-upgrades/Sunnyside-Sanitary-Lift-Station-Replacement.aspx.

Community Response and Resiliency Division. 2014. “Excerpts from a Presentation.” June 3.

Compute Canada. 2018. “Cedar - CC Doc.” August 29, 2018. https://docs.computecanada.ca/wiki/Cedar.

Cornell, Sean, Duncan Fitzgerald, Nathan Frey, and Ioannis Georgiou. 2018. “Terp Mounds.” Coastal Processes, Hazards, and Society. 2018. https://www.e-education.psu.edu/earth107/node/1082.

CRCAG. 2016. “Flood Hazard Mapping and Floodway Development Regulations.” 2016. http://us7.campaign-archive1.com/?u=b3c5162e31826e7b90bf51799&id=71f78f4133&e=9f179d940e.

Davlasheridze, Meri, Karen Fisher-Vanden, ., and H. Allen Klaiber. 2017. “The Effects of Adaptation Measures on Hurricane Induced Property Losses: Which FEMA Investments Have the Highest Returns?” *Journal of Environmental Economics and Management* 81 (January): 93–114. https://doi.org/10.1016/j.jeem.2016.09.005.

Dawson, Richard J., Roger Peppe, ., and Miao Wang. 2011. “An Agent-Based Model for Risk-Based Flood Incident Management.” *Natural Hazards* 59 (1): 167–189.

Di Baldassarre, G, A. Viglione, G. Carr, L. Kuil, J. L. Salinas, and G. Blöschl. 2013. “Socio-Hydrology: Conceptualising Human-Flood Interactions.” *Hydrology and Earth System Sciences* 17 (8): 3295–3303. https://doi.org/10.5194/hess-17-3295-2013.

Di Baldassarre, G, Alberto Viglione, Gemma Carr, Linda Kuil, Kun Yan, Luigia Brandimarte, and Günter Blöschl. 2015. “Debates-Perspectives on Socio-Hydrology: Capturing Feedbacks between Physical and Social Processes: A Socio-Hydrological Approach to Explore Flood Risk Changes.” *Water Resources Research* 51 (6): 4770–81. https://doi.org/10.1002/2014WR016416.

Dubbelboer, Jan, Igor Nikolic, Katie Jenkins, and Jim Hall. 2017. “An Agent-Based Model of Flood Risk and Insurance.” *Journal of Artificial Societies and Social Simulation* 20 (1). http://jasss.soc.surrey.ac.uk/20/1/6.html.

Epcor. 2018. “Backwater Valve Subsidy Program.” 2018. https://www.epcor.com/products-services/drainage/flooding-flood-prevention/flood-prevention-homeowner-programs/Pages/backwater-valve-subsidy-program.aspx.

Farjad, Babak, Anil Gupta, and Danielle J. Marceau. 2015. “Hydrological Regime Responses to Climate Change for the 2020s and 2050s Periods in the Elbow River Watershed in Southern Alberta, Canada.” In *Environmental Management of River Basin Ecosystems*, edited by Mu. Ramkumar, K Kumaraswamy, and R. Mohanraj, 65–89. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-13425-3_4.

FEMA. 2014. “Homeowner’s Guide to Retrofitting 3rd Edition.” P-312. https://www.fema.gov/media-library/assets/documents/480.

Frechette, Jean-Denis. 2016. “Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements Due to Weather Events.”

Frohlich, Julia. 2018. “Study Update Notice - Bow and Elbow River Hazard Study Update.” http://aep.alberta.ca/water/programs-and-services/flood-hazard-identification-program/river-hazard-studies/documents/BowElbowRiverHazardStudy-Mar16-2018.pdf.

Gerl, Tina, Heidi Kreibich, Guillermo Franco, David Marechal, and Kai Schröter. 2016. “A Review of Flood Loss Models as Basis for Harmonization and Benchmarking.” *PloS One* 11 (7): e0159791.

Ghosh, S. N. 2014. *Flood Control and Drainage Engineering*. CRC Press. http://www.crcnetbase.com/isbn/9781315769660.

Gizaw, Mesgana Seyoum, and Thian Yew Gan. 2016. “Possible Impact of Climate Change on Future Extreme Precipitation of the Oldman, Bow and Red Deer River Basins of Alberta: CLIMATE CHANGE IMPACT ON EXTREME PRECIPITATION OF SOUTHERN ALBERTA.” *International Journal of Climatology* 36 (1): 208–24. https://doi.org/10.1002/joc.4338.

Golder Associates. 2014. “Bow River and Elbow River - Basin-Wide Hydrology Assessment and 2013 Flood Documentation.” 13-1326-0054–2000.

———. 2015. “Bow River and Elbow River - Hydraulic Model and Flood Inundation Mapping Update.” 13-1326–0054.

Gordon, Julien, and Niko Yiannakoulias. 2017. “Review of the Use of Agent-Based Models in the Study of Natural Disasters.” McMaster University.

Grames, Johanna, Alexia Prskawetz, Dieter Grass, Alberto Viglione, and Günter Blöschl. 2016. “Modeling the Interaction between Flooding Events and Economic Growth.” *Ecological Economics* 129 (September): 193–209. https://doi.org/10.1016/j.ecolecon.2016.06.014.

Haer, Toon, W. J. Wouter Botzen, Hans de Moel, and Jeroen C. J. H. Aerts. 2016. “Integrating Household Risk Mitigation Behavior in Flood Risk Analysis: An Agent-Based Model Approach: Integrating Household Risk Mitigation.” *Risk Analysis*, December. https://doi.org/10.1111/risa.12740.

Haer, Toon, W.J. Wouter Botzen, ., and Jeroen C.J.H. Aerts. 2016. “The Effectiveness of Flood Risk Communication Strategies and the Influence of Social Networks—Insights from an Agent-Based Model.” *Environmental Science & Policy* 60 (June): 44–52.

Haimes, Yacov Y. 2009. *Risk Modeling, Assessment, and Management*. 3rd ed. Wiley Series in Systems Engineering and Management. Hoboken, NJ: John Wiley & Sons.

Hall, Jim W., Paul B. Sayers, ., and Richard J. Dawson. 2005. “National-Scale Assessment of Current and Future Flood Risk in England and Wales.” *Natural Hazards* 36 (1–2): 147–64. https://doi.org/10.1007/s11069-004-4546-7.

Harrison, Kathryn. 1996. *Passing the Buck: Federalism and Canadian Environmental Policy*. UBC Press.

Harvest Digital Planning. 2018. “Sunnyside Storm Lift Stations 1 & 2.” Engage. 2018. https://engage.calgary.ca/SunnysideLS.

Highfield, Wesley E., and Samuel D. Brody. 2013. “Evaluating the Effectiveness of Local Mitigation Activities in Reducing Flood Losses.” *Natural Hazards Review* 14 (4): 229–36. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000114.

IBI Group. 2015. “Benefit/Cost Analysis of Flood Mitigation Projects for the City of Calgary: Springbank Off-Stream Flood Storage.”

IBI Group, and Golder Associates. 2015. “Provincial Flood Damage Assessment Study.” Government of Alberta. http://www.alberta.ca/albertacode/images/pfdas-alberta-main.pdf.

———. 2017. “Flood Mitigation Options Assessment.” 38737. Calgary.

Ipsos. 2016. “2016 Flood Mitigation Research - Key Findings Report.”

Jongman, B, H Kreibich, H Apel, JI Barredo, PD Bates, L Feyen, A Gericke, J Neal, JCJH Aerts, and PJ Ward. 2012. “Comparative Flood Damage Model Assessment: Towards a European Approach.” *Natural Hazards and Earth System Sciences* 12 (12): 3733–3752.

Jonkman, S.N., M. Bočkarjova, M. Kok, and P. Bernardini. 2008. “Integrated Hydrodynamic and Economic Modelling of Flood Damage in the Netherlands.” *Ecological Economics* 66 (1): 77–90. https://doi.org/10.1016/j.ecolecon.2007.12.022.

Kamerman, Karel. 2018. “Basement Flooding Survey,” November 19, 2018. https://mail.google.com/mail/u/3/#inbox/FMfcgxvzLhhSXZSsHDHfmgdFCsfDjKDw.

Koning, Koen de, Tatiana Filatova, ., and Okmyung Bin. 2017. “Bridging the Gap Between Revealed and Stated Preferences in Flood-Prone Housing Markets.” *Ecological Economics* 136 (June): 1–13. https://doi.org/10.1016/j.ecolecon.2017.01.022.

KPMG. 2012. “Lesser Slave Lake Regional Urban Interface Wildfire – Lessons Learned.”

Kreibich, Heidi, Philip Bubeck, Mathijs Van Vliet, and Hans De Moel. 2015. “A Review of Damage-Reducing Measures to Manage Fluvial Flood Risks in a Changing Climate.” *Mitigation and Adaptation Strategies for Global Change* 20 (6): 967–89. https://doi.org/10.1007/s11027-014-9629-5.

Kreibich, Heidi, and Annegret H. Thieken. 2009. “Coping with Floods in the City of Dresden, Germany.” *Natural Hazards* 51 (3): 423–36. https://doi.org/10.1007/s11069-007-9200-8.

Kreibich, Heidi, Annegret H. Thieken, Th Petrow, Meike Müller, and Bruno Merz. 2005. “Flood Loss Reduction of Private Households Due to Building Precautionary Measures–Lessons Learned from the Elbe Flood in August 2002.” *Natural Hazards and Earth System Sciences* 5 (1): 117–126.

Kreutzwiser, Reid, Ian Woodley, ., and Dan Shrubsole. 1994. “Perceptions of Flood Hazard And Floodplain Development Regulations In Glen Williams, Ontario.” *Canadian Water Resources Journal* 19 (2): 115–24. https://doi.org/10.4296/cwrj1902115.

Kundzewicz, Zbigniew W., Shinjiro Kanae, Sonia I. Seneviratne, John Handmer, Neville Nicholls, Pascal Peduzzi, Reinhard Mechler, et al. 2014. “Flood Risk and Climate Change: Global and Regional Perspectives.” *Hydrological Sciences Journal* 59 (1): 1–28. https://doi.org/10.1080/02626667.2013.857411.

Lamond, Jessica, Carly Rose, Namrata Bhattacharya-Mis, and Rotimi Joseph. 2018. “Evidence Review for Property Flood Resilience Phase 2 Report.” London: Flood Re. https://www.floodre.co.uk/wp-content/uploads/UWE-report_Evidence-review-for-PFR_Phase-2-report.pdf.

Lonnquest, John, Bert Toussaint, Joe Manous, and others, eds. 2014. *Two Centuries of Experience in Water Resources Management*. Institute for Water Resources, U.S. Army Corps of Engineers.

Löwe, Roland, Christian Urich, Nina Sto. Domingo, Ole Mark, Ana Deletic, and Karsten Arnbjerg-Nielsen. 2017. “Assessment of Urban Pluvial Flood Risk and Efficiency of Adaptation Options through Simulations – A New Generation of Urban Planning Tools.” *Journal of Hydrology* 550 (July): 355–67. https://doi.org/10.1016/j.jhydrol.2017.05.009.

MacDonald, A. M., D. J. Lapworth, A. G. Hughes, C. A. Auton, L. Maurice, A. Finlayson, and D. C. Gooddy. 2014. “Groundwater, Flooding and Hydrological Functioning in the Findhorn Floodplain, Scotland.” *Hydrology Research* 45 (6): 755–73. https://doi.org/10.2166/nh.2014.185.

Mainline. 2013. “Fullport Backwater Valve.” Mainline Backflow Products. 2013. http://backwatervalve.com/products/fullport-backwater-valve.html.

Merz, B, F Elmer, ., and AH Thieken. 2009. “Significance of" High Probability/Low Damage" versus" Low Probability/High Damage" Flood Events.” *Natural Hazards and Earth System Sciences* 9 (3): 1033–1046.

Merz, B., H. Kreibich, ., and U. Lall. 2013. “Multi-Variate Flood Damage Assessment: A Tree-Based Data-Mining Approach.” *Natural Hazards and Earth System Sciences* 13 (1): 53–64. https://doi.org/10.5194/nhess-13-53-2013.

Merz, B., H. Kreibich, R. Schwarze, and A. Thieken. 2010. “Review Article ‘Assessment of Economic Flood Damage.’” *Natural Hazards and Earth System Sciences* 10 (8): 1697–1724. https://doi.org/10.5194/nhess-10-1697-2010.

Merz, B., S. Vorogushyn, U. Lall, A. Viglione, and G. Blöschl. 2015. “Charting Unknown Waters-On the Role of Surprise in Flood Risk Assessment and Management: CHARTING UNKNOWN WATERS.” *Water Resources Research* 51 (8): 6399–6416. https://doi.org/10.1002/2015WR017464.

Messner, Frank. 2007. “FLOODSite: Evaluating Flood Damages: Guidance and Recommendations on Principles and Methods.” T09-06–01. Helmholz Unweltforschungszentrum (UFZ). http://repository.tudelft.nl/view/hydro/uuid:5602db10-274c-40da-953f-34475ded1755/.

Meyer, V., N. Becker, V. Markantonis, R. Schwarze, J. C. J. M. van den Bergh, L. M. Bouwer, P. Bubeck, et al. 2013. “Review Article: Assessing the Costs of Natural Hazards – State of the Art and Knowledge Gaps.” *Natural Hazards and Earth System Sciences* 13 (5): 1351–73. https://doi.org/10.5194/nhess-13-1351-2013.

Minister of Municipal Affairs. 2013. *Bill 27: Flood Recovery and Reconstruction Act*.

Minnery, John. 2013. “Planning and Retrofitting for floods: Insights from Australia.” In *Living with Flood Risk*, 10. Planning Theory & Practice. http://dx.doi.org/10.1080/14649357.2012.761904.

Montz, Burrell E, Graham A Tobin, ., and Ronald R Hagelman. 2017. *Natural Hazards: Explanation and Integration*. Guilford Publications.

Morrison, Alasdair, Bram F. Noble, ., and Cherie J. Westbrook. 2018. “Flood Risk Management in the Canadian Prairie Provinces: Defaulting towards Flood Resistance and Recovery versus Resilience.” *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques*, February, 1–14. https://doi.org/10.1080/07011784.2018.1428501.

Moudrak, NATALIA, and BLAIR Feltmate. 2017. “Preventing Disaster Before It Strikes: Developing a Canadian Standard for Flood-Resilient Residential Communities.” http://www.intactcentreclimateadaptation.ca/wp-content/uploads/2017/09/Preventing-Disaster-Before-It-Strikes.pdf.

Nistor, Ioan, Dan Palermo, Younes Nouri, Tad Murty, and Murat Saatcioglu. 2009. “Tsunami-Induced Forces on Structures.” *Handbook of Coastal and Ocean Engineering*, 261–286.

O’Connell, P. E., and G. O’Donnell. 2014. “Towards Modelling Flood Protection Investment as a Coupled Human and Natural System.” *Hydrology and Earth System Sciences* 18 (1): 155–71. https://doi.org/10.5194/hess-18-155-2014.

Peters, D.L., D. Caissie, W.A. Monk, S.B. Rood, and A. St-Hilaire. 2016. “An Ecological Perspective on Floods in Canada.” *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques* 41 (1–2): 288–306. https://doi.org/10.1080/07011784.2015.1070694.

picswe.com. 2018. “Dugout Cellar.” 2018. https://www.picswe.com/pics/dugout-cellar-1a.html.

Pomeroy, John W., Ronald E. Stewart, Paul H. Whitfield, and others. 2016. “The 2013 Flood Event in the South Saskatchewan and Elk River Basins: Causes, Assessment and Damages.” *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques* 41 (1–2): 105–17.

Poussin, Jennifer K., W.J. Wouter Botzen, ., and Jeroen C.J.H. Aerts. 2015. “Effectiveness of Flood Damage Mitigation Measures: Empirical Evidence from French Flood Disasters.” *Global Environmental Change* 31 (March): 74–84. https://doi.org/10.1016/j.gloenvcha.2014.12.007.

Province of Alberta. 2017. *Municipal Government Act*. *M-26*.

Public Safety Canada. 2017. "Canadian Disaster Database (CDD)." Public Safety Canada. 2017. http://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-eng.aspx.

Rambaldi, Alicia N., Cameron S. Fletcher, Kerry Collins, and Ryan R.J. McAllister. 2013. "Housing Shadow Prices in an Inundation-Prone Suburb." *Urban Studies* 50 (9): 1889–1905. https://doi.org/10.1177/0042098012465904.

Renzetti, Steven, and Diane P. Dupont, eds. 2017. *Water Policy and Governance in Canada*. Vol. 17. Global Issues in Water Policy. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-42806-2.

Roos, Ir W. 2003. "Damage to Buildings." Delft Cluster.

Rufat, Samuel, Eric Tate, Christopher G. Burton, and Abu Sayeed Maroof. 2015. "Social Vulnerability to Floods: Review of Case Studies and Implications for Measurement." *International Journal of Disaster Risk Reduction* 14 (December): 470–86. https://doi.org/10.1016/j.ijdrr.2015.09.013.

Sandalack, Beverly Ann, and Andrei Nicolai. 2006. *The Calgary Project: Urban Form/Urban Life*. Calgary: University of Calgary Press.

Sandink, Dan. 2009. "Handbook for Reducing Basement Flooding." ICLR. https://www.iclr.org/images/Basement_Flood_Handbook_-_ICLR_-_2009.pdf.

Sayers, Paul B., ed. 2012. *Flood Risk: Planning, Design and Management of Flood Defence Infrastructure*. London: ICE Publishing.

Sayers, Paul B., Gerald E. Galloway, ., and Jim W. Hall. 2012. "Robust Decision-Making under Uncertainty – towards Adaptive and Resilient Flood Risk Management Infrastructure." In *Flood Risk*.

Schröter, Kai, Heidi Kreibich, Kristin Vogel, Carsten Riggelsen, Frank Scherbaum, and Bruno Merz. 2014. "How Useful Are Complex Flood Damage Models?" *Water Resources Research* 50 (4): 3378–95. https://doi.org/10.1002/2013WR014396.

Shrubsole, Dan. 2013. "A History of Flood Management Strategies in Canada Revisited." In *Climate Change and Flood Risk Management: Adaptation and Extreme Events at the Local Level*, 95.

Shrubsole, Dan, Milford Green, ., and John Scherer. 1997. "The Actual and Perceived Effects Of Floodplain Land-Use Regulations On Residential Property Values In London, Ontario." *The Canadian Geographer/Le Géographe Canadien* 41 (2): 166–178.

Simonovic, Slobodan. 2013. *Floods in a Changing Climate: Risk Management*. Cambridge University Press.

Smith, DI. 1994. "Flood Damage Estimation- A Review of Urban Stage-Damage Curves and Loss Functions." *Water S. A.* 20 (3): 231–238.

Smith, Nicky, Charlotte Brown, and Wendy Saunders. 2016. "Disaster Risk Management Decision-Making: Review."

Southwick, Reid. 2014. "Neighbours Miss Caring Woman." *Calgary Herald*, June 14, 2014. http://www.calgaryherald.com/Neighbours+miss+caring+woman/9937884/story.html.

Statistics Canada. 2017. "Consumer Price Index, Historical Summary (1916 to 1936)." January 20, 2017. http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/econ46e-eng.htm.

Stevens, Mark R., and Steve Hanschka. 2013. "Multilevel Governance of Flood Hazards: Municipal Flood Bylaws in British Columbia, Canada." *Natural Hazards Review* 15 (1): 74–87.

Teufel, Bernardo, G. T. Diro, K. Whan, S. M. Milrad, D. I. Jeong, A. Ganji, O. Huziy, et al. 2016. "Investigation of the 2013 Alberta Flood from Weather and Climate Perspectives." *Climate Dynamics*, June. https://doi.org/10.1007/s00382-016-3239-8.

Thieken, Annegret H., Holger Cammerer, Christian Dobler, Johannes Lammel, and Fritz Schöberl. 2016. "Estimating Changes in Flood Risks and Benefits of Non-Structural Adaptation Strategies - a Case Study from Tyrol, Austria." *Mitigation and Adaptation Strategies for Global Change* 21 (3): 343–76. https://doi.org/10.1007/s11027-014-9602-3.

Thistlethwaite, Jason, and Daniel Henstra. 2017. “Municipal Flood Risk Sharing in Canada: A Policy Instrument Analysis.” *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques* 42 (4): 349–63. https://doi.org/10.1080/07011784.2017.1364144.

Thistlethwaite, Jason, Daniel Henstra, Craig Brown, and Daniel Scott. 2018. “How Flood Experience and Risk Perception Influences Protective Actions and Behaviours among Canadian Homeowners.” *Environmental Management* 61 (2): 197–208. https://doi.org/10.1007/s00267-017-0969-2.

UNDESA. 2015. *World Urbanization Prospects: The 2014 Revision*. New York: United Nations Department of Economics and Social Affairs, Population Division.

UNISDR, May. 2009. “UNISDR Terminology for Disaster Risk Reduction.”

Urban Futures. 2012. “A Context for Change Management in the Calgary Regional Partnership Area.” Calgary Regional Partnership.

Valeo, C, Z Xiang, FJ-C Bouchart, P Yeung, and MC Ryan. 2007. “Climate Change Impacts in the Elbow River Watershed.” *Canadian Water Resources Journal* 32 (4): 285–302.

White, Gilbert F. 1945. *Human Adjustment to Floods*.

White, Iain, and Graham Haughton. 2017. “Risky Times: Hazard Management and the Tyranny of the Present.” *International Journal of Disaster Risk Reduction* 22 (June): 412–19. https://doi.org/10.1016/j.ijdrr.2017.01.018.

Whitfield, Paul H., and John W. Pomeroy. 2016. “Changes to Flood Peaks of a Mountain River: Implications for Analysis of the 2013 Flood in the Upper Bow River, Canada: Changes Affecting Flood Peaks of Upper Bow River.” *Hydrological Processes* 30 (25): 4657–73. https://doi.org/10.1002/hyp.10957.

Winterton, Mark. 2017. “2016 Flooding Event Follow-up Report.” City of Windsor.

Zevenbergen, Chris, Adrian Cashman, Niki Evelpidou, Erik Pasche, Stephen Garvin, and Richard Ashley. 2010. *Urban Flood Management*. CRC Press.

Appendix A: Study Area Plates

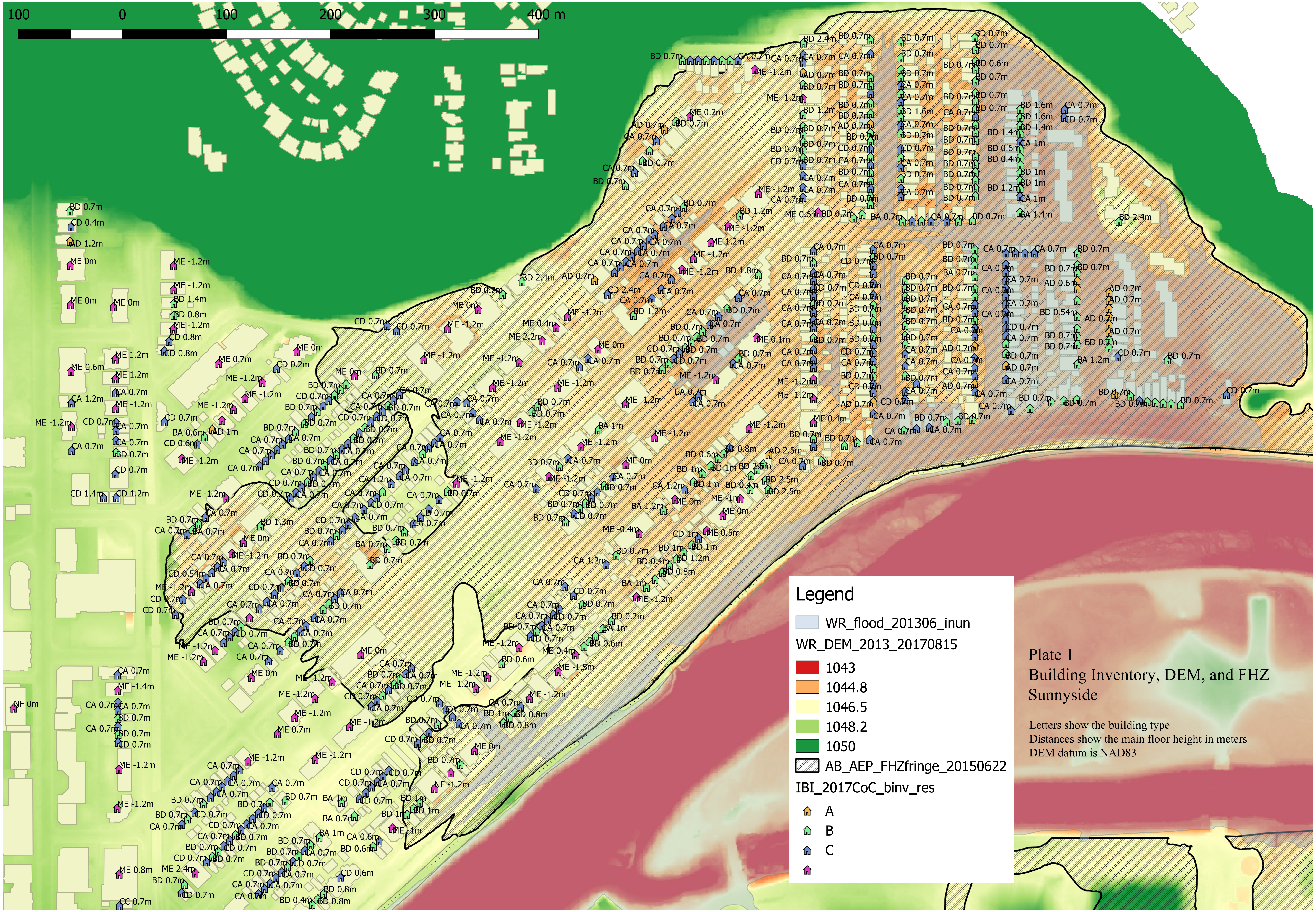

Plate 1
Building Inventory, DEM, and FHZ
Sunnyside

Letters show the building type
Distances show the main floor height in meters
DEM datum is NAD83

Plate 2
Building Inventory, DEM and FHZ
Hillhurst

Letters show the building type
Distances show the main floor height in meters.
DEM datum is NAD83

Appendix B: Flood Hazard Regulations in Calgary

Flood Hazard Regulations in Calgary

B1. Introduction

Flood Hazard Regulations (FHRs) in the City of Calgary (CoC) were adopted in the early 80's to limit the exposure of buildings to flood damage and to avoid the blockage of flood flows. To accomplish this, flood hazard maps are developed through a hazard mapping study based on the model predictions for a design-event (e.g. 100-year flood). In Alberta, these hazard maps divide floodprone areas into the three zones shown in Figure 1-1:

- **Floodway**: "the area within which the entire design flood can be conveyed while meeting certain water elevation rise, water velocity and water depth criteria. Typically, the floodway includes the river channel and some adjacent overbank areas" (Alberta Environment 2011, 15).
- **Flood fringe**: "the land along the edges of the flood hazard area that has relatively shallow water (less than 1 metre deep) with lower velocities (less than 1 m/s)" (Alberta Environment 2011, 15).
- **Overland flow area**: Land inundated by shallow floodwaters not included in the above (City of Calgary 2017). This designation is no longer used by mapping studies in Alberta.

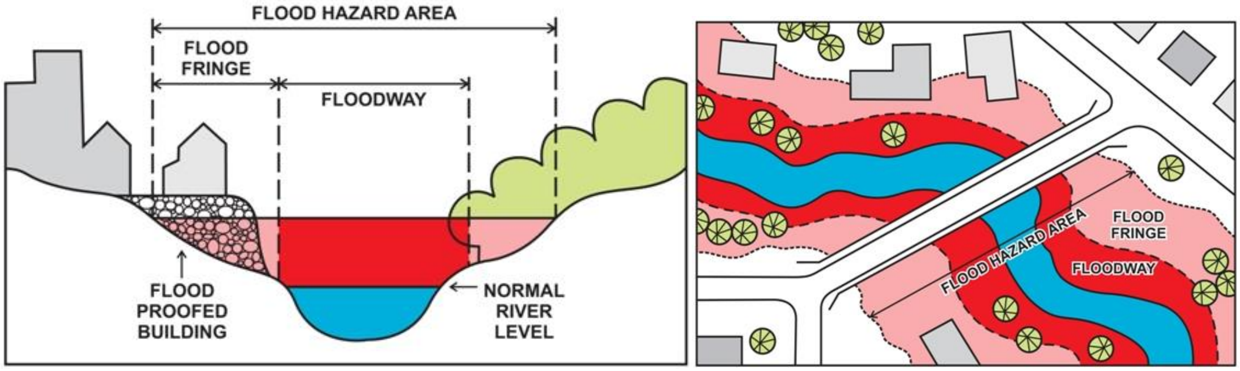

Figure 1-1: Flood Hazard Zone (FHZ) diagram [left] profile and [right] plan-view diagram from Alberta Government (2017).

An example flood hazard map is provided in Figure 1-2.

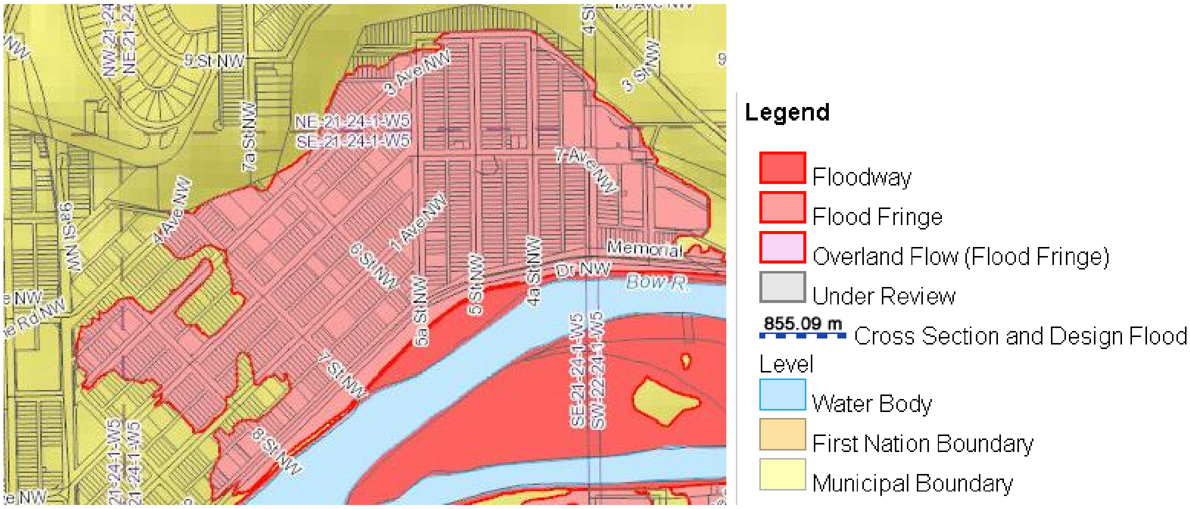

Figure 1-2: Flood hazard map for Sunnyside, AB from http://maps.srd.alberta.ca/floodhazard/.

Young (2011) provides a good summary of the Canada Flood Damage Reduction Program (FDRP), the first flood hazard mapping program in Canada. Starting in 1975, this federal-provincial cost-sharing program was a nation-wide campaign to first identify high-hazard zones along populated rivers — then prohibit federal investment, discourage provincial investment, and encourage local regulation. Following the 1999 federal retreat from the Canada-Alberta Flood Damage Reduction Program, FHZ mapping is now conducted under the Flood Hazard Identification Program (FHIP) in Alberta. From 1999 to 2014, the FHIP has continued to map the floodway and flood fringe using the original 100 ARI regulatory event (Alberta Environment 2011). However, funding has been inconsistent, and by 2014, only 55% of rivers in the province were been mapped (MMM Group 2014) — with 21 of the 63 flood hazard maps older than twenty years[1] (Auditor General of Alberta 2015). In particular, a study is underway to re-map the FHZ in Calgary with results originally expected December 2017 (Frohlich 2018).

B2. History of FHZs in Calgary

FHZs were first mapped for Calgary under the CADFRP in 1983 and adopted into the land-use bylaw shortly thereafter (p.c.). Except for the mapping and inclusion of the Nose Creek FHZ in 2012, no substantial changes to the FHZ have occurred since this original study. Since 1983, the GoA has made three official updates to the flood hazard mapping study documented in Quazi et

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[1] In their review of international practices, MMM Group (2014) suggested maps be updated every 5 (urban) and 20 (rural) years to reflect changes in data collection technology, hydrology, land-use, and river morphology.

al. (1983). These minor updates were each re-issued with no changes to the body of the original report — only the appendices and maps themselves were changed. Table 2-1 summarizes the changes and makes reference to three example flood hazard maps. These figures show that the FHZ in this area has not changed since 1983.

Table 2-1: Summary of updates to the GoA's "City Of Calgary Floodplain Study" (Alberta Government 2016, 1).

Date	**Update**	**Example Map**
1983	Original Quazi et al. (1983)	Figure 2-1
1996	"Additional hydraulic modeling work" but the "report was not updated"	Figure 2-2
2012	Maps were converted to digital	Figure 2-3

Figure 2-1: 1983 FHZ in Sunnyside from Quazi et al. (1983) (colour added for clarity).

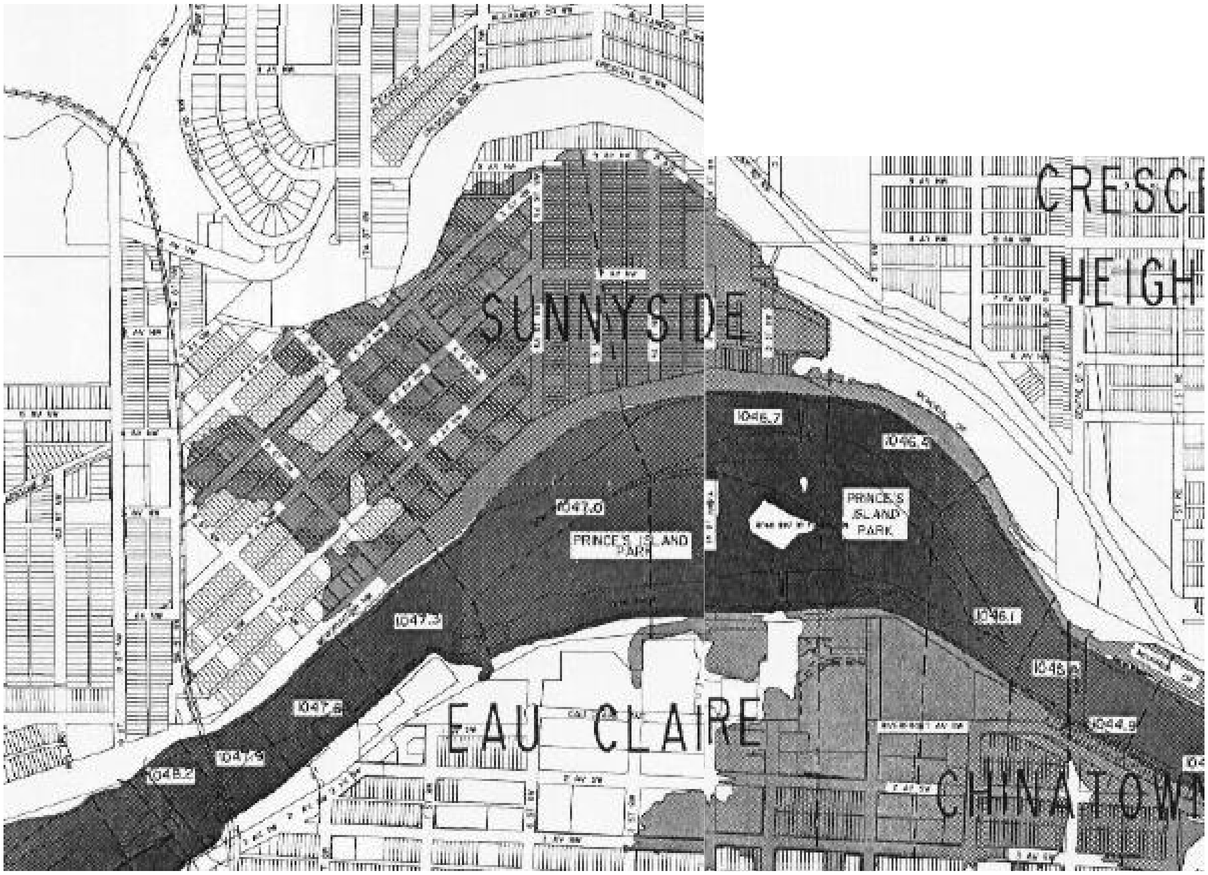


Figure 2-2: 1996 FHZ in Sunnyside from Quazi et al. (1983).

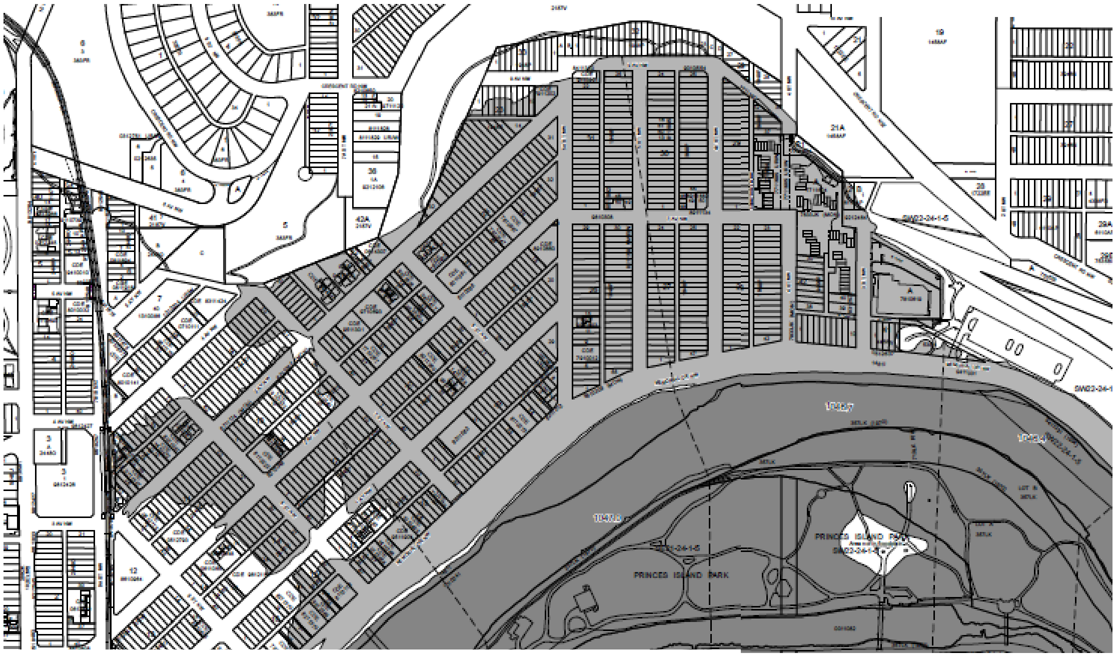


Figure 2-3: 2012 FHZ in Sunnyside from City of Calgary (2017).

B3. History of Rules

At the conclusion of a flood hazard mapping study, the GoA provides the resulting maps to the relevant municipality for use. Under the jurisdiction of the Municipal Government Act (Province of Alberta 2017), municipalities can then incorporate these maps with some development rules into their local land use bylaws (LUB). Table 3-1 summarizes the progression of FHR rules in Calgary's flood fringe since the 2007 LUB.

Table 3-1: Progression of major rules for building design for new construction in Calgary's flood fringe (LUB section 60).

Date	Number	Requirements	Exemptions
1983		???	
2007-07-23	1P2007	(1a) to prevent structural damage by floodwaters; (1b) main floor elevation above BFE; (1c) M&E above BFE. (4) driveways above BFE	redevelopment of, or areas designated for: • Single Detached Dwellings; • Semi-detached Dwellings; • or Duplex Dwellings.
2012-12-03	32P2012		In addition to the above: • Accessory Residential Buildings, • Contextual Semi-detached Dwellings, • Contextual Single Detached Dwellings, • Secondary Suites, • Secondary Suites – Detached Garage, • Secondary Suites – Detached Garden
2014-06-09	11P2014	In addition to the above (excluding #4): (1d) sewer backup valve	Increases in floor area < 10% fence, gate, deck, landing, patio, air conditioning unit, satellite dish, hot tub, above ground private swimming pool, and an Accessory Residential Building.
Bylaws retrieved on 2018-11-15 from http://publicaccess.calgary.ca			

B4. Current FHRs

The current FHRs for Calgary are described in the LUB *Part 3 - Division 3: Floodway, Flood Fringe and Overland Flow* (City of Calgary 2017). This section contains regulations 55-61 which are summarized in Table 4-1. The legacy division of FHZs between 'overland' and 'flood fringe' has been retained in these rules, however the regulations governing each are now effectively identical.

Table 4-1: CoC LUB Division 3 summary.

Section #	Name	Applies to	Requirements/Regulations	Exemptions
55	Floodway, Flood Fringe and Overland Flow	Parcels within the FHZ		
56	Floodway Regulations	Parcels within the Floodway	Limited land use	Designated prior to 1985 with a structure
57	New Buildings and Alterations	Parcels within the Floodway	No new buildings. No increase in footprint. No storage outside the building.	
58	Alterations to the Floodway and Riverbanks	Area within the Floodway	Only the city can construct	
59	Fringe and Overland Flow Area Regulations	Flood fringe and Overland flow areas	Only storage of easily movable goods. Setbacks from floodway and riverbanks.	
60	Building Design in the Flood Fringe	Flood fringe	Building design: (1a) to prevent structural damage by floodwaters; (1b) main floor elevation above BFE; (1c) M&E above BFE. (1d) sewer backup valve	Increases in floor area < 10% fence, gate, deck, landing, patio, air conditioning unit, satellite dish, hot tub, above ground private swimming pool, and an Accessory Residential Building.
61	Building Design in the Overland Flow Area	Overland flow area	Building design: Same as above but the BFE is defined as the 0.3 m above the abutting street.	Same as above
Bylaws retrieved on 2018-11-15 from http://publicaccess.calgary.ca				

B5. Standard Comments

In addition to the FHRs described above, which are mostly enforced by the CoC's Planning Division, many floodprone permit applications are also passed to the CoC's River Engineering team for comment prior to approval. In this way, the CoC can provide recommendations to reduce the vulnerability of the development or to deny the permit altogether based on the level of flood risk. Generally, these comments apply a higher standard than the FHRs; however, the process is less formal and largely at the discretion of the reviewer.

Bibliography

Alberta Environment. 2011. “Flood Hazard Identification Program Guidelines.”

Alberta Government. 2016. “Calgary – Bow and Elbow Rivers – Flood Hazard Study – Summary.” http://aep.alberta.ca/water/programs-and-services/flood-hazard-identification-program/flood-hazard-studies/documents/Calgary-Bow.pdf.

———. 2017. “Flood Hazard Identification Program.” 2017. http://aep.alberta.ca/water/programs-and-services/flood-hazard-identification-program/.

Auditor General of Alberta. 2015. “Report of the Auditor General of Alberta MARCH 2015.”

City of Calgary. 2017. *Land Use Bylaw 1P2007*.

Frohlich, Julia. 2018. “Study Update Notice - Bow and Elbow River Hazard Study Update.” http://aep.alberta.ca/water/programs-and-services/flood-hazard-identification-program/river-hazard-studies/documents/BowElbowRiverHazardStudy-Mar16-2018.pdf.

MMM Group. 2014. “National Floodplain Mapping Assessment - Final Report.”

Province of Alberta. 2017. *Municipal Government Act*. *M-26*.

Quazi, M. E., S. A. Lowe, F.E. Hicks, and A. Deboer. 1983. “City Of Calgary Floodplain Study.”

Young, Dorian Maurice. 2011. “FLOOD INSURANCE FOR CANADA?” American Public University System.

Appendix C: Study Survey Questionnaires and Consent Form

INFORMATION LETTER and CONSENT FORM

Survey Title: Homeowner Flood Response and Recovery

Research Investigator:	*Supervisor:*
Seth Bryant, P.Eng., CPESC	Evan Davies, Ph.D., P.Eng.
Graduate Research Assistant	Associate Professor,
University of Alberta	University of Alberta
sbryant@ualberta.ca	evan.davies@ualberta.ca
780 709 3061	780 492 5134

Background

- You have been selected to participate in this survey based on your relationship to flood risk in Alberta.
- This survey is funded by the Natural Sciences and Engineering Research Council of Canada (NSERC). Your responses may support the graduate MSc thesis of Seth Bryant and other publications.

Purpose

- The purpose of this project is to better understand how homeowners respond to, and recover from, floods. Information gathered in this survey will help calibrate a flood management decision tool under development by the study team.

Survey Procedures

- We may collect your responses by email, phone, in electronic form, or in-person.
- Initial participation should take between 5 and 10 minutes. We may contact you for a follow-up.

Benefits

- You will not directly benefit from participation in this survey.
- The results of this research may benefit flood management policies in Alberta.

Risk

- Questions may trigger traumatic memories. If you become uncomfortable at any time, the survey will be terminated.

Voluntary Participation

- You are under no obligation to participate in this survey.
- You are not obliged to answer any specific questions even if participating in the survey.
- You can withdraw from the survey up to 1 week following the close of the survey. At that time, if requested, your responses will be destroyed.

Confidentiality & Anonymity

- Individual responses will be kept confidential and anonymous. For data analysis, identifying information may be aggregated and linked with census information to discern behavioral trends correlated with demographic indicators.
- Your responses will be kept on password protected systems that only the research team can access.
- We may use the data we get from this survey in future research. If we do this it will have to be approved by a Research Ethics Board (as per the TCPS2).

Further Information

- The plan for this survey has been reviewed for its adherence to ethical guidelines by the Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

Consent Statement (for non-electronic participation)

I have read this form and the research survey has been explained to me. I have been given the opportunity to ask questions and my questions have been answered. If I have additional questions, I have been told whom to contact. I agree to participate in the research survey described above. I will receive a copy of this consent form after I sign it.

____ ____________________

Participant's Name (printed) and Signature Date

____ ____________________

Name (printed) and Signature of Person Obtaining Consent Date

FloodVicSurvey - Consent Form (RevD 2017 09 06).docx

A. House Details

A1) E-mail address?

A2) Current physical home address?

A3) Rent or Own?

A4) Date of acquisition or move in?

A5) Approximate construction year?

A6) Major renovation/remodel/repair(s)?

Year	Purpose	Scope	Permit	Footprint change?

B. House Flood Vulnerability

B1) Basement *type*?

Full Basement (typical)	Dugout/ Stepped	Crawlspace	None (slab on grade)	Other	Not Sure

B2) Basement *finish* level?

Unfinished	Partially finished	Fully finished	Other	Not Sure

B3) *Vertical distance* from the floor to the following:

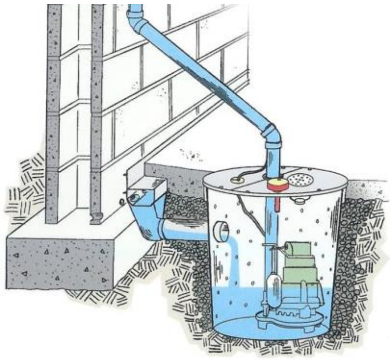
	Ceiling (bottom of floor joist)		Lowest opening (window/door sill, vent, etc.)		Lowest electrical panel		Bottom of furnace	
From Main floor	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)
From Basement floor	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)

B4) Backflow valve inspection?

Not installed	
Annually	
Less than annually	
Never	
Unsure	

B5) Sump pump type?

Not installed/None	
Electric	
Portable (gas/diesel/generator)	
Other	
Unsure	



B6) Sandbags or some other temporary barriers?

B7) Any other floodproofing measures?

B8) Overland flood insurance?

Yes	Working on it	No	Unsure	Not sure

B9) Since living here, when has your home experienced flooding?

	Date	Type	Damage
Not while I've lived here			
June 21st 2013			
Other			
Other			
Other			

C. The 2013 Flood

C1) Type of flooding?

Basement	Overland	None

C2) How did the 2013 flood waters enter your home?

Through the sewer/drain	Through the foundation walls/floor	Windows	Door	Everywhere!	Not Sure	Not flooded

C3) How high did the water rise?

From Main floor	(ft) (m)
From Basement floor	(ft) (m)

C4) In the basement, what was the damage?

	No Damage (minor cleaning)	Mostly Repaired	Mostly Removed/Replaced
Flooring			
Walls			
Furnace			
Water Heater			
Windows			
Electrical			

C5) What items were you able to move out of harms way before the flood?

C6) What happened to the damaged contents?

% Thrown away	% Replaced

C7) What was the total cost of all these replacements?

C8) Including this, what are your total costs (so far)?

C9) Did you apply for the DRP?

Applied and rejected	Amount Received	Unsure

i) Did you abide by the DRP repair/rebuild requirements (STANDATA)?

C10) Did you make an insurance claim?

i) What % of this claim value did you receive?

C11) Following the flood, what floodproofing measures did you undertake/install?

C12) Have you had any problems with mould since the flood?

C13) Was your neighbourhood ordered to evacuate?

i) Approximately how many days were you away from your home?

ii) Next time, would you obey a similar evacuation order?

Living with Rivers

A University of Alberta survey of Calgary homes

https://docs.google.com/forms/d/e/1FAIpQLSfJzM-zwEtF3S_W8znp7Mm-Xh6cCLEJSXMSUlksPzq_pgtk0Q/viewform?usp=sf_link

* Required

INFORMATION and CONSENT

STUDY TITLE: Flood Response and Recovery

RESEARCH INVESTIGATOR:	SUPERVISOR:
Seth Bryant, P.Eng., CPESC	Evan Davies, Ph.D., P.Eng.
Graduate Research Assistant	Associate Professor
University of Alberta	University of Alberta
sbryant@ualberta.ca	evan.davies@ualberta.ca
780 709 3061	780 492 5134

BACKGROUND
-You have been selected to participate in this survey based on your relationship to flood risk in Alberta.
-This survey is funded by the Natural Sciences and Engineering Research Council of Canada (NSERC). Your responses may support the graduate MSc thesis of Seth Bryant and other publications.

PURPOSE
-The purpose of this project is to better understand how homeowners respond to, and recover from, floods. Information gathered in this survey will help calibrate a flood management decision tool under development by the study team.

SURVEY PROCEDURES
-We may collect your responses by email, phone, in electronic form, or in-person.
-Initial participation should take between 5 and 10 minutes. We may contact you for a follow-up.

BENEFITS
-You will not directly benefit from participation in this survey.
-The results of this research may benefit flood management policies in Alberta.

RISKS
-Questions may trigger traumatic memories. If you become uncomfortable at any time, terminate the survey.

VOLUNTARY PARTICIPATION
-You are under no obligation to participate in this survey.
-You are not obliged to answer any specific questions even if participating in the survey.
-You can withdraw from the survey up to 1 week following the close of the survey. At that time, if requested, your responses will be destroyed.

CONFIDENTIALITY & ANONYMITY
-Individual responses will be kept confidential and anonymous. For data analysis, identifying information may be aggregated and linked with census information to discern behavioral trends correlated with demographic indicators.
-Your responses will be kept on password protected systems that only the research team can access.
-We may use data from this survey in future research. If we do this it will have to be approved by a Research Ethics Board (as per the TCPS2).

FURTHER INFORMATION
-The plan for this survey has been reviewed for its adherence to ethical guidelines by the Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

CONSENT STATEMENT
By continuing, you confirm that you have read and understand the above. If you have any questions, please send them to sbryant@ualberta.ca prior to proceeding. By continuing in this survey, you confirm that you agree to participate in the research study described above. After completing this form, you may select "Send me a copy of my responses" to receive a copy of your responses and the above text.

1. *

Check all that apply.

☐ I understand, agree to participate, and wish to continue

Let's Get Started

We know your time is valuable, so we designed this survey to be quick and pleasant.

If you don't have an answer for a particular question, or answering takes more than 1 minute, please answer 'unsure' and move on. Participation typically takes 5-10 minutes.

If you wish to return to a survey page, do not use your browser's back button as this will erase your entries. Instead, use the buttons at the bottom of the survey page.

Space is provided at the end of some sections for you to provide any additional comments if you'd like.

And finally, please feel free to answer honestly and candidly. Neither your name, address, or email will be published or shared with anyone outside the study team (except in rare cases we may request your permission to quote you).

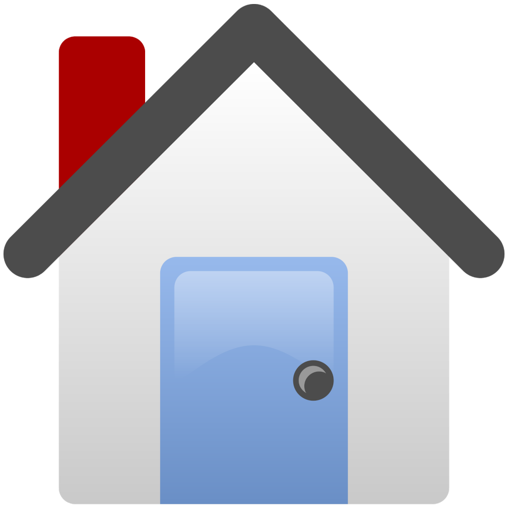
2. **Your email address**

____

3. **Additional comments...**

____
____
____
____
____

Your Current Home



4. **What is your current house/physical address?**

____

5. **What year did you move into this house?**

____

6. **What type of basement does your house have?**

Mark only one oval.

○ Full *After the last question in this section, skip to question 8.*
○ Dugout/Stepped *After the last question in this section, skip to question 8.*
○ Crawlspace *After the last question in this section, skip to question 22.*
○ None (slab on grade) *After the last question in this section, skip to question 22.*
○ N/A (apartment/multi-level) *After the last question in this section, skip to question 22.*
○ Unsure *After the last question in this section, skip to question 22.*
○ Other: ____

7. **Additional comments...**

____
____
____
____
____

Current House Basement

8. **What level of finish does your basement have?**
Mark only one oval.

○ Unfinished (none)
○ Partially finished
○ Fully finished
○ Unsure
○ Other: ______________________________

Basement height

Distance from the basement floor to the underside of the main floor joist

9. ______________________________

10. **Units**
Mark only one oval.

○ m
○ ft

Lowest opening to the outside

Distance from the basement floor to the bottom of the lowest window, door, vent, etc.

11. *Mark only one oval.*

○ No openings

12. ______________________________

13. **Units**
Mark only one oval.

○ m
○ ft

14. **Where is your furnace?**
Mark only one oval.

- ○ Don't have one
- ○ In the basement (on the floor)
- ○ In the basement (elevated)
- ○ On the main floor
- ○ Unsure
- ○ Other: ____________________

15. **Additional comments...**

____
____
____
____
____

Backflow Valve

16. **Backflow valve inspection**
Mark only one oval.

- ○ Not installed (don't have)
- ○ Annualy
- ○ Less than annually
- ○ Never
- ○ Unsure

17. **Additional comments...**

____

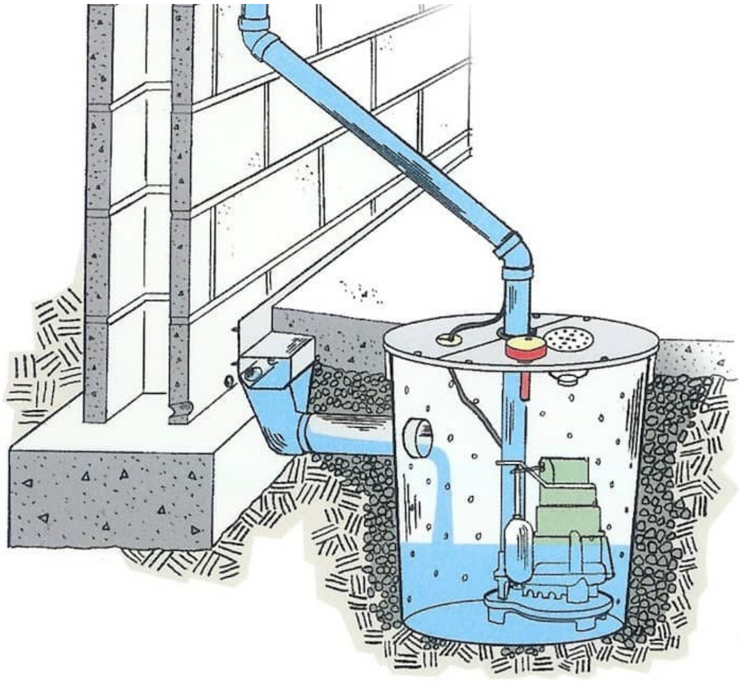
____

____

____

____

Sumps



18. **Do you have a sump?**

Mark only one oval.

- ○ Yes *Skip to question 19.*
- ○ No *Skip to question 22.*
- ○ Unsure *Skip to question 22.*

Sump Pump

19. **How many pumps do you have on the property for this sump?**

Mark only one oval.

- ○ One *Skip to question 20.*
- ○ More than one *Skip to question 20.*
- ○ None *Skip to question 22.*
- ○ Unsure *Skip to question 22.*

Sump Pump Type

20. **Check all that apply**

Check all that apply.

☐ Portable
☐ Discharges to sewer (storm or sanitary)
☐ Discharges to street
☐ Regularly inspected and maintained
☐ Backup generator with fuel
☐ Other: ____________________

21. **Additional comments...**

____
____
____
____
____

Flood Experience

At your current house

22. *Mark only one oval.*

○ No flooding since moving in (phew!)

23. *Check all that apply.*

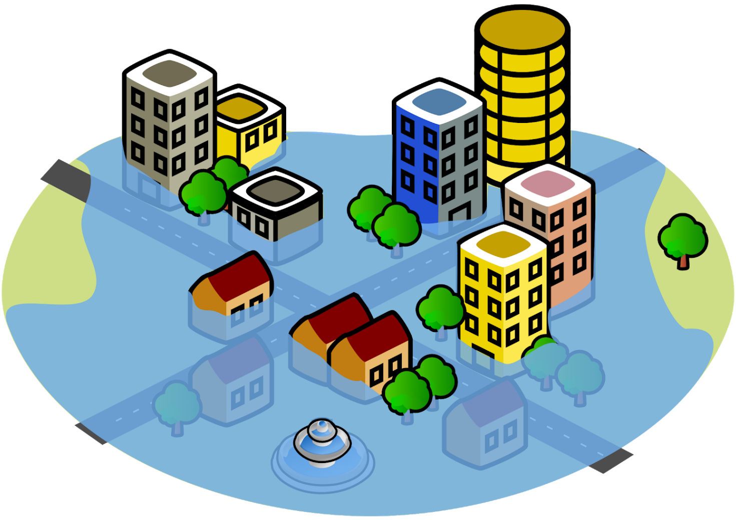
	Basement	Overland	Sewer backup	No damage
June 2013	☐	☐	☐	☐
July 2013	☐	☐	☐	☐
June 2005	☐	☐	☐	☐

24. *Mark only one oval.*

○ Other floods/dates?

Skip to question 26.

Other floods?



25. **Briefly, please tell us about these other floods (year, type, damage, etc.)**

June 2013 Flood

26. **Have you had any problems with mold since June 2013?**

Mark only one oval.

○ Yes
○ No
○ Unsure
○ Other: ____________________

27. **What type of flooding did your home have in June 2013?**

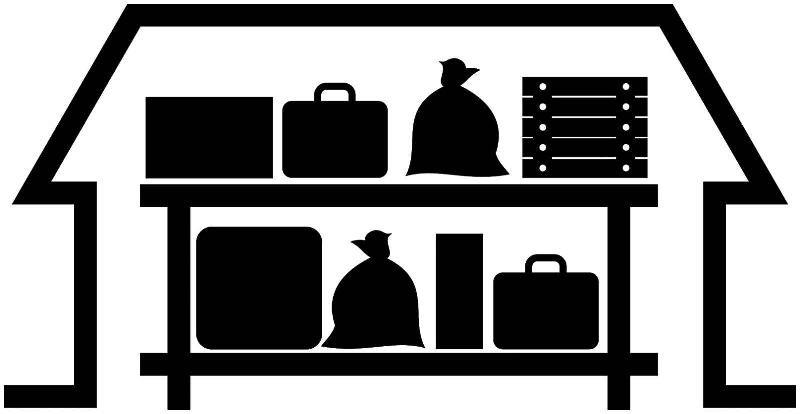
Mark only one oval.

○ Basement only
○ Overland
○ None *After the last question in this section, skip to question 34.*

28. **Additional comments...**

June 2013 Flood

Contents



What happened to the flood affected contents?

movable things like TVs, furniture, and books. Does not include things like carpet, walls, doors, etc.

29. *Mark only one oval.*

○ No contents were flood affected

30. **% thrown away (of wet contents)**

31. **% replaced (of wet contents)**

32. **Total cost for these replacements ($CAD) ?**

33. **Additional comments...**

____

____

____

____

____

June 2013 Evacuation

34. **Were you ordered to evacuate during the flood?**

Mark only one oval.

○ Yes
○ No
○ Unsure
○ Other: ______________________________

35. **If there were another flood, would you obey the evacuation order?**

Mark only one oval.

○ Yes
○ No
○ Only if the water was really high
○ Unsure
○ Other: ______________________________

36. **Additional comments...**

____

____

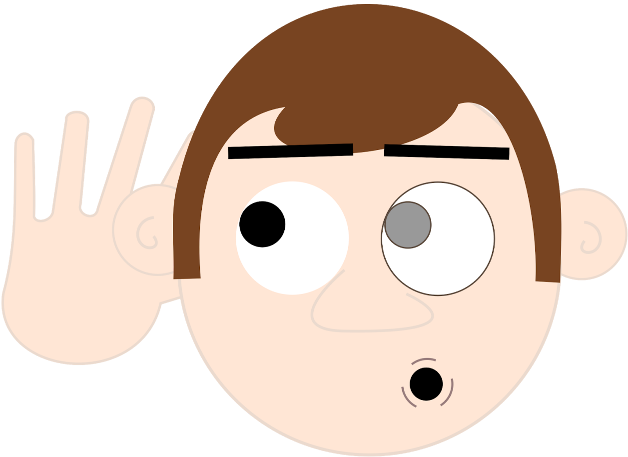
____

____

____

Anything else you'd like to tell us?

Please share any additional thoughts on the 2013 flood, current flood management policy, and/or your view on how to reduce flood risk.



37.

Thank you!

We really appreciate your participation and trust.

If we decide to quote any of your long form responses, we will first contact you to obtain permission.

If you know of anyone else who may be interested in participating in this survey, please forward the link or let us know.

If you have any questions or additional comments, please feel free to contact the research team (sbryant@ualberta.ca).

For more information on flood management in Calgary, see the city's Flooding in Calgary webpage:
http://www.calgary.ca/UEP/Water/Pages/Flood-Info/Flood-Information.aspx

For general information on preparing for floods, Flood Smart Canada provides some good resources:
http://floodsmartcanada.ca/


Thanks!

Appendix D: SOFDA User’s Manual

SOFDA User’s Manual

D1. Introduction

The Stochastic Object-based Flood damage Dynamic Assessment model framework (SOFDA) was developed to simulate flood risk over time using the Alberta Curves and a residential re-development forecast. Framework development was motivated by a desire to quantify the benefits of FHRs and to help incorporate the dynamics of risk into decision-making. This manual provides guidance to a risk analyst seeking to use SOFDA to develop a model that estimates flood risk. Evaluating flood risk is a challenging task that requires experience and knowledge well beyond what is provided in this manual. The reader should be well informed of the flood risk assessment process (Messner 2007), and aware of the pre-curser Rapid Flood Damage Assessment model work that lead to the Alberta Curves (section D1.2).

SOFDA is written in python 2.7. Implementation in python allows the model to leverage a vast array of publicly available modules and promotes readability and reusability (see Attachment A for the list of dependencies and source code). This manual assumes the user is familiar with python 2.7 and has installed the necessary dependencies (section D3).

D1.1. Workflow

A typical workflow for risk assessments executed with SOFDA is presented in Figure 1-1. This manual provides guidance, for a flood risk modeller, to apply SOFDA once all the required inputs are collected, the hazard analysis complete, and the study objectives well established. Post-processing is not addressed.

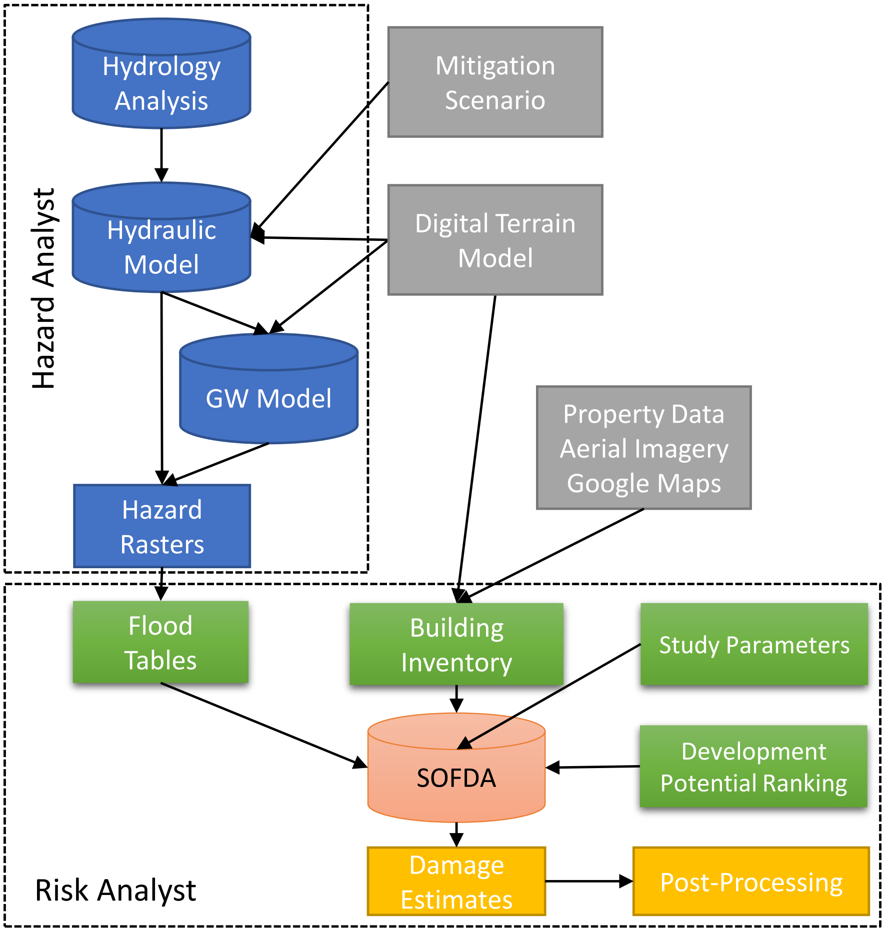


Figure 1-1: Risk assessment workflow for studies implementing SOFDA. Green boxes denote primary inputs to SOFDA.

D1.2. Alberta Curves

The Alberta Curves are a set of eleven residential (Figure 1-4) and 20 commercial loss functions which were developed to predict direct structural (S) and contents (C) building damages from flood depth. These are further divided into main floor (M) and basement (B) damages[1]. Residential categories were developed from expert knowledge of typical Canadian building typology and divide buildings by: 1) size; 2) quality; 3) construction technique; and 4) number of stories. In practice, analysts use government datasets (e.g. property assessment records), aerial imagery, and Google Street View to assign categories to houses. To develop the residential curves, 83 in person surveys were conducted of representative flood-unaffected homes and their contents during 2014

---

[1] Garage damages were also tabulated and reported separately, but combined into both curves (M, B) with the assumption that the garage floor is 2’ below the main floor elevation.

in Calgary and Edmonton. For more information on the Alberta Curves, the reader is referred to IBI Group and Golder Associates (2015).

Table 1-1: Alberta Curve building types in study area adapted from IBI Group and Golder Associates(2015).

Class[b]	**Type**	**Building Type**[a]	**Class Description**	**Type Description**
A	A	AA	Home with living space defined as equal to or between 3,999 and 2,400 ft^2.	1 storey
A	D	AD	Home with living space defined as equal to or between 3,999 and 2,400 ft^2.	2 storeys
B	A	BA	Home with living space defined as equal to or between 2,399 and 1,200 ft^2.	1 storey
B	D	BD	Home with living space defined as equal to or between 2,399 and 1,200 ft^2.	2 storeys
C	A	CA	Home with living space defined equal to or less than 1,199 ft^2.	1 storey
C	D	CD	Home with living space defined equal to or less than 1,199 ft^2.	2 storeys

a) RFDA requires class and type variables from each entry in the building inventory. These are combined to select the appropriate damage curve. SOFDA only requires one variable.

b) See fig XXX for photographs of typical homes.

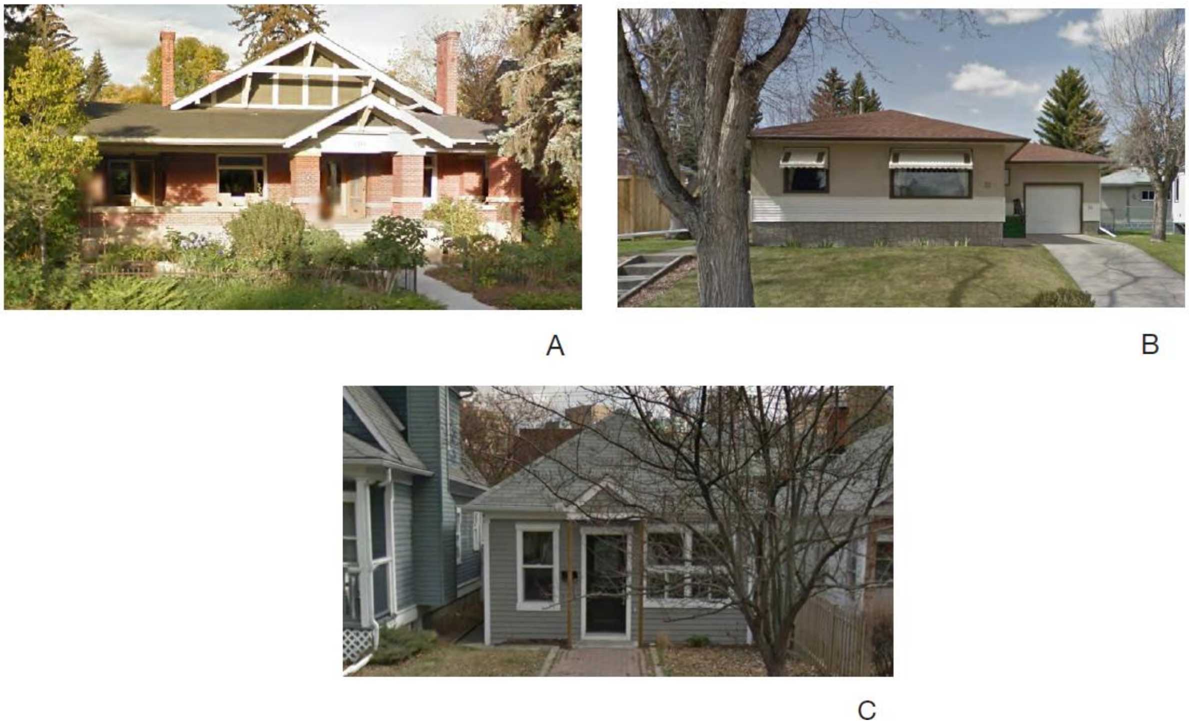
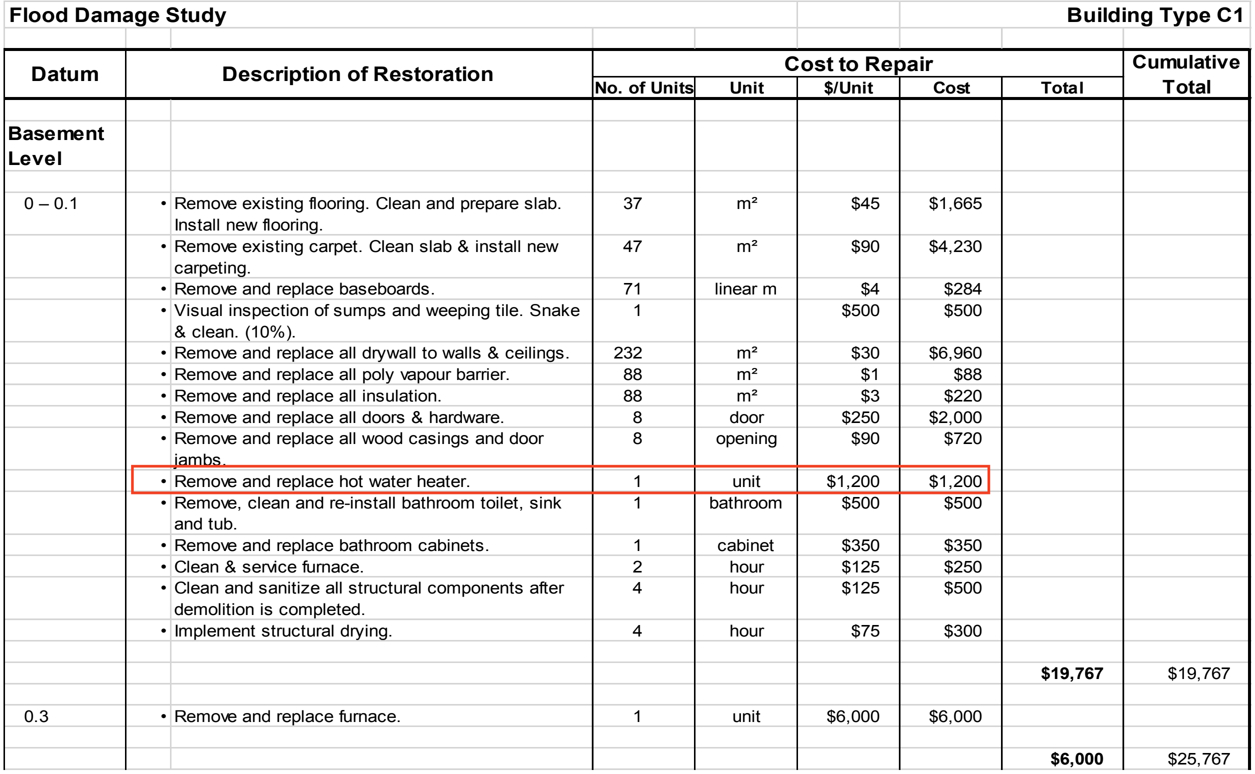


Figure 1-2: Street-view photographs of typical buildings representing three (of eleven) Alberta Curve building classes from IBI Group and Golder Associates (2015).



Flood Damage Study **Building Type C1**

Datum	Description of Restoration	Cost to Repair No. of Units	Unit	$/Unit	Cost	Total	Cumulative Total
Basement Level							
0 – 0.1	• Remove existing flooring. Clean and prepare slab. Install new flooring.	37	m²	$45	$1,665		
	• Remove existing carpet. Clean slab & install new carpeting.	47	m²	$90	$4,230		
	• Remove and replace baseboards.	71	linear m	$4	$284		
	• Visual inspection of sumps and weeping tile. Snake & clean. (10%).	1		$500	$500		
	• Remove and replace all drywall to walls & ceilings.	232	m²	$30	$6,960		
	• Remove and replace all poly vapour barrier.	88	m²	$1	$88		
	• Remove and replace all insulation.	88	m²	$3	$220		
	• Remove and replace all doors & hardware.	8	door	$250	$2,000		
	• Remove and replace all wood casings and door jambs.	8	opening	$90	$720		
	• Remove and replace hot water heater.	1	unit	$1,200	$1,200		
	• Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	$500	$500		
	• Remove and replace bathroom cabinets.	1	cabinet	$350	$350		
	• Clean & service furnace.	2	hour	$125	$250		
	• Clean and sanitize all structural components after demolition is completed.	4	hour	$125	$500		
	• Implement structural drying.	4	hour	$75	$300		
						$19,767	$19,767
0.3	• Remove and replace furnace.	1	unit	$6,000	$6,000		
						$6,000	$25,767

Figure 1-3: Sample structural damage feature table for a 'C' class house from IBI Group and Golder Associates (2015). Red box denotes a single damage feature.

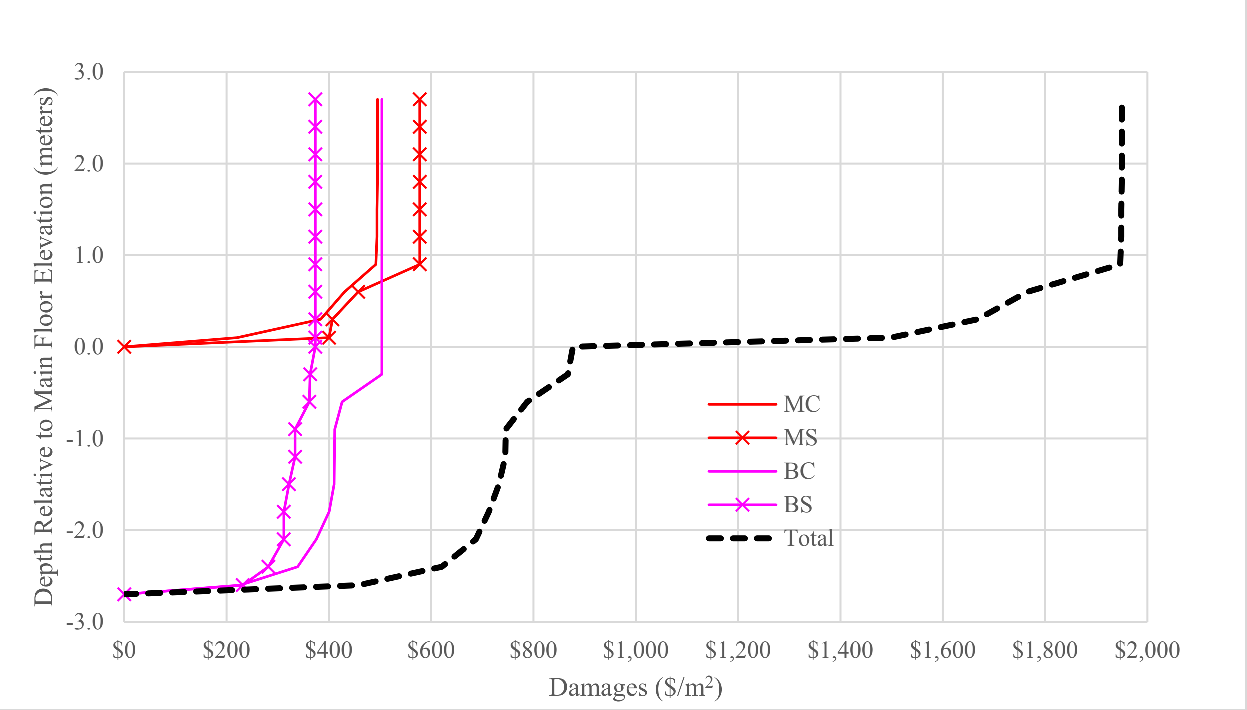


Figure 1-4: RFDA depth-damage curve for a class C house.

The Alberta Curves datafile is provided in Attachment D.

D1.3. SOFDA vs RFDA

The primary advantage of SOFDA over the precursor RFDA is the ability to simulate risk dynamics (e.g. the effect of urban development on flood risk). However, SOFDA still provides some advantage over RFDA when evaluating the static risk using the Alberta Curves (i.e. flood risk in the first timestep):

- enhanced error messaging;
- input error checking;
- faster simulation time;
- expanded and customizable output support (including results figures);
- internal EAD calculation;
- geometric scaling of damage features;
- basement and area-protections exposure reductions (e.g. backflow valve exposure reductions);

D2. SOFDA Description

SOFDA is designed to provide property level, direct-damage, risk estimates from a flood WSL table. To accomplish this, the study area is discretized into assets categorized by loss function type (Figure 2-1). While SOFDA can support any depth-damage loss function (in the correct format), the framework was designed for use with the *Alberta Curves* — a set of 11 residential and 20 commercial engineered depth-damage loss functions (section D1.2). Using the Alberta Curves, SOFDA can provide static risk assessments for the study area with the following major assumptions:

- direct financial damage is the sole contributor of consequence;
- the loss functions accurately predict the total damage to each asset from depth at its discrete anchor point;
- the flood WSL raster accurately predicts the WSL at the corresponding frequency at all locations;
- the range of floods considered accurately represents the set of all flood hazards possible in the study area;

Figure 2-1: Example of spatially represented building inventory showing building type and main floor height. Yellow geometry shows the measured building foot prints, red/blue shading shows a WSL raster shaded by depth above the DEM.

The primary advantage of SOFDA (over the pre-cursor RFDA) is the adoption of a dynamic-view of risk, or the ability to simulate the accumulation of flood risk over time. To accomplish this, SOFDA was designed as a flexible framework, within which the user can apply a wide range of changes at any point in the simulation to nearly all model objects. For example, a user can simulate the stochastic redevelopment of 10% (of assets every year) and/or an increase in flood depths every third year. Such flexibility allows for study objectives to quantify the accumulation of risk as a result of urban re-development or infilling. Such a study may be useful to explore the balance of risk increasing mechanisms, like the infilling with larger houses, against risk reducing mechanisms, like flood hazard regulations (FHRs). However, the current version of SOFDA does not support asset joining or splitting, limiting such a study to the evaluation of single-structure infills.

D2.1. Modes

SOFDA can generate flood risk simulations in the following modes:

- *Stochastic:* The default mode for SOFDA, this leverages those Dynps the user provided stochastic parameters to stochastically simulate an ensemble of predictions for flood risk. The number of simulations SOFDA executes is controlled by the 'run_cnt' parameter (Table 4-3).
- *Deterministic*: Useful for testing and debugging, this mode only leverages the mean values for each Dynp to deterministically calculate one prediction for flood risk. This mode is controlled via the 'glbl_stoch_f' parameter (Table 4-3).
- *Sensitivity analysis (SA)*: Useful for identifying the sensitivity of model predications to specific parameters, this mode executes a set of deterministic simulations based on the user provided extremes for each Dynp. This mode is controlled via the 'sensi_f' flag (Table 4-3).
- *Debugging*: Useful for debugging model crashes, this mode can be layered on top of any of the above, does not influence the results, but includes more routines for error checking and log file outputting. This mode significantly reduces performance and is controlled via the 'dbg_fld_cnt'

The remainder of this section focuses on executing SOFDA in stochastic mode (glbl_stoch_f=FALSE); except for section 0 which discusses the SA mode.

D2.2. Hierarchy

To reflect the view that a flood damage prediction should be calculated for each asset in the study area, before summing to obtain the area estimate, SOFDA spawns digital objects for each model feature, placing them in a logical hierarchy. This leverages python's object-oriented programing style (where each SOFDA object is coded as a 'base class'). Figure 2-2 provides a simplified diagram of this hierarchy, and the required inputs and how they relate to objects.

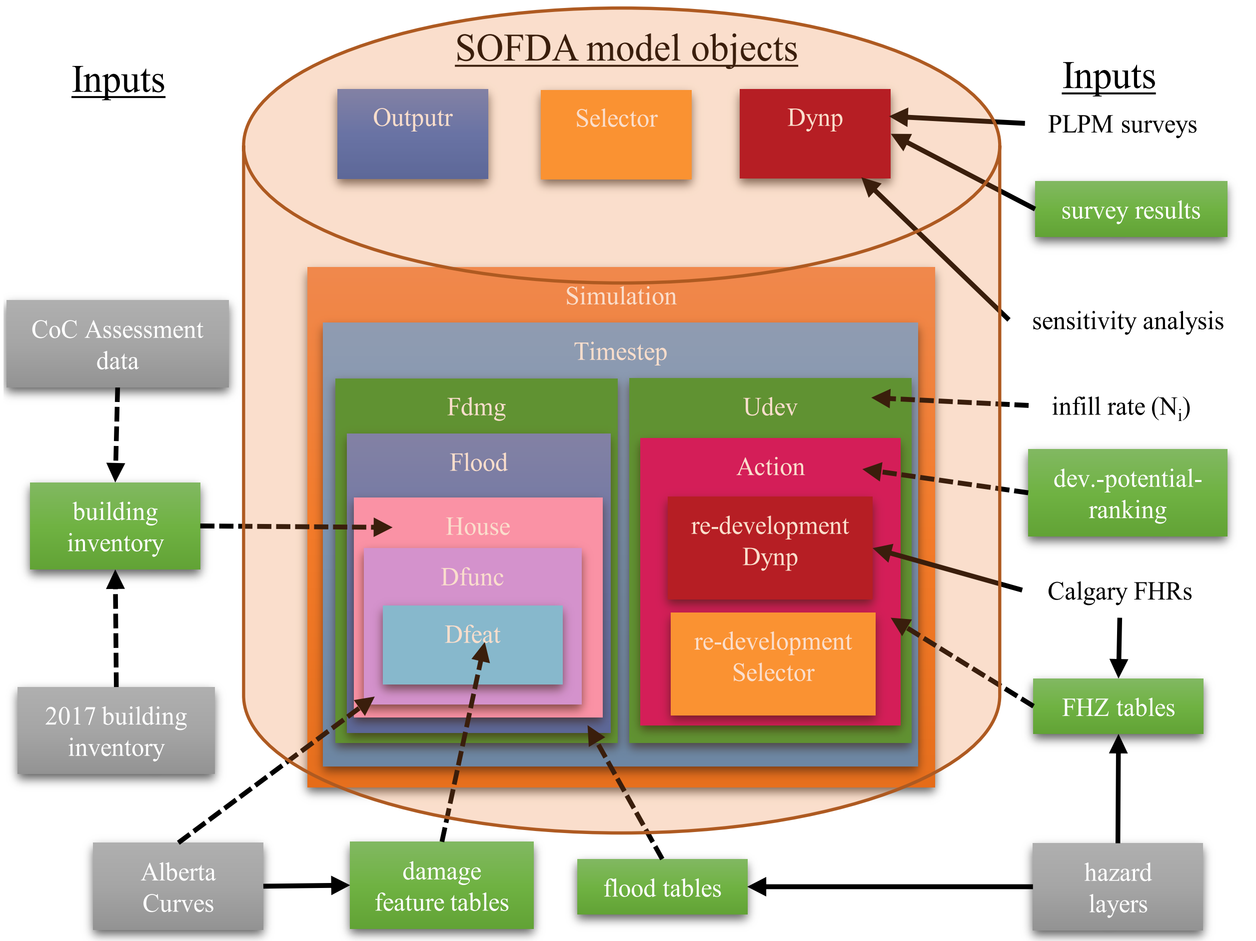


Figure 2-2: SOFDA object simplified hierarchy and input requirements conceptual diagram. Solid arrows denote 'leads' or 'contributes to' while dashed arrows represent information flow. Inputs drawn with boxes represent data sets, with gray boxes sourced from third parties while green boxes were generated by this thesis work. Some arrows and inputs omitted for clarity.

As shown, SOFDA is organized into 13 modules and objects with the following hierarchy:

- *Scenario module*: The highest level contains parameters broadcast down to all other sub-modules. These parameters are generally used to define scenarios (e.g. development rates, # of simulations).
  - *Simulation object*: As a stochastic model, numerous simulation objects are spawned by a scenario (using the same scenario parameters) to randomize key parameters.
    - *Timestep object*: As a simulation model, calculations are performed under a timestep object which contains a string of Action objects parameterized on the timeline.
      - *Flood damage module (**Fdmg**)*: This main module generates an annualized damage estimate (EAD) on the building inventory from the user provided parameters.
        - *Flood object*: Spawned for each annualized recurrence interval (ARI) provided by the user, these objects are associated with one column from the flood table.
          - *House object*: Spawned for each entry in the building inventory, these objects represent one of the 652 properties in the study area.
            - *Damage function object (**Dfunc**)*: Generally, five Dfuncs are spawned for each house (MC, MS, BC, BS, GS). These build, own, and execute the loss functions predicting direct-damage from flood depths for each house.
              - *Damage feature object (**Dfeat**)*: On select Dfuncs (generally MS, BS, and GS), a Dfeat is spawned for each entry found in the corresponding damage feature table (e.g. ‘replace dry-wall’). The set of Dfeats are used to generate the loss function for the parent Dfunc.
    - *Urban re-development module (**Udev**)*: This module executes Action objects to modify some other objects in the model (e.g. re-development of a house).
  - *Action object*: These objects carry out some change during model simulation of the timeline. Actions are specified with: 1) object class to be modified (e.g. House); 2) selector name (see below); 3) child actions (for chaining multiple actions together); and 4) triggered dynamic parameters (see below).
  - *Dynamic parameter workers (**Dynp**)*: These flexible worker objects change a single attribute on a group of objects (e.g. all House backflow valves = True).
  - *Selector objects*: These flexible worker objects select a group of objects based on some user provided logic (e.g. all houses inside the FHZ) for use by a Dynp, an Action, or an Outputer.
  - *Outputer objects*: These objects specify the model object attributes to output (e.g. total flood damage)

Additional object descriptions are provided in section 0.

D2.3. Flood Risk Simulations

Two diagrams are provided to demonstrate how SOFDA leverages the hierarchy to estimate EAD over time. Figure 2-3 shows how within the highest model level (Session object), Simulation objects, then Timestep objects are nested. These Timestep objects control how the urban re-development module (Udev) updates the building inventory, before the flood damage module (Fdmg) re-calculates EAD.

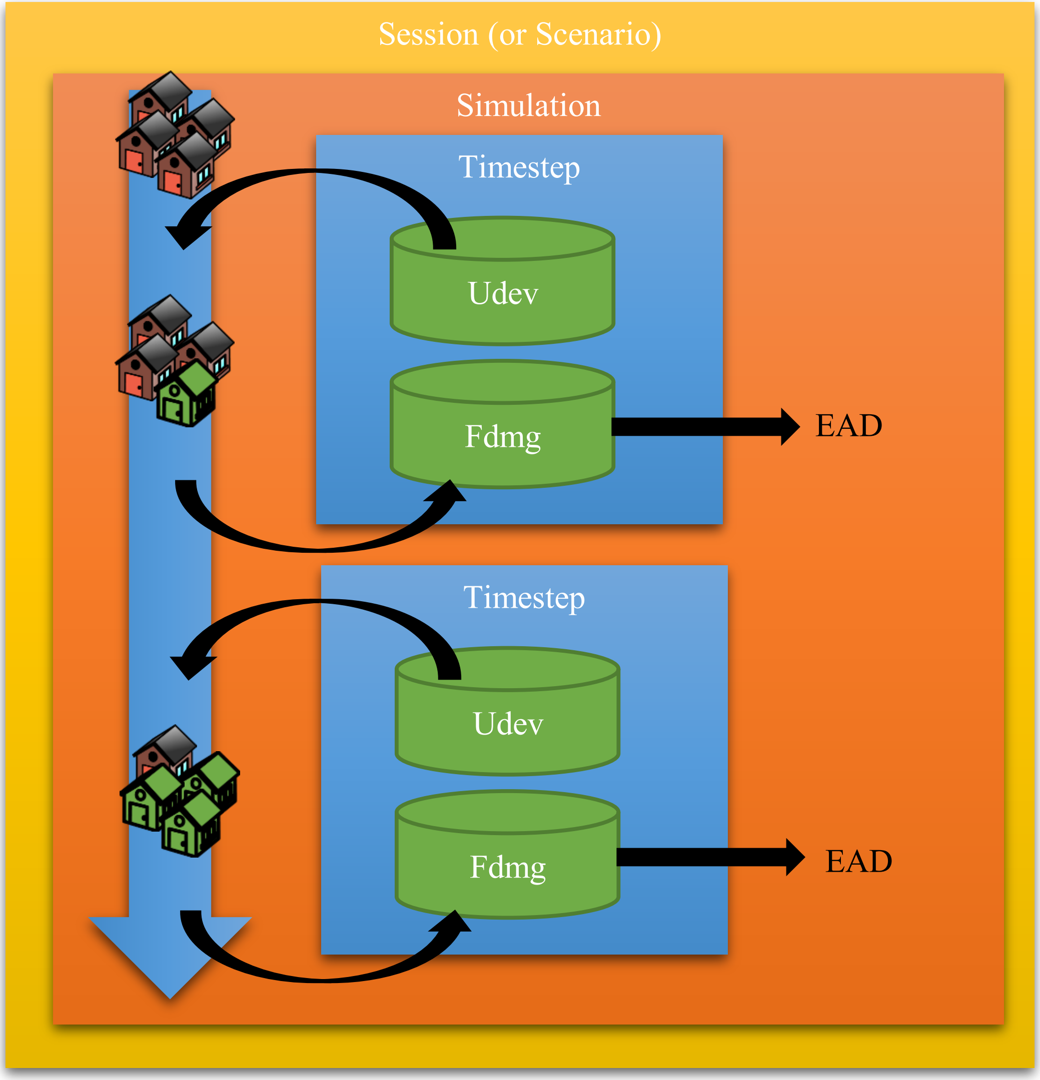


Figure 2-3: SOFDA module hierarchy conceptual diagram.

Figure 2-4 shows how, within this Fdmg module, Flood objects, then House objects, then Damage function objects (Dfuncs) are nested. The figure also shows how each Flood object controls the evaluation of damages from flood depths by the Dfuncs, before Fdmg calculates the total EAD.

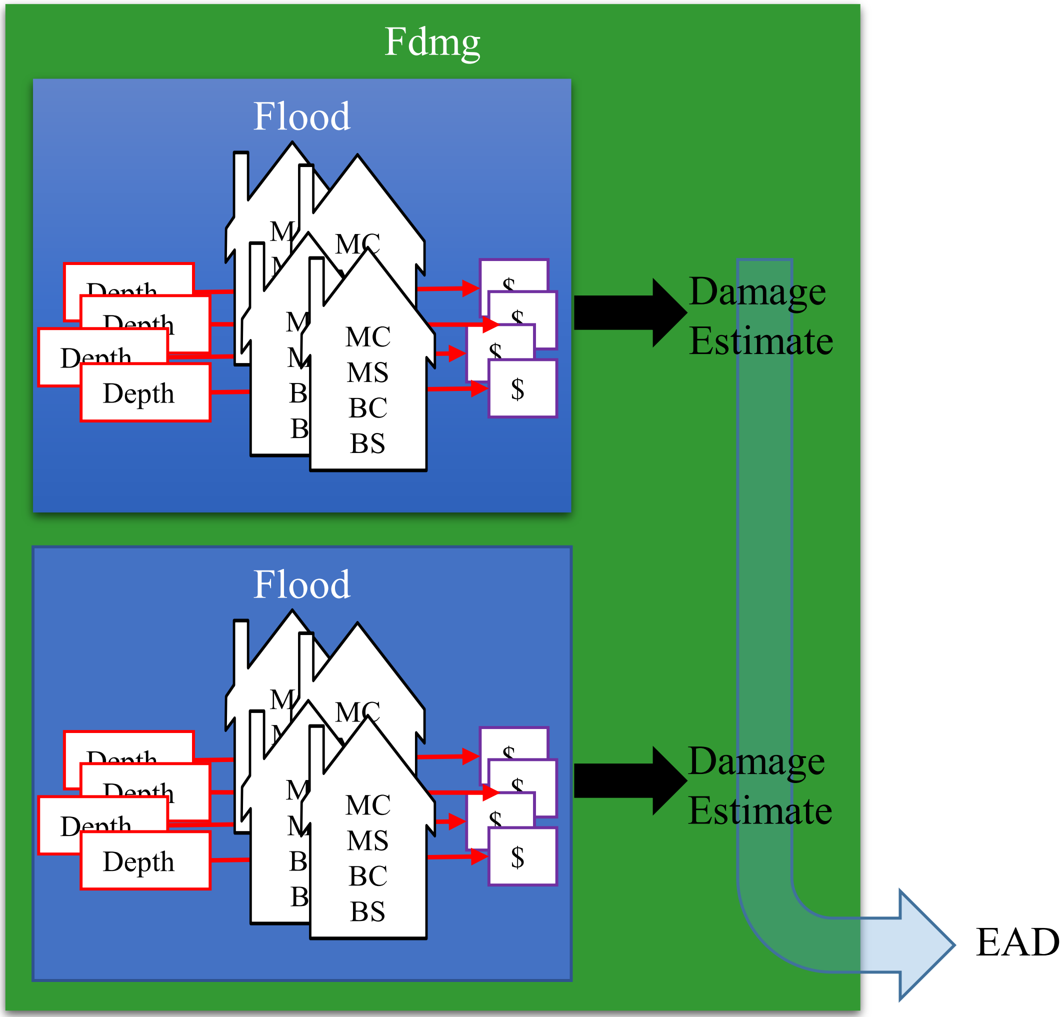


Figure 2-4: Conceptual diagram for the Fdmg module.

Session Run Sequence

SOFDA executes a stochastic model in this basic, Monte-Carlo style, sequence:

1) *Build Session*: Set parameter values (e.g. number of runs) or probability distributions (e.g. normal distribution for infill basement finish height). All objects are built during this step.
    a. *Run simulation*: Within the scenario parameters, a simulation is spawned with discrete parameter values generated as samples from the scenario distributions to simulate one possible forecast for the study area's dynamic flood risk. This simulation controls the execution of all the modules.
        i. *Execute timeline*: During this step, the user provided timeline is executed (see next section).

Upkeep Sequence

Between each of these steps (and the timesteps of the timeline), SOFDA executes the following upkeep sequence:

1. run active Selectors;
2. run active Dynps;
3. execute the module or object; then
4. calculate post-run metrics and execute Outputrs.

Dynp and Selector Activation

Dynps and Selectors can be activated in two ways:

- *explicitly*: These are only activated when named and called by some other model object (e.g. by the timeline). This facilitates intermittent or irregular model updates.
- *periodically*: These are activated by the upkeep sequence, where the model simulation level is less than or equal to the objects 'upd_sim_lvl' (Table 2-1). For example, a Selector with upd_sim_lvl = 2 would re calculate the objects within its selection at the start of each timestep.

Table 2-1: Periodic activation upd_sim_lvl.

Calling Object	upd_sim_lvl
Session	0 (never updates)
Simulation	1
Timestep	2
Model	3

D2.3.1. Simulation Timeline

The timeline is how the user schematizes the time dimension in SOFDA from the Control File. This is where the user tells SOFDA what to do for each timestep. With the timeline, the user can pass a complex and customizable sequence of operations to the Fdmg module and the Udev module for each timestep via the ‘run_seq_d’ list. This ‘run_seq_d’ list accepts a string of length 2 tuples: 1) module name to call; and 2) command sequence to execute on that module. Each module command sequence accepts Action names, or special commands (‘*’), as shown in the following table:

Table 2-2: Accepted commands in the timeline module command sequence.

Command	**Description**
*run	Execute the module’s main ‘run()’ method.
*model.[some module function]	Execute the provided method (e.g. when paired with the Fdmg module, ‘*model.plot_dmgs()’ calls Fdmg.plot_dmgs().
[some Action name]	Execute the named action’s ‘run()’ method (see section D4.7).

The below table gives a simple example of a timeline with three timesteps.

Table 2-3: Example timeline in SOFDA.

Timestep name	**Timestep execution description**	**run_seq_d**
t0	Calculate EAD on current inventory	[('Fdmg',['*run'])]
t1	1) Call the ‘a_redev’ Action to simulate urban re-development on the inventory; 2) calculate the new EAD	[('Udev',['a_redev']), ('Fdmg', ['*run'])]
t2	same	[('Udev',['a_redev']), ('Fdmg', ['*run'])]

During startup, a timestep is spawned for each row of the timeline. These timesteps are executed in sequence by each simulation:

1) Update model objects;
2) Run Selectors;
3) Run Dynps;
4) Execute each module in the run sequence;
    a. Run Selectors;
    b. Execute each command in the command sequence;
        i. Update model objects;
        ii. Execute command (see Table 2-2);
    c. Get module results;
5) Get Timestep results;

D2.3.2. Flood Damage Module (Fdmg)

Figure 2-5 shows the calculation loop of the for Fdmg's main 'run()' method.

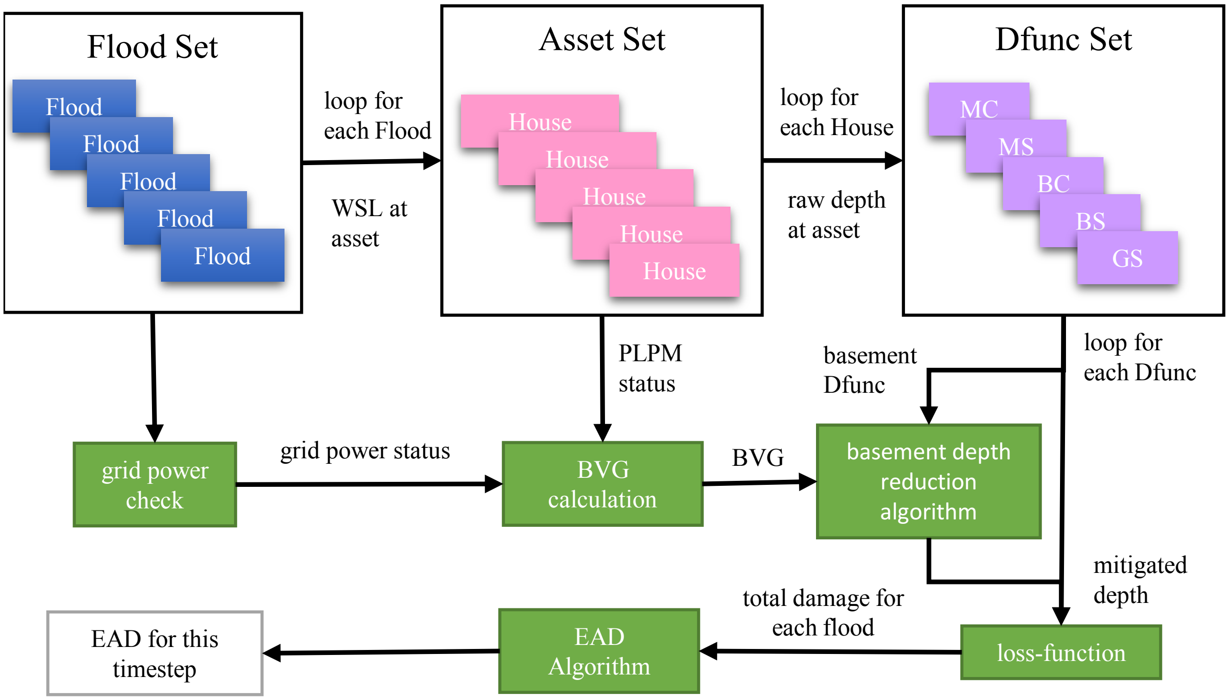


Figure 2-5: SOFDA's Fdmg 'run()' method calculation diagram.

D2.3.3. Urban Re-Development Module (Udev)

Unlike the Fdmg module, the Udev module is mostly a vessel for Action objects. Udev has no ‘run()’ method, but does collect metrics on changes to the building inventory following Action executions.

D3. Installing SOFDA

[placeholder]

D4. Building a SOFDA Model

Once the user has prepared the data files and familiarized themselves with the basic functions and purpose of SOFDA, the next step is to build the flood risk model using the SOFDA framework. As discussed in section 0, a model is defined in SOFDA via the user provided control file which points to all the user data files. Model construction is an iterative process which typically follows these basic steps:

1. Format all data files for use in SOFDA;
2. Assign partial interim values for the global parameters which facilitate model development (e.g. glbl_stoch_f=False, run_cnt=2, _parlo_f=True);
3. Define file locations for all user data files;
4. Define static parameters on ‘fdmg’, ‘dfunc’, ‘hse_geo’, ‘floods’ tabs;
5. Define a simple interim static timeline (e.g. '[('Fdmg',['*run'])]);
6. Define a set of basic outputs (and Selectors if necessary);
7. Test interim partial static model — debugging if necessary;
8. Define parameters on ‘timeline’, ‘actions’, ‘selectors’, ‘dynp’ tabs;
9. Test interim partial dynamic model — debugging if necessary;
10. Assign final global parameter values for a single simulation (e.g. glbl_stoch_f=True, run_cnt=1, _parlo_f=False);
11. Test interim dynamic model — debug if necessary;

In this way, a single model scenario can be built in SOFDA. Section D5 describes how to run the model once built. For multiple scenarios, a basic ‘parent’ model can be developed first before branching off ‘child’ scenarios or models. Additional testing and interim model values should be considered depending on data quality, model complexity, and user judgement. The remainder of this section provides guidance on how to parameterize each of the tabs on the control file.

Inputs Summary

Information that controls the execution of SOFDA, which is separate from the source code, can be divided by user interaction type:

- *Execution parameters*: These are high level parameters that control how the model is executed in python. Except for those parameters described in Table 4-1, these are typically only modified for debugging and source code development.
- *Program data files:* These are internal data files that are outside the source code. Typically, the user does not interact with these.
- *Model input parameters*: These define a SOFDA Session and parameterize how it is executed. The user provides these through the SOFDA Control File, an excel spreadsheet with 11 (active) tabs described in Table 4-2. A complete sample control file is provided in Attachment B and section 0 gives a description of each tab.
- *Model data files*: Connected to a SOFDA Session via special user input parameters, these external data files and their parameters help define a SOFDA model.

Table 4-1: Execution parameter summary table.

Input name	Code	Description
User control file name	pars_filename	File name for the user control file found in the input folder.
Global debugging mode control	_dbgmstr	Parameter to control the debugging mode.
Output folder name	out_fldr	Folder name to place output files.
Input folder name	in_fldr	Folder name to search for the user control file.

This manual focuses on model input parameters and data files summarized in Table 4-2. The remainder of this section details the inputs required for each tab in the Control File, with some additional object description.

Table 4-2: SOFDA control file description. See section 0 for a detailed description of each tab.

Input name	**Code**	**Description**
Global parameters	gen	Tab with high level control parameters for model function (e.g. debug mode control, number of simulations) and some default values (e.g. basement opening height).
Fdmg datasets	fdmg	Tab assigning model data files for the Fdmg module
Dfunc parameters	dfunc	Tab for assigning Dfunc properties for each place and damage code.
House geometry parameters	hse_geo	Tab for assigning default geometry logic for houses.
Flood table datasets	flood_tbls	Tab assigning flood tables and configuring their area protection grades.
Flood table	flood_tbl	Model data file with entries for each building in the inventory and tabs: *wet*) WSL for area protection failure; *dry*) WSL with area protections performing; *aprot*) area protection level.
Flood object set parameters	floods	Tab to provide the ARI for each flood event (and area protection code)
Action set parameters	actions	Tab to schematize each model Action object.
Selector set parameters	selectors	Tab to schematize the Selector objects.
Ranked choice list		Model data file with a ranked list of object names (for re-development selection).
Dynp parameters	dynp	Tab to schematize each Dynp.
Timeline	timeline	Tab to specify the sequence of model Actions.
Output setup	outputs	Tab to schematize Outputr objects.

D4.1. Global Parameters

Global parameters provide the high-level control parameters for a SOFDA model (e.g. debug mode control, number of simulations). Additionally, some key default values (to pass to the modules) can be entered here (e.g. basement opening height).

Table 4-3: Global parameter summary table. For a complete set, see Attachment B.

Input name	**Code**	**Description**
Session run count	**run_cnt**	number of simulations to run --for deterministic runs: set to 1 --for stochastic (monte-carlo): set to many --for sensitivity analysis: set the maximum number of toggles to evaluate
Session sensitivity analysis mode flag	**sensi_f**	flag whether to run in sensitivity analysis mode --TRUE: ignores run_cnt. instead does 1 run for each value on each variable on the pars tab --FALSE: (default) execute with normal Dynp behavior
Session stochastic mode flag	**glbl_stoch_f**	flag whether to use [TRUE] stochastic Dynps (default) or [FALSE] deterministic Dynps.

D4.2. Fdmg Datasets

On the Fdmg parameters tab, the user specifies file locations for the four main datafiles used by SOFDA:

Input name	Code	Description
Alberta Curves	rfda_curve	Model data file with Alberta Curve depth-damage values formatted for use in RFDA.
Building Inventory	binv	Model data file with vulnerability data on each asset (e.g. main floor height, building type). The first 26 columns can be formatted for use in RFDA.
Damage feature tables	dfeat_tbl	Model data file and tabs with damage feature data. Attachment C provides the default tables, developed from the original Alberta Curve damage feature tables.
FHZ tables	fhr_tbl	Model data file with FHZ and BFE on each asset for each FHR.

Two of these are described below.

D4.2.1. Building Inventory

The building inventory contains vulnerability attributes for each asset in the study area, with variables like building type, main floor height, and basement presence. This dataset is meant to describe the study area as it is today, in terms that are relevant for flood risk modeling of direct building damages. SOFDA builds a digital model of the study area by spawning a House object (and its nested hierarchy) from the values in each row of this building inventory during model startup.

For backwards compatibility of model data files, SOFDA can convert building inventory's from the legacy RFDA format with the legacy_binv_f=True parameter value. This tells SOFDA to read the building inventory based on location (column index) rather than the header value, as shown in the following table. As SOFDA is a flexible framework, any number of attributes can be assigned to each House object. Those attributes required by the basic Fdmg.run() method are highlighted in green.

Table 4-4: Typical building inventory attribute description. Green rows indicate those attributes required for the Fdmg.run() method.

Attribute name	**Typical legacy datafile code**	**Legacy datafile index**[a]	**SOFDA code**	**Attribute description**
Identifier	ID	0	ID	Arbitrary unique asset identifier
Asset address		1	address	
Data identifier	CPID	2	CPID	Arbitrary unique asset identifier that corresponds to other model data files
Asset class	ClAss	10	class	
Asset stories	StruCt_Typ	11	struct_type	
Asset type			bldg._type	Asset type for assigning Dfuncs from the Alberta Curves
Building area	area_GIS_m	13	gis_area	Asset area for scaling Dfuncs
Basement status	Bsmt-Prkd	18	bsmt_f	Flag indicating whether House should spawn Dfuncs with place_code = 'B'.
Main floor height	Height_m	19	ff_height	Height used to calculate House.anchor_el (added to House.dem_el).
X-coordinate		20	xcoord	
Y-coordinate		21	ycoord	
DEM elevation	integrated	25	dem_el	Ground elevation from which to calculate House.anchor_el
Property land value			land_value	
Property total value			value	
Development-potential-ranking			devpot_rnk	
Year of construction			ayoc	
Asset's parcel area			parcel_area	

a) When legacy_binv_f=True, these attributes are loaded from the building inventory data file based on these index values, rather than the header value.

D4.2.2. Damage Feature Tables

To facilitate manipulation, and allow for more accurate object scaling, SOFDA includes the 'damage feature curve' mode for Dfuncs (dfunc_type = dfeats). This is assigned on the dfunc tab. With this novel algorithm, depth-damage curves are generated directly from damage feature tables. Typically, these tables use the results from the 2014 Alberta Curve surveys. These tables record typical restoration activates that may be required for a given depth of flooding (e.g. 'remove and replace water heater'). Typical damage feature tables are provided in Attachment C. Each entry (i.e. line) of these tables is referred to as a ‘damage feature’ (and each column provides the Dfeat attributes). Damage features are discussed further in section D4.4.1.

D4.2.3. FHZ tables

The FHZ Tables model data file allows the user to provide ‘bfe’ and ‘fhz’ attributes to each asset via the model index value (e.g. ‘CPID’). Each tab in this data file is loaded by name, then accessed via the global parameter ‘fhr_nm’. In this way, the user can simulate the influence of different FHRs by changing the BFE and FHZ of attributes.

D4.3. Houses

House objects in SOFDA correspond to the object-based asset-level predictions of flood damage framed by the Alberta Curves. For single-family homes, these correspond to a single parcel — and facilitate the estimate of damages for the primary structure and any accessory structures (i.e. garages).

Geometry

During startup, Houses are spawned, and given attributes from, each entry in the building inventory. Typically, only the floor area (gis_area) attribute is provided to describe the geometry of the House. To facilitate accurate scaling of Dfeat price attributes, SOFDA provides algorithms to calculated more nuanced House geometry from simple geometric assumptions (scaled from the floor area). For example, a the price of a Dfeat like ‘remove and replace all drywall to walls & ceilings’ should not be scaled by the floor area of the house, but by the interior area (‘f_inta’). To calculate these secondary geometric attributes, the ‘set_geo_dxcol’ method is called during startup (and re-called if a base attribute is modified).

This ‘set_geo_dxcol’ method calculates the floor area, height, perimeter (per), and interior area (floor + walls; m^2) or the main floor (M), basement (B), and garage (G) from the user supplied parameters on the ‘hse_geo’ tab. Once calculated, these attributes are stored in the 3 dimensional ‘geo_dxcol’ dataframe to facilitate access by other routines.

Startup

Once the basic attributes are assigned from the Building Inventory, each house executes the following functions to calculate their secondary attributes:

1. *Calculate geometry (set_geo_dxcol):* see above
2. *Calculate anchor elevation (set_hse_anchor):* calculates the House’s anchor elevation (House.anchor_el) based on the DEM elevation and the main floor height (first provided in the building inventory).
3. *Calculate the basement vulnerability grade (set_bsmt_egrd)*: calculates the ‘bsmt_egrd’ based on the grid power (model.gpwr_f) and PLPM status as shown in Table 4-5.

Then, if the House has a basement, these secondary basement attributes are calculated:

4. *Calculate basement opening height (set_bsmt_opn_ht):* calculates the 'bsmt_opn_ht' value based on the global 'bsmt_opn_ht_code'. This value is used to calculate the basemetnt spill height and during the Dfunc. get_depth() method to modify the flood depth when House.bsmt_egrd = 'dry' .
5. *Calculate the basement spill height (set_damp_spill_ht):* calculates the 'damp_spill_ht' value as half the 'bsmt_opn_ht' parameter. This value is used during the Dfunc.get_depth() method to modify the flood depth when House.bsmt_egrd = 'damp' and model.damp_func_code = 'spill'.

During the upkeep sequence, each of these functions can be queued and re-run as a result of some modification instigated by a Dynp.

Table 4-5: Basement vulnerability grade (BVG) calculation logic.

grid power = ON	**grid power = OFF**	**BVG**
valve & pump	valve & pump & generator	**dry**
valve OR sump	valve OR (pump & generator)	**damp**
otherwise[a]	otherwise[a]	**wet**
b) any combination not included in the above		

D4.4. Dfuncs

Damage Function objects (Dfuncs) generate damage predictions from flood depths in consideration of an asset’s vulnerability. Each House object spawns Dfuncs based on the input parameters for place (e.g. garage, basement, main floor) and damage type (e.g. structural or contents). Following this, Dfuncs specified as ‘damage feature curves’ (discussed below) spawn a collection of Dfeats from the damage feature tables, as shown in the following figure:

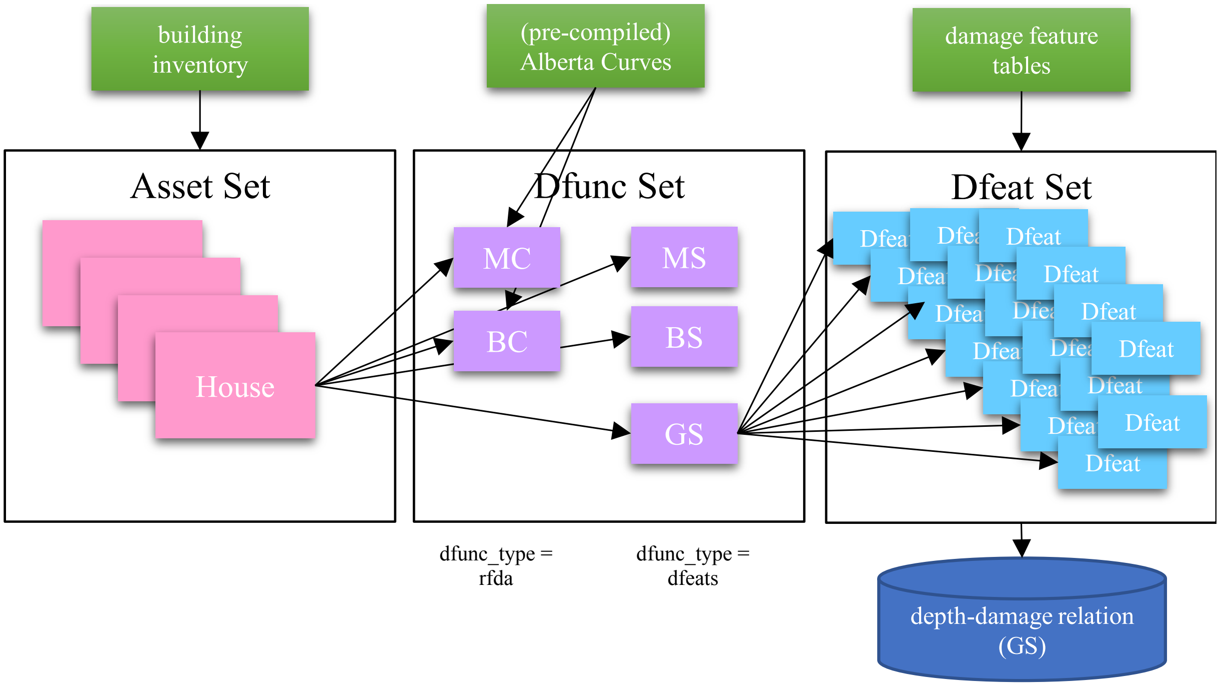


Figure 4-1: Typical house object hierarchy.

Generally, five Dfuncs are specified for each House to simulate the five types of damage considered by the Alberta Curves, as shown in the following table:

Table 4-6: Typical Dfunc model parameters.

place_code	dmg_code	dfunc_type	rat_attn	anchor_ht_code
M	C	rfda	self.parent.gis_area	*hse
M	S	dfeats	*none	*hse
B	C	rfda	self.parent.gis_area	*hse
B	S	dfeats	*none	*hse
G	S	dfeats	*none	*dem

Startup

During startup, each Dfunc executes the following functions:

1. *Calculate the anchor elevation:* The anchor elevation of the house, and the place code of the Dfunc are used to calculate the anchor elevation of the Dfunc, as shown on Table 4-7.
2. *Build the loss function:* depth-damage arrays are compiled based on the House and Dfunc attributes — especially the user provided 'dfunc_type'

During the upkeep sequence, each of these functions can be queued and re-run as a result of some modification instigated by a Dynp.

Table 4-7: Dfunc anchor elevation formulas used in this study. See Appendix E for a complete description of Dfunc parameters.

Place code	**Anchor elevation formula**
Main Floor (M)	House main floor elevation (HMFE)
Basements (B)	HMFE – basement finish height – joist spacing
Garage (G)	House DEM elevation

D4.4.1. Depth-Damage Arrays

To improve performance, discrete loss functions are compiled during startup (and, if necessary, during updating) for each Dfunc. These are numpy arrays with 'depth' and 'damage' columns. during the Fdmg.run() method, these depth-damage arrays can be quickly interpolated (by the Dfunc.get_dmg() method) to calculate the damage corresponding to the passed depth. The method used to compile these depth-damage arrays is controlled with the 'dfunc_type' parameter for each Dfunc class on the 'dfunc' tab in the Control File as shown in the following table:

Table 4-8: Dfunc depth-damage array (dd_ar) compilation method options by dfunc_type parameter.

dfunc_type	**Method name**	**Method description**
rfda	get_ddar_rfda	Load the dd_ar directly from the 'rfda_curve' model data file (in the Alberta Curve format).
dfeats	raise_dfeats	Build the dd_ar as damage feature curves from the child Dfeats initially loaded from the damage feature tables (section D4.2.2).
depdmg	get_ddar_depdmg	Load the dd_ar directly from the specified model data file (in the headpath/tailpath columns).

Damage Feature Curves

With the 'dfeats' parameter, SOFDA builds a custom loss function where each component is exposed to the user for manipulation. This loss function is comprised of a set of Damage Feature objects (Dfeat) spawned from each line (on the corresponding tab) of the damage feature tables described in section D4.2.2. Using the global parameter 'dfeat_xclud_price', a filter for the minimum Dfeat value can be set to improve performance. Once the full Damage Feature object set is spawned, the Dfeat prices are summed at each depth and the depth-damage array is generated and made ready for the first damage estimate.

A sample collection of the loss functions generated by five Dfuncs for a class 'C' house is provided in Figure 4-2.

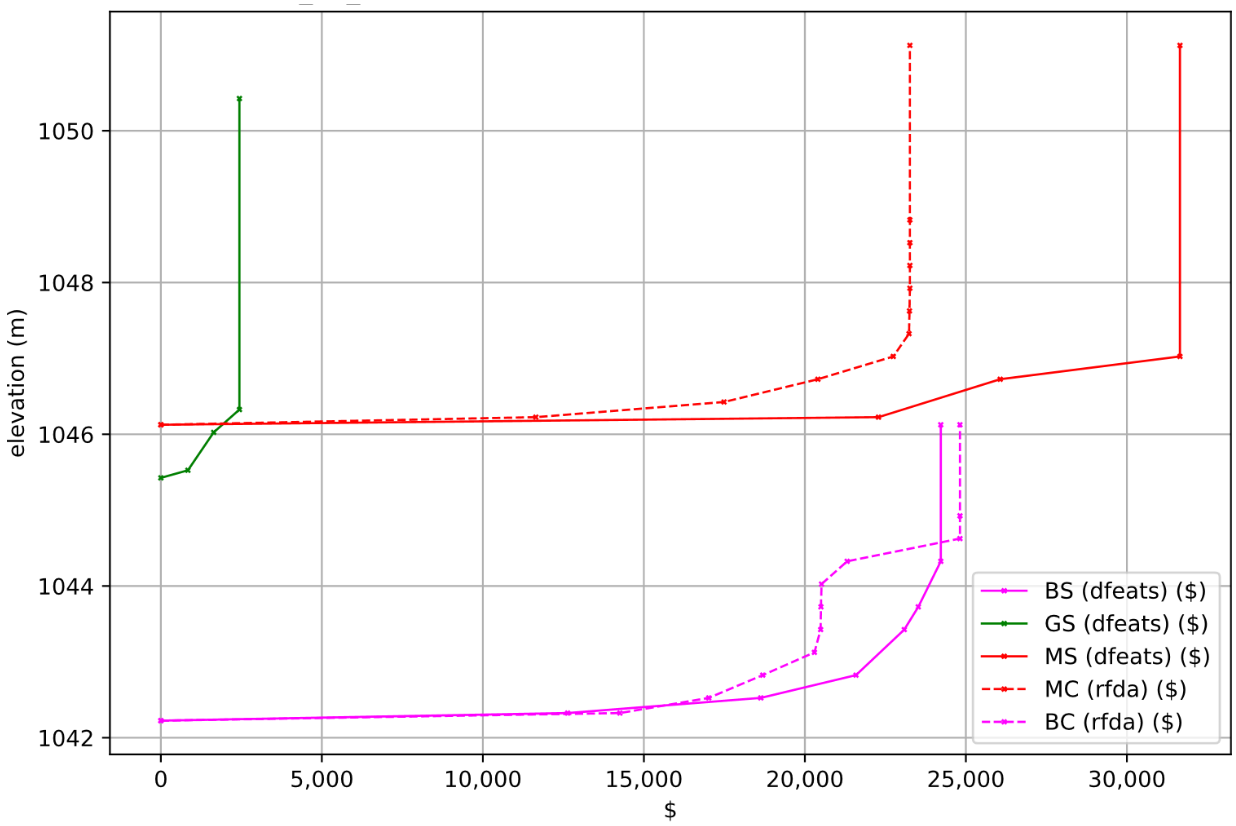


Figure 4-2: Depth-damage relations on five Dfuncs for a typical asset in SOFDA. See ***Error! Reference source not found.*** *for Dfunc acronym definitions (BS, GS, etc.). Dfuncs marked with '(dfeats)' are generated in mode 'Damage Feature Curves' while those marked with '(rfda)' are 'Alberta Curves.'*

D4.5. Flood Tables (Exposure Variables)

Flood Tables contain hazard attributes for each asset in the study area, with flood WSL provided for each of the Floods considered. These datasets are generated from river model predictions for flood WSL under different scenarios for discharge and structural protections.

Multiple flood tables can be loaded into SOFDA to simulate changes in hazard or area protections. The flood tables are queried during the Fdmg.run() method based on the 'flood_tbl_nm' parameter value.

Area Protections

To facilitate simulations that consider the reliability (i.e. likelihood of failure) of area protections, SOFDA considers three versions of the WSLs in each flood table — similar to the House.bsmt_egrd discussed above. These three WSL versions are described in the following table:

Table 4-9: Flood table area exposure grades and corresponding WSL generation method.

area_egrd	**Typical performance scenario**	**WSL generation method**
wet	Failure of area protections	WSL values from the 'wet tab on the data file
damp	Partial performance of area protections	Calculated based on the 'damp_build_code' parameter.
dry	Full performance of area protections	WSL values from the 'dry' tab on the data file

Which of these three WSL versions are used during the Fdmg.run() method is controlled via the 'area_egrd' matrix on the 'flood' tab of the Control File. Further, on the third 'aprot' tab of the flood tables, each asset is assigned an 'area_prot_lvl' of 0, 1, or 2. For study areas with heterogeneous structural protections (e.g. a levee only protecting a few houses), these asset scale area_prot_lvl attributes can be used to assign different versions of the flood table WSLs to different assets (i.e. failure in one area and performance in another). Using a Dynp, either of these area protection levels can be modified, and reliability simulated stochastically. In this way, the approximate performance of area protections can be simulated on two dimensions:

- spatially: by assigning assets different area_prot_lvl values on the 'aprot' tab; and

- as a function of flood magnitude: by assigning area_egrd (of each area_prot_lvl) to each Flood object on the ‘flood’ tab.

While this three-WSL-version approach provides a means to approximate the exposure considering the reliability of an area protection, it does not account for the mechanisms and complexities associated with the failure of different area protections (i.e. levee over-topping vs breaching) and their corresponding likelihoods. Therefore, a more robust approach is to incorporate failure mechanics directly into the hazard analysis.

D4.6. Flood Objects

Flood objects facilitate the estimation of damages to calculate risk using the EAD metric. These Flood objects are parameterized on the 'flood' tab, where each row corresponds to a column in the flood table (see previous). The primary parameter supplied on this tab is the flood ARI. This ARI is used to scale the Flood object damages by the EAD algorithm. Further, this flood ARI is used by the grid power algorithm, to predict whether grid power will be active or not during a flood event of that magnitude. This threshold is controlled via the 'gpwr_ari' global parameter. For example, when gpwr_ari = 100, SOFDA simulates all flood events more extreme than 100 ARI as having grid power failure (grid power = OFF).

D4.7. Timeline

For timeline schematization, see section D2.3.1.

D4.8. Actions

In SOFDA, Action objects bundle Dynps to simulate a unified change to the model via the timeline. Actions can also reference Selectors to apply changes to a subset of model objects. To make a more complex model change, Action objects can be bundled or nested so that one Action can call many other child Actions — passing down the parent's object subset to the child Actions. Further, the object hierarchy is respected, so that an Action passed a group of House objects knows which Dfuncs to target with its Dynps. In this way, changes can be made to subsets of subsets of subsets, etc. Similarly, complexity can be added by calling specific Actions in sequence on the timeline. It is up to the user to decide how best to manage the temporal, spatial, and object complexity Action objects afford to best suite the model objectives.

Each Action accepts the following parameters, specified via the 'actions' tab:

Table 4-10: Action attribute parameters.

Name	**Code**	**description**
Name	name	Unique string identifying the Action. Used to reference this Action by a command on the timeline or by another Action.
Target object class name	pclass_n	Class name of objects on which this Action applies
Selector name	sel_n	Selector to apply to passed object set (should match the pclass_n) to generate the selected object set.
Child Action names list	act_n_l	List of other Action names to execute (in sequence) n the selected object set. — prior to executing the dynp_n_l.
Dynp names list	dynp_n_l	List of Dynp names to execute (in sequence) on the selected object set.

D4.9. Selectors

Selectors are flexible worker objects used to identify a subset of objects for manipulation by some other ‘subscriber’ object. Selectors can be used, or subscribed to, by Actions, Dynps, and Outputrs to refine which model objects these subscribers apply to. Similar to Dynps, Selectors can be activated periodically (via the ‘upd_sim_lvl’ parameter) or explicitly (via some subscriber). The attributes used to schematize selectors are provided in the following table:

Table 4-11: Selector main attribute parameters.

Name	**Code**	**Description**
Name	name	Unique string identifying the Selector. Used by Action, Dynp, and Outputr objects to subscribe to the Selector.
Target object class name	pclass_n	Class name of objects on which to make selection.
Simulation level for periodic updates	upd_sim_lvl	Sim_lvl on which to recalculate selection

The three main options provided in SOFDA to execute object selection are provided in the following table:

Table 4-12: Selector selection method options.

Name	**Code**	**Description**
Object selection by meta-data	metadf_bool_exe	Using the metadata stored on the object’s parent (in a pandas dataframe), the user can provide code snippets in this cell to generate a boolean array (where each True result will be included in the selection).
Object selection by local Boolean	obj_bool_exe	Looping through each target object in the session, the code snippet provided in this cell should generate a boolean (where each True result will be included in the selection)
Special object selection	spcl_f_exe_str	See next section

D4.9.1. Special Functions

Special function selectors are parametrized by specifying some custom script for execution as an object method in the ‘spcl_f_exe_str’ column (e.g. self.foobar()). This allows the user to define more complex selection than may otherwise be available in the standard selection methods. The available special functions are summarized in the following sections.

Ranked Choice

A common application for the ‘ranked_choice’ function (Table 4-13) is the downscaling of urban re-development from some user provided list. To include some stochasticity in how objects are selected from this list, a non-zero positive ‘model.bucket_size’ parameter can be specified. This tells the ranked_choice function to use the 'get_random_pick_from_bucket' function (Table 4-14) to select from the user provided list.

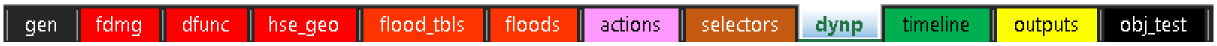
Table 4-13: Selector special function 'ranked_choice'.

Attribute	**Description**	**Default or typical values**
Name	List based selection	
Function code	**ranked_choice**	self.ranked_choice(n ='udev')
Function description	select objects based on some user provided list (ranked_l) and the model bucket size parameter (model.bucket_size).	
Inputs and Parameters		
n	number of entries to select from list	‘udev’: use value from ‘session.udev.infil_cnt’
update	whether to update the master list (remove recent picks)	True
Major dependencies		
self.ranked_l	list of object names for this selector object loaded via specifying some csv with the ‘headpath’ and ‘tailpath’ parameters.	
model.bucket_size	int for the bucket size to use for random bucket selection. Specified on the ‘gen’ tab.	0: no random bucket sampling. Just select the top ‘n’ objects from the list. >0: execute ‘self.get_random_pick_from_bucket’
Output/Result	Returns a dictionary of selected objects	return pick_d

Table 4-14: Selector special function 'get_random_pick_from_bucket'

Attribute	**Description**	**Default or typical values**
Name	Random bucket selection	
Function code	**get_random_pick_from_bucket**	self.get_random_pick_from_bucket(self.ranked_l, n + self.model.bucket_size, n)
Function description	generate a random sample from a bucket built from a passed list	
Parameters/Inputs		
full_l	ranked list of objects used to construct bucket from	
bucket_size	int for size of bucket to build from full_l	
pick_cnt	int for count to randomly select from bucket	
Major dependencies		
Output/Result	Returns a randomly selected list of length ‘pick_cnt’	return pick_l

D4.10. Dynamic Parameters (Dynp)



Dynamic Parameter objects are session level workers that make some change to another object within the session. They can be triggered at irregular intervals on the simulation timeline via an Action, or at regular intervals (e.g. every timestep). Attribute changes can be: 1) stochastic (e.g. pulling a random sample from a Scipy distribution), formulaic (e.g. new value = DEM elevation + 0.6 m), or a simple value. Typical applications of Dynps may be; 1) assigning initial conditions at simulation startup; 2) setting a House object’s current year to zero to simulate redevelopment; or 3) stochastically assigning the urban development rate for the timestep.

D4.11. Outputs

Outputr objects facilitate the selection and outputting of any model object attribute in the simulation. This allows the user to optimize what metrics are reported by SOFDA. During the upkeep sequence, Outputrs scan through the session objects and collect their attributes of interest (i.e. results values). These results values are stored by each Outputr and held for the full simulation. At the end of the simulation, all Outputrs are cleared and readied for the next simulation.

D5. Running a SOFDA Model

Once a model has been built via the user control file, a user can execute the model in the SOFDA platform. An efficient model builder should progressively run and test the model before it achieves the desired final complexity. Section D2.1 describes the different run modes of SOFDA. For the default, stochastic mode, SOFDA program execution is described in section D2.3 — and the deterministic mode is similar.

D5.1. Sensitivity Analysis (SA)

Model sensitivity analysis (SA) can provide valuable insight into model performance and variable interaction. Such insight can help inform model development and data collection, by identifying those parameters which are most significant in driving the model outcomes. Once known, a modeller can focus resources on refining these parameters — reducing the predictive uncertainty (and increasing the utility) of the model. In a stochastic model, like SOFDA, such parameter refinement may support the tightening of model input parameter distributions — reducing the spread of the results ensemble.

The SA is a set of special deterministic model runs on the study area that, instead of seeking a reasonable prediction for flood risk, seeks to quantify the importance of each parameter in making such a prediction. Generally, all parameters are kept at some median or 'best-guess' value — except for the focus parameter, which is toggled between extremes to explore its significance.

The SA mode in SOFDA is controlled with the 'sensi_f=TRUE' global parameter on the 'gen' tab of the Control File. In SA mode, SOFDA executes a model in these basic steps:

1. build the parameter matrix (Dynp parameters that will be applied to each simulation);
2. execute the baseline simulation (first row of parameter matrix; all default values);
3. execute all focus simulations; then
4. post process delta metrics.

In general, this approach does not consider connections between parameters, but instead explores deviations from some 'baseline' that represents an 'average' scenario. To evaluate non-linear connections between parameters (e.g. where both deviate from the baseline), the full stochastic mode of SOFDA should be employed. Further, the SA method of SOFDA assumes all Dynp parameters are independent.

D5.1.1. Focus Parameters

For SA sessions, the user selects those Dynps on which to quantify sensitivity via the ‘dynp’ tab’s ‘sensi’ columns (Table 5-1). Based on these user provided values, SOFDA builds a set of deterministic simulations from the user provided extremes — holding all other Dynps at their base value. These values are calculated during startup and stored in the parameter matrix (included as a tab in the output file).

Table 5-1: Sensitivity analysis control parameter options. Set via the ‘dynp’ tab columns ‘sensi1’, ‘sensi2’, ‘sensi3’.

Option description	**‘sensi’ input code**	**Description**
Numerical extremes	*min/max	Generate two SA focus simulations on this parameter from the values provided in the min/max columns
Empty	(blank)	Apply this parameter deterministically and do not include any focus simulations
Custom value	(any other value)	Generate a SA focus simulation for this parameter using the value provided

The user is free to select any of the model Dynps for inclusion as a focus parameter in the SA, with any range of extremes. When selecting Dynps for inclusion, the following provides a useful framework by *application type*:

- *Model structure*: a replacement of some concise model sub-function with some functional alternative (e.g. swapping damage depth functions from 'seep' to 'damp');
- *Model parameter*: replacing a single parameter value with some alternative (e.g. swapping infill_cnt from 300 to 500);
- *Model parameter delta:* adding some delta to a model parameter (e.g. adding 0.5 m to all House.anchor_el). These are always 'zero' value when not the focal Dynp.

The results of any SA are dependent upon;

- *Model structure*: How the model is conceptualized and formalized determines the results generated from different input values.
- *Parameter extremes*: What values the user provides for the analysis determines the results generated by the deterministic model structure.

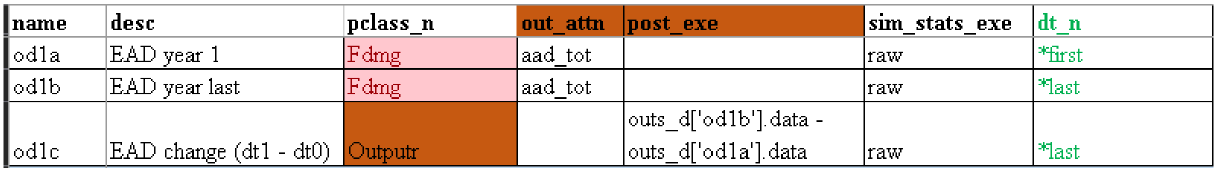
Considering this, the user should ensure the selected parameter extremes accurately represent the range of ‘reasonable’ parameter values of the system.

D5.1.2. Sensitivity Metrics

To quantify model sensitivity, the user must schematize Outputrs to capture the desired model object attributes (section D4.11). Generally, flood risk — expressed as EAD — is the metric of most interest for a SOFDA SA. For a SA, these key metrics (calculated for a focus simulation) are compared against the baseline simulation to obtain a delta value (i.e. change in risk between focus and baseline). As SOFDA is dynamic, typically two metrics are leveraged to quantify sensitivity:

- **EAD baseline delta at the start (EAD_0)**: This is the risk in the first year (before redevelopment) compared against the baseline. This quantifies how much the focus parameter influences risk estimates. This metric is not influenced by vulnerability dynamics.
- **EAD baseline delta change (EAD_d):** This is the risk change (last year minus first year) compared against the baseline (delta of a delta). This quantifies how much this parameter influences the simulation of risk over time.

To output these two metrics in SOFDA, three Outputr objects are required:



name	desc	pclass_n	out_attn	post_exe	sim_stats_exe	dt_n
od1a	EAD year 1	Fdmg	aad_tot		raw	*first
od1b	EAD year last	Fdmg	aad_tot		raw	*last
od1c	EAD change (dt1 - dt0)	Outputr		outs_d['od1b'].data - outs_d['od1a'].data	raw	*last

These calculate EAD at the first and last timestep, before calculating the difference on a single simulation. To compare these to the baseline simulation's value, these Outputr names are referenced as a list in the global parameter 'delta_compare_col_nl' to calculate the final delta value.

Bibliography

IBI Group, and Golder Associates. 2015. “Provincial Flood Damage Assessment Study.” Government of Alberta. http://www.alberta.ca/albertacode/images/pfdas-alberta-main.pdf.

Messner, Frank. 2007. “FLOODSite: Evaluating Flood Damages: Guidance and Recommendations on Principles and Methods.” T09-06–01. Helmholz Unweltforschungszentrum (UFZ). http://repository.tudelft.nl/view/hydro/uuid:5602db10-274c-40da-953f-34475ded1755/.

Attachment A: Source Code

The SOFDA source code can be found in the following link:

https://github.com/cefect/SOFDA0

Attachment B: Sample Control File

See Appendix E, Attachment B

Attachment C: Damage Feature Table

name	hse_type	place_cod	dmg_code	cat_code	base_area	base_per	base_heigh	base_inta	raw_index	depth_dflt	desc	quantity	unit	unit_price	base_price	price_calc_str
on of first 4	id1	id2. B, G, M	generally 'S' for	category (for group	the house assumed	area). GUESSE	height. GUESSE	area (excludin	rank/inde x/position	depth at which this	description from legacy table			$/unit	from the legacy	has access to these additional geometry attributes (floor intelligent): t_area = None #finished + unfinished area f_area = None# finished area for this floor
ADBS05	AD	B	S	F	133.3	46.18225	2.4	244.1374	5	0.1	Remove and replace all drywall to walls & ceilings.	333	m2	30	$ 9,990	base_price*f_inta/base_inta
ADBS02	AD	B	S	F	133.3	46.18225	2.4	244.1374	2	0.1	Remove existing carpet. Clean slab & install new carpeting.	79	m2	110	$ 8,690	base_price*f_area/base_area
ADBS21	AD	B	S	none	133.3	46.18225	2.4	244.1374	21	1.5	Remove and replace windows.	10	window	500	$ 5,000	base_price*t_area/base_area
ADBS08	AD	B	S	F	133.3	46.18225	2.4	244.1374	8	0.1	Remove and replace all doors & hardware.	9	door	400	$ 3,600	base_price*t_area/base_area
ADBS01	AD	B	S	F	133.3	46.18225	2.4	244.1374	1	0.1	Remove existing flooring. Clean and prepare slab. Install new flooring.	54	m2	60	$ 3,240	base_price*f_area/base_area
ADBS17	AD	B	S	none	133.3	46.18225	2.4	244.1374	17	0.6	Remove and replace stairs.	1	staircase	2000	$ 2,000	base_price
ADBS09	AD	B	S	F	133.3	46.18225	2.4	244.1374	9	0.1	Remove and replace all wood casings and door jambs.	9	opening	125	$ 1,125	base_price*t_area/base_area
ADBS12	AD	B	S	F	133.3	46.18225	2.4	244.1374	12	0.1	Remove and replace bathroom cabinets.	1	cabinet	750	$ 750	base_price*t_area/base_area
ADBS03	AD	B	S	F	133.3	46.18225	2.4	244.1374	3	0.1	Remove and replace baseboards.	105	linear m	7	$ 735	base_price*f_per/base_per
ADBS04	AD	B	S	none	133.3	46.18225	2.4	244.1374	4	0.1	Visual inspection of sumps and weeping tile. Snake & clean. (10%).	1	ea	600	$ 600	base_price*t_area/base_area
ADBS15	AD	B	S	none	133.3	46.18225	2.4	244.1374	15	0.1	Implement structural drying.	8	hour	75	$ 600	base_price*t_area/base_area
ADBS11	AD	B	S	F	133.3	46.18225	2.4	244.1374	11	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	500	$ 500	base_price*t_area/base_area
ADBS14	AD	B	S	none	133.3	46.18225	2.4	244.1374	14	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
ADBS07	AD	B	S	F	133.3	46.18225	2.4	244.1374	7	0.1	Remove and replace all insulation.	111	m2	2.5	$ 278	base_price*t_area/base_area
ADBS24	AD	B	S	none	133.3	46.18225	2.4	244.1374	24	2.4	Inspect beams and floor joists.	2	hour	125	$ 250	base_price*t_area/base_area
ADBS06	AD	B	S	F	133.3	46.18225	2.4	244.1374	6	0.1	Remove and replace all poly vapour barrier.	111	m2	1	$ 111	base_price*t_area/base_area
ADMS09	AD	M	S	none	133.3	46.18225	2.7	257.9921	9	0.1	Remove and replace all kitchen cabinets and counter tops.	1	kitchen	40000	$ 40,000	base_price*t_area/base_area
ADMS17	AD	M	S	none	133.3	46.18225	2.7	257.9921	17	0.9	Remove and replace all windows.	20	window	1500	$ 30,000	base_price*t_area/base_area
ADMS16	AD	M	S	E	133.3	46.18225	2.7	257.9921	16	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	main floor	20000	$ 20,000	base_price*t_area/base_area
ADMS02	AD	M	S	none	133.3	46.18225	2.7	257.9921	2	0.1	Remove existing carpet. Clean and sand subfloor sheathing. Install new	133	m2	125	$ 16,625	base_price*f_area/base_area
ADMS04	AD	M	S	none	133.3	46.18225	2.7	257.9921	4	0.1	Remove and replace all drywall to walls & ceilings.	484	m2	30	$ 14,520	base_price*f_inta/base_inta
ADMS07	AD	M	S	none	133.3	46.18225	2.7	257.9921	7	0.1	Remove and replace all doors & hardware.	12	door	700	$ 8,400	base_price*t_area/base_area
ADMS11	AD	M	S	none	133.3	46.18225	2.7	257.9921	11	0.1	Remove and replace bathroom cabinets.	2.5	cabinet	1250	$ 3,125	base_price*t_area/base_area
ADMS08	AD	M	S	none	133.3	46.18225	2.7	257.9921	8	0.1	Remove and replace all wood casings and door jambs.	12	opening	125	$ 1,500	base_price*t_area/base_area
ADMS10	AD	M	S	none	133.3	46.18225	2.7	257.9921	10	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	2.5	bathroom	500	$ 1,250	base_price
ADMS03	AD	M	S	none	133.3	46.18225	2.7	257.9921	3	0.1	Remove and replace baseboards.	147	linear m	8	$ 1,176	base_price*f_per/base_per
ADMS14	AD	M	S	none	133.3	46.18225	2.7	257.9921	14	0.1	Implement structural drying.	8	hour	75	$ 600	base_price*t_area/base_area
ADMS12	AD	M	S	none	133.3	46.18225	2.7	257.9921	12	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
ADMS13	AD	M	S	none	133.3	46.18225	2.7	257.9921	13	0.1	Clean and sanitize all exterior building finishes.	4	hour	125	$ 500	base_price*t_area/base_area
ADMS06	AD	M	S	none	133.3	46.18225	2.7	257.9921	6	0.1	Remove and replace all insulation.	111	m2	2.5	$ 278	base_price*t_area/base_area
ADMS05	AD	M	S	none	133.3	46.18225	2.7	257.9921	5	0.1	Remove and replace all poly vapour barrier.	111	m2	1	$ 111	base_price*t_area/base_area

name	hse_type	place_code	dmg_code	cat_code	base_area	base_per	base_heigh	base_inta	raw_index	depth_dflt	desc	quantity	unit	unit_price	base_price	price_calc_str
on of first		id2. B, G,	generally	category	the house	area).	height.	area	rank/inde	depth at					from the	has access to these additional geometry attributes (floor intelligent): t_area = None #finished + unfinished area f_area = None# finished area for this floor
4	id1	M	'S' for	(for group	assumed	GUESSE	GUESSE	(excludin	x/position	which this	description from legacy table			$/unit	legacy	
BABS01	BA	B	S	none	149.4	48.89172	2.4	266.7401	1	0.1	Remove existing flooring. Clean and prepare slab. Install new flooring.	46	m2	50	$ 2,300	base_price*f_area/base_area
BABS02	BA	B	S	none	149.4	48.89172	2.4	266.7401	2	0.1	Remove existing carpet. Clean slab & install new carpeting.	105	m2	100	$ 10,500	base_price*f_area/base_area
BABS03	BA	B	S	none	149.4	48.89172	2.4	266.7401	3	0.1	Remove and replace baseboards.	125	linear m	5	$ 625	base_price*f_per/base_per
BABS04	BA	B	S	none	149.4	48.89172	2.4	266.7401	4	0.1	Visual inspection of sumps and weeping tile. Snake & clean. (10%).	1		600	$ 600	base_price*t_area/base_area
BABS05	BA	B	S	none	149.4	48.89172	2.4	266.7401	5	0.1	Remove and replace all drywall to walls & ceilings.	439	m2	30	$ 13,170	base_price*f_inta/base_inta
BABS06	BA	B	S	none	149.4	48.89172	2.4	266.7401	6	0.1	Remove and replace all poly vapour barrier.	118	m2	1	$ 118	base_price*t_area/base_area
BABS07	BA	B	S	none	149.4	48.89172	2.4	266.7401	7	0.1	Remove and replace all insulation.	118	m2	2.5	$ 295	base_price*t_area/base_area
BABS08	BA	B	S	none	149.4	48.89172	2.4	266.7401	8	0.1	Remove and replace all doors & hardware.	9	door	300	$ 2,700	base_price*t_area/base_area
BABS09	BA	B	S	none	149.4	48.89172	2.4	266.7401	9	0.1	Remove and replace all wood casings and door jambs.	9	opening	100	$ 900	base_price*t_area/base_area
BABS10	BA	B	S	M	149.4	48.89172	2.4	266.7401	10	0.1	Remove and replace hot water heater.	1	unit	1200	$ 1,200	base_price*t_area/base_area
BABS11	BA	B	S	none	149.4	48.89172	2.4	266.7401	11	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	500	$ 500	base_price*t_area/base_area
BABS12	BA	B	S	none	149.4	48.89172	2.4	266.7401	12	0.1	Remove and replace bathroom cabinets.	1	cabinet	500	$ 500	base_price*t_area/base_area
BABS13	BA	B	S	M	149.4	48.89172	2.4	266.7401	13	0.1	Clean & service furnace.	2	hour	125	$ 250	base_price*t_area/base_area
BABS14	BA	B	S	none	149.4	48.89172	2.4	266.7401	14	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
BABS15	BA	B	S	none	149.4	48.89172	2.4	266.7401	15	0.1	Implement structural drying.	6	hour	75	$ 450	base_price*t_area/base_area
BABS16	BA	B	S	M	149.4	48.89172	2.4	266.7401	16	0.3	Remove and replace furnace.	1	unit	7500	$ 7,500	base_price
BABS17	BA	B	S	none	149.4	48.89172	2.4	266.7401	17	0.6	Remove and replace stairs.	1	staircase	1500	$ 1,500	base_price
BABS18	BA	B	S	E	149.4	48.89172	2.4	266.7401	18	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	basement	3000	$ 3,000	base_price*t_area/base_area
BABS20	BA	B	S	E	149.4	48.89172	2.4	266.7401	20	1.2	Remove and replace electrical service panel.	1	unit	1500	$ 1,500	base_price
BABS21	BA	B	S	none	149.4	48.89172	2.4	266.7401	21	1.5	Remove and replace windows.	6	window	300	$ 1,800	base_price*t_area/base_area
BABS23	BA	B	S	M	149.4	48.89172	2.4	266.7401	23	2.1	Remove and replace all mechanical ductwork.	1	basement	1500	$ 1,500	base_price*t_area/base_area
BABS24	BA	B	S	none	149.4	48.89172	2.4	266.7401	24	2.4	Inspect beams and floor joists.	2	hour	125	$ 250	base_price*t_area/base_area
BAMS01	BA	M	S	none	149.4	48.89172	2.7	281.4076	1	0.1	Remove existing flooring. Clean and sand subfloor sheathing. Install new	8	m2	75	$ 600	base_price*f_area/base_area
BAMS02	BA	M	S	none	149.4	48.89172	2.7	281.4076	2	0.1	Remove existing carpet. Clean and sand subfloor sheathing. Install new	143	m2	100	$ 14,300	base_price*f_area/base_area
BAMS03	BA	M	S	none	149.4	48.89172	2.7	281.4076	3	0.1	Remove and replace baseboards.	155	linear m	5	$ 775	base_price*t_area/base_area
BAMS04	BA	M	S	none	149.4	48.89172	2.7	281.4076	4	0.1	Remove and replace all drywall to walls & ceilings.	524	m2	30	$ 15,720	base_price*t_area/base_area
BAMS05	BA	M	S	none	149.4	48.89172	2.7	281.4076	5	0.1	Remove and replace all poly vapour barrier.	118	m2	1	$ 118	base_price*t_area/base_area
BAMS06	BA	M	S	none	149.4	48.89172	2.7	281.4076	6	0.1	Remove and replace all insulation.	118	m2	2.5	$ 295	base_price*t_area/base_area
BAMS07	BA	M	S	none	149.4	48.89172	2.7	281.4076	7	0.1	Remove and replace all doors & hardware.	13	door	500	$ 6,500	base_price*t_area/base_area
BAMS08	BA	M	S	none	149.4	48.89172	2.7	281.4076	8	0.1	Remove and replace all wood casings and door jambs.	13	opening	100	$ 1,300	base_price*t_area/base_area
BAMS09	BA	M	S	none	149.4	48.89172	2.7	281.4076	9	0.1	Remove and replace all kitchen cabinets and counter tops.	1	kitchen	15000	$ 15,000	base_price*t_area/base_area
BAMS10	BA	M	S	none	149.4	48.89172	2.7	281.4076	10	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	2.5	bathroom	500	$ 1,250	base_price
BAMS11	BA	M	S	none	149.4	48.89172	2.7	281.4076	11	0.1	Remove and replace bathroom cabinets.	2.5	cabinet	1000	$ 2,500	base_price*t_area/base_area
BAMS12	BA	M	S	none	149.4	48.89172	2.7	281.4076	12	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
BAMS13	BA	M	S	none	149.4	48.89172	2.7	281.4076	13	0.1	Clean and sanitize all exterior building finishes.	4	hour	125	$ 500	base_price*t_area/base_area
BAMS14	BA	M	S	none	149.4	48.89172	2.7	281.4076	14	0.1	Implement structural drying.	6	hour	75	$ 450	base_price*t_area/base_area
BAMS16	BA	M	S	E	149.4	48.89172	2.7	281.4076	16	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	main floor	7500	$ 7,500	base_price*t_area/base_area
BAMS17	BA	M	S	none	149.4	48.89172	2.7	281.4076	17	0.9	Remove and replace all windows.	18	window	1000	$ 18,000	base_price*t_area/base_area
BAGS01	BA	G	S	none	50	28.28427	2.4	117.8823	1	0.1	Clean and sanitize concrete floor.	1	hour	125	$ 125	base_price*t_area/base_area
BAGS02	BA	G	S	none	50	28.28427	2.4	117.8823	2	0.1	Remove and replace all poly vapour barrier.	349	m2	1	$ 349	base_price*t_area/base_area
BAGS03	BA	G	S	none	50	28.28427	2.4	117.8823	3	0.1	Remove and replace all insulation.	349	m2	2.5	$ 873	base_price*t_area/base_area
BAGS04	BA	G	S	none	50	28.28427	2.4	117.8823	4	0.1	Remove and replace all man doors & hardware.	1	door	500	$ 500	base_price*t_area/base_area
BAGS05	BA	G	S	none	50	28.28427	2.4	117.8823	5	0.1	Clean and sanitize all structural components after demolition is completed.	2	hour	125	$ 250	base_price*t_area/base_area
BAGS06	BA	G	S	none	50	28.28427	2.4	117.8823	6	0.1	Clean and sanitize all exterior building finishes and overhead door.	2	hour	125	$ 250	base_price*t_area/base_area
BAGS07	BA	G	S	none	50	28.28427	2.4	117.8823	7	0.1	Implement structural drying.	4	hour	75	$ 300	base_price*t_area/base_area
BAGS09	BA	G	S	none	50	28.28427	2.4	117.8823	9	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	garage	1500	$ 1,500	base_price*t_area/base_area
BAGS10	BA	G	S	none	50	28.28427	2.4	117.8823	10	0.9	Remove and replace all windows.	2	window	500	$ 1,000	base_price*t_area/base_area

name	hse_type	place_code	dmg_code	cat_code	base_area	base_per	base_heigh	base_inta	raw_index	depth_dflt	desc	quantity	unit	unit_price	base_price	price_calc_str
on of first	id1	M	generally	category	the house	area).	height.	area	rank/inde	depth at	description from legacy table			$/unit	the legacy	has access to these additional geometry attributes (floor intelligent):
BDBS01	BD	B	S	none	84	36.66061	2.4	171.9855	1	0.1	Remove existing flooring. Clean and prepare slab. Install new	30	m2	50	$ 1,500	base_price*f_area/base_area
BDBS02	BD	B	S	none	84	36.66061	2.4	171.9855	2	0.1	Remove existing carpet. Clean slab & install new carpeting.	53	m2	100	$ 5,300	base_price*f_area/base_area
BDBS03	BD	B	S	none	84	36.66061	2.4	171.9855	3	0.1	Remove and replace baseboards.	66	linear m	5	$ 330	base_price*f_per/base_per
BDBS04	BD	B	S	none	84	36.66061	2.4	171.9855	4	0.1	Visual inspection of sumps and weeping tile. Snake & clean. (10%).	1		500	$ 500	base_price*t_area/base_area
BDBS05	BD	B	S	none	84	36.66061	2.4	171.9855	5	0.1	Remove and replace all drywall to walls & ceilings.	219	m2	30	$ 6,570	base_price*f_inta/base_inta
BDBS06	BD	B	S	none	84	36.66061	2.4	171.9855	6	0.1	Remove and replace all poly vapour barrier.	87	m2	1	$ 87	base_price*t_area/base_area
BDBS07	BD	B	S	none	84	36.66061	2.4	171.9855	7	0.1	Remove and replace all insulation.	87	m2	2.5	$ 218	base_price*t_area/base_area
BDBS08	BD	B	S	none	84	36.66061	2.4	171.9855	8	0.1	Remove and replace all doors & hardware.	6	door	300	$ 1,800	base_price*t_area/base_area
BDBS09	BD	B	S	none	84	36.66061	2.4	171.9855	9	0.1	Remove and replace all wood casings and door jambs.	6	opening	100	$ 600	base_price*t_area/base_area
BDBS10	BD	B	S	M	84	36.66061	2.4	171.9855	10	0.1	Remove and replace hot water heater.	1	unit	1200	$ 1,200	base_price*t_area/base_area
BDBS11	BD	B	S	none	84	36.66061	2.4	171.9855	11	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	500	$ 500	base_price*t_area/base_area
BDBS12	BD	B	S	none	84	36.66061	2.4	171.9855	12	0.1	Remove and replace bathroom cabinets.	1	cabinet	500	$ 500	base_price*t_area/base_area
BDBS13	BD	B	S	M	84	36.66061	2.4	171.9855	13	0.1	Clean & service furnace.	2	hour	125	$ 250	base_price*t_area/base_area
BDBS14	BD	B	S	none	84	36.66061	2.4	171.9855	14	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
BDBS15	BD	B	S	none	84	36.66061	2.4	171.9855	15	0.1	Implement structural drying.	6	hour	75	$ 450	base_price*t_area/base_area
BDBS16	BD	B	S	M	84	36.66061	2.4	171.9855	16	0.3	Remove and replace furnace.	1	unit	7500	$ 7,500	base_price
BDBS17	BD	B	S	none	84	36.66061	2.4	171.9855	17	0.6	Remove and replace stairs.	1	staircase	1500	$ 1,500	base_price
BDBS18	BD	B	S	E	84	36.66061	2.4	171.9855	18	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	basement	3000	$ 3,000	base_price*t_area/base_area
BDBS20	BD	B	S	E	84	36.66061	2.4	171.9855	20	1.2	Remove and replace electrical service panel.	1	unit	1500	$ 1,500	base_price
BDBS21	BD	B	S	none	84	36.66061	2.4	171.9855	21	1.5	Remove and replace windows.	5	window	300	$ 1,500	base_price*t_area/base_area
BDBS23	BD	B	S	M	84	36.66061	2.4	171.9855	23	2.1	Remove and replace all mechanical ductwork.	1	basement	1500	$ 1,500	base_price*t_area/base_area
BDBS24	BD	B	S	none	84	36.66061	2.4	171.9855	24	2.4	Inspect beams and floor joists.	2	hour	125	$ 250	base_price*t_area/base_area
BDMS01	BD	M	S	none	84	36.66061	2.7	182.9836	1	0.1	Remove existing flooring. Clean and sand subfloor sheathing. Install new flooring.	9	m2	75	$ 675	base_price*f_area/base_area
BDMS02	BD	M	S	none	84	36.66061	2.7	182.9836	2	0.1	Remove existing carpet. Clean and sand subfloor sheathing. Install new carpeting.	74	m2	100	$ 7,400	base_price*f_area/base_area
BDMS03	BD	M	S	none	84	36.66061	2.7	182.9836	3	0.1	Remove and replace baseboards.	106	linear m	5	$ 530	base_price*t_area/base_area
BDMS04	BD	M	S	none	84	36.66061	2.7	182.9836	4	0.1	Remove and replace all drywall to walls & ceilings.	336	m2	30	$ 10,080	base_price*t_area/base_area
BDMS05	BD	M	S	none	84	36.66061	2.7	182.9836	5	0.1	Remove and replace all poly vapour barrier.	87	m2	1	$ 87	base_price*t_area/base_area
BDMS06	BD	M	S	none	84	36.66061	2.7	182.9836	6	0.1	Remove and replace all insulation.	87	m2	2.5	$ 218	base_price*t_area/base_area
BDMS07	BD	M	S	none	84	36.66061	2.7	182.9836	7	0.1	Remove and replace all doors & hardware.	8	door	500	$ 4,000	base_price*t_area/base_area
BDMS08	BD	M	S	none	84	36.66061	2.7	182.9836	8	0.1	Remove and replace all wood casings and door jambs.	8	opening	100	$ 800	base_price*t_area/base_area
BDMS09	BD	M	S	none	84	36.66061	2.7	182.9836	9	0.1	Remove and replace all kitchen cabinets and counter tops.	1	kitchen	15000	$ 15,000	base_price*t_area/base_area
BDMS10	BD	M	S	none	84	36.66061	2.7	182.9836	10	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	2.5	bathroom	500	$ 1,250	base_price
BDMS11	BD	M	S	none	84	36.66061	2.7	182.9836	11	0.1	Remove and replace bathroom cabinets.	2.5	cabinet	1000	$ 2,500	base_price*t_area/base_area
BDMS12	BD	M	S	none	84	36.66061	2.7	182.9836	12	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
BDMS13	BD	M	S	none	84	36.66061	2.7	182.9836	13	0.1	Clean and sanitize all exterior building finishes.	4	hour	125	$ 500	base_price*t_area/base_area
BDMS14	BD	M	S	none	84	36.66061	2.7	182.9836	14	0.1	Implement structural drying.	6	hour	75	$ 450	base_price*t_area/base_area
BDMS16	BD	M	S	none	84	36.66061	2.7	182.9836	16	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	main floor	7500	$ 7,500	base_price*t_area/base_area
BDMS17	BD	M	S	none	84	36.66061	2.7	182.9836	17	0.9	Remove and replace all windows.	14	window	1000	$ 14,000	base_price*t_area/base_area
BDGS01	BD	G	S	none	50	28.28427	2.4	117.8823	1	0.1	Clean and sanitize concrete floor.	1	hour	125	$ 125	base_price*t_area/base_area
BDGS02	BD	G	S	none	50	28.28427	2.4	117.8823	2	0.1	Remove and replace all poly vapour barrier.	349	m2	1	$ 349	base_price*t_area/base_area
BDGS03	BD	G	S	none	50	28.28427	2.4	117.8823	3	0.1	Remove and replace all insulation.	349	m2	2.5	$ 873	base_price*t_area/base_area
BDGS04	BD	G	S	none	50	28.28427	2.4	117.8823	4	0.1	Remove and replace all man doors & hardware.	1	door	500	$ 500	base_price*t_area/base_area
BDGS05	BD	G	S	none	50	28.28427	2.4	117.8823	5	0.1	Clean and sanitize all structural components after demolition is completed.	2	hour	125	$ 250	base_price*t_area/base_area
BDGS06	BD	G	S	none	50	28.28427	2.4	117.8823	6	0.1	Clean and sanitize all exterior building finishes and overhead door.	2	hour	125	$ 250	base_price*t_area/base_area
BDGS07	BD	G	S	none	50	28.28427	2.4	117.8823	7	0.1	Implement structural drying.	4	hour	75	$ 300	base_price*t_area/base_area
BDGS09	BD	G	S	E	50	28.28427	2.4	117.8823	9	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	garage	1500	$ 1,500	base_price*t_area/base_area
BDGS10	BD	G	S	none	50	28.28427	2.4	117.8823	10	0.9	Remove and replace all windows.	2	window	500	$ 1,000	base_price*t_area/base_area

name	hse_type	place_code	dmg_code	cat_code	base_area	base_per	base_heigh	base_inta	raw_index	depth_dflt	desc	quantity	unit	unit_price	base_price	price_calc_str
on of first 4	id1	id2. B, G, M	generally 'S' for	category (for group	the house assumed	area). GUESSE	height. GUESSE	area (excludin	rank/inde x/position	depth at which this	description from legacy table			$/unit	from the legacy	damage). has access to these additional geometry attributes (floor intelligent): t_area = None #finished + unfinished area
CABS01	CA	B	S	none	83.5	36.55133	2.4	171.2232	1	0.1	Remove existing flooring. Clean and prepare slab. Install new flooring.	37	m2	45	$ 1,665	base_price*f_area/base_area
CABS02	CA	B	S	none	83.5	36.55133	2.4	171.2232	2	0.1	Remove existing carpet. Clean slab & install new carpeting.	47	m2	90	$ 4,230	base_price*f_area/base_area
CABS03	CA	B	S	none	83.5	36.55133	2.4	171.2232	3	0.1	Remove and replace baseboards.	71	linear m	4	$ 284	base_price*f_per/base_per
CABS04	CA	B	S	none	83.5	36.55133	2.4	171.2232	4	0.1	Visual inspection of sumps and weeping tile. Snake & clean. (10%).	1		500	$ 500	base_price*t_area/base_area
CABS05	CA	B	S	none	83.5	36.55133	2.4	171.2232	5	0.1	Remove and replace all drywall to walls & ceilings.	232	m2	30	$ 6,960	base_price*f_inta/base_inta
CABS06	CA	B	S	none	83.5	36.55133	2.4	171.2232	6	0.1	Remove and replace all poly vapour barrier.	88	m2	1	$ 88	base_price*t_area/base_area
CABS07	CA	B	S	none	83.5	36.55133	2.4	171.2232	7	0.1	Remove and replace all insulation.	88	m2	2.5	$ 220	base_price*t_area/base_area
CABS08	CA	B	S	none	83.5	36.55133	2.4	171.2232	8	0.1	Remove and replace all doors & hardware.	8	door	250	$ 2,000	base_price*t_area/base_area
CABS09	CA	B	S	none	83.5	36.55133	2.4	171.2232	9	0.1	Remove and replace all wood casings and door jambs.	8	opening	90	$ 720	base_price*t_area/base_area
CABS10	CA	B	S	M	83.5	36.55133	2.4	171.2232	10	0.1	Remove and replace hot water heater.	1	unit	1200	$ 1,200	base_price*t_area/base_area
CABS11	CA	B	S	none	83.5	36.55133	2.4	171.2232	11	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	500	$ 500	base_price*t_area/base_area
CABS12	CA	B	S	none	83.5	36.55133	2.4	171.2232	12	0.1	Remove and replace bathroom cabinets.	1	cabinet	350	$ 350	base_price*t_area/base_area
CABS13	CA	B	S	M	83.5	36.55133	2.4	171.2232	13	0.1	Clean & service furnace.	2	hour	125	$ 250	base_price*t_area/base_area
CABS14	CA	B	S	none	83.5	36.55133	2.4	171.2232	14	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
CABS15	CA	B	S	none	83.5	36.55133	2.4	171.2232	15	0.1	Implement structural drying.	4	hour	75	$ 300	base_price*t_area/base_area
CABS16	CA	B	S	M	83.5	36.55133	2.4	171.2232	16	0.3	Remove and replace furnace.	1	unit	6000	$ 6,000	base_price
CABS17	CA	B	S	none	83.5	36.55133	2.4	171.2232	17	0.6	Remove and replace stairs.	1	staircase	1500	$ 1,500	base_price
CABS18	CA	B	S	E	83.5	36.55133	2.4	171.2232	18	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the	1	basement	2500	$ 2,500	base_price*t_area/base_area
CABS20	CA	B	S	E	83.5	36.55133	2.4	171.2232	20	1.2	Remove and replace electrical service panel.	1	unit	1500	$ 1,500	base_price
CABS21	CA	B	S	none	83.5	36.55133	2.4	171.2232	21	1.5	Remove and replace windows.	3	window	250	$ 750	base_price*t_area/base_area
CABS23	CA	B	S	M	83.5	36.55133	2.4	171.2232	23	2.1	Remove and replace all mechanical ductwork.	1	basement	1200	$ 1,200	base_price*t_area/base_area
CABS24	CA	B	S	none	83.5	36.55133	2.4	171.2232	24	2.4	Inspect beams and floor joists.	2	hour	125	$ 250	base_price*t_area/base_area
CAMS01	CA	M	S	none	83.5	36.55133	2.7	182.1886	1	0.1	Remove existing flooring. Clean and sand subfloor sheathing. Install new flooring.	21	m2	65	$ 1,365	base_price*f_area/base_area
CAMS02	CA	M	S	none	83.5	36.55133	2.7	182.1886	2	0.1	Remove existing carpet. Clean and sand subfloor sheathing. Install new carpeting.	62	m2	90	$ 5,580	base_price*f_area/base_area
CAMS03	CA	M	S	none	83.5	36.55133	2.7	182.1886	3	0.1	Remove and replace baseboards.	102	linear m	4	$ 408	base_price*t_area/base_area
CAMS04	CA	M	S	none	83.5	36.55133	2.7	182.1886	4	0.1	Remove and replace all drywall to walls & ceilings.	327	m2	30	$ 9,810	base_price*t_area/base_area
CAMS05	CA	M	S	none	83.5	36.55133	2.7	182.1886	5	0.1	Remove and replace all poly vapour barrier.	88	m2	1	$ 88	base_price*t_area/base_area
CAMS06	CA	M	S	none	83.5	36.55133	2.7	182.1886	6	0.1	Remove and replace all insulation.	88	m2	2.5	$ 220	base_price*t_area/base_area
CAMS07	CA	M	S	none	83.5	36.55133	2.7	182.1886	7	0.1	Remove and replace all doors & hardware.	9	door	350	$ 3,150	base_price*t_area/base_area
CAMS08	CA	M	S	none	83.5	36.55133	2.7	182.1886	8	0.1	Remove and replace all wood casings and door jambs.	9	opening	90	$ 810	base_price*t_area/base_area
CAMS09	CA	M	S	none	83.5	36.55133	2.7	182.1886	9	0.1	Remove and replace all kitchen cabinets and counter tops.	1	kitchen	15000	$ 15,000	base_price*t_area/base_area
CAMS10	CA	M	S	none	83.5	36.55133	2.7	182.1886	10	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	500	$ 500	base_price
CAMS11	CA	M	S	none	83.5	36.55133	2.7	182.1886	11	0.1	Remove and replace bathroom cabinets.	1	cabinet	750	$ 750	base_price*t_area/base_area
CAMS12	CA	M	S	none	83.5	36.55133	2.7	182.1886	12	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
CAMS13	CA	M	S	none	83.5	36.55133	2.7	182.1886	13	0.1	Clean and sanitize all exterior building	4	hour	125	$ 500	base_price*t_area/base_area
CAMS14	CA	M	S	none	83.5	36.55133	2.7	182.1886	14	0.1	Implement structural drying.	4	hour	75	$ 300	base_price*t_area/base_area
CAMS16	CA	M	S	none	83.5	36.55133	2.7	182.1886	16	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the	1	main floor	6500	$ 6,500	base_price*t_area/base_area
CAMS17	CA	M	S	none	83.5	36.55133	2.7	182.1886	17	0.9	Remove and replace all windows.	12	window	800	$ 9,600	base_price*t_area/base_area
CAGS01	CA	G	S	none	50	28.28427	2.4	117.8823	1	0.1	Clean and sanitize concrete floor.	1	hour	125	$ 125	base_price*t_area/base_area
CAGS02	CA	G	S	none	50	28.28427	2.4	117.8823	2	0.1	Remove and replace all poly vapour barrier.	220	m2	1	$ 220	base_price*t_area/base_area
CAGS03	CA	G	S	none	50	28.28427	2.4	117.8823	3	0.1	Remove and replace all insulation.	220	m2	2.5	$ 550	base_price*t_area/base_area
CAGS04	CA	G	S	none	50	28.28427	2.4	117.8823	4	0.1	Remove and replace all man doors &	1	door	500	$ 500	base_price*t_area/base_area
CAGS05	CA	G	S	none	50	28.28427	2.4	117.8823	5	0.1	Clean and sanitize all structural components after demolition is completed.	2	hour	125	$ 250	base_price*t_area/base_area
CAGS06	CA	G	S	none	50	28.28427	2.4	117.8823	6	0.1	Clean and sanitize all exterior building finishes and overhead door.	2	hour	125	$ 250	base_price*t_area/base_area
CAGS07	CA	G	S	none	50	28.28427	2.4	117.8823	7	0.1	Implement structural drying.	4	hour	75	$ 300	base_price*t_area/base_area
CAGS09	CA	G	S	E	50	28.28427	2.4	117.8823	9	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the	1	garage	1000	$ 1,000	base_price*t_area/base_area
CAGS10	CA	G	S	none	50	28.28427	2.4	117.8823	10	0.9	Remove and replace all windows.	2	window	500	$ 1,000	base_price*t_area/base_area

name	hse_type	place_code	dmg_code	cat_code	base_area	base_per	base_heigh	base_inta	raw_index	depth_dflt	desc	quantity	unit	unit_price	base_price	price_calc_str
on of first 4	id1	id2. B, G, M	generally 'S' for	category (for group	the house assumed	area). GUESSE	height. GUESSE	area (excludin	rank/inde x/position	depth at which this	description from legacy table			$/unit	the legacy table	damage). has access to these additional geometry attributes (floor intelligent): t_area = None #finished + unfinished area
CDBS01	CD	B	S	none	52	28.84441	2.4	121.2266	1	0.1	Remove existing flooring. Clean and prepare slab. Install new flooring.	25	m2	45	$ 1,125	base_price*f_area/base_area
CDBS02	CD	B	S	none	52	28.84441	2.4	121.2266	2	0.1	Remove existing carpet. Clean slab & install new carpeting.	24	m2	90	$ 2,160	base_price*f_area/base_area
CDBS03	CD	B	S	none	52	28.84441	2.4	121.2266	3	0.1	Remove and replace baseboards.	26	linear m	4	$ 104	base_price*f_per/base_per
CDBS04	CD	B	S	none	52	28.84441	2.4	121.2266	4	0.1	Visual inspection of sumps and weeping tile. Snake & clean. (10%).	1		400	$ 400	base_price*t_area/base_area
CDBS05	CD	B	S	none	52	28.84441	2.4	121.2266	5	0.1	Remove and replace all drywall to walls & ceilings.	87	m2	30	$ 2,610	base_price*f_inta/base_inta
CDBS06	CD	B	S	none	52	28.84441	2.4	121.2266	6	0.1	Remove and replace all poly vapour barrier.	67	m2	1	$ 67	base_price*t_area/base_area
CDBS07	CD	B	S	none	52	28.84441	2.4	121.2266	7	0.1	Remove and replace all insulation.	67	m2	2.5	$ 168	base_price*t_area/base_area
CDBS08	CD	B	S	none	52	28.84441	2.4	121.2266	8	0.1	Remove and replace all doors & hardware.	3	door	250	$ 750	base_price*t_area/base_area
CDBS09	CD	B	S	none	52	28.84441	2.4	121.2266	9	0.1	Remove and replace all wood casings and door jambs.	3	opening	90	$ 270	base_price*t_area/base_area
CDBS10	CD	B	S	M	52	28.84441	2.4	121.2266	10	0.1	Remove and replace hot water heater.	1	unit	1200	$ 1,200	base_price*t_area/base_area
CDBS11	CD	B	S	none	52	28.84441	2.4	121.2266	11	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	500	$ 500	base_price*t_area/base_area
CDBS12	CD	B	S	none	52	28.84441	2.4	121.2266	12	0.1	Remove and replace bathroom cabinets.	1	cabinet	350	$ 350	base_price*t_area/base_area
CDBS13	CD	B	S	M	52	28.84441	2.4	121.2266	13	0.1	Clean & service furnace.	2	hour	125	$ 250	base_price*t_area/base_area
CDBS14	CD	B	S	none	52	28.84441	2.4	121.2266	14	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
CDBS15	CD	B	S	none	52	28.84441	2.4	121.2266	15	0.1	Implement structural drying.	4	hour	75	$ 300	base_price*t_area/base_area
CDBS16	CD	B	S	M	52	28.84441	2.4	121.2266	16	0.3	Remove and replace furnace.	1	unit	6000	$ 6,000	base_price
CDBS17	CD	B	S	none	52	28.84441	2.4	121.2266	17	0.6	Remove and replace stairs.	1	staircase	1500	$ 1,500	base_price
CDBS18	CD	B	S	E	52	28.84441	2.4	121.2266	18	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	basement	2500	$ 2,500	base_price*t_area/base_area
CDBS20	CD	B	S	E	52	28.84441	2.4	121.2266	20	1.2	Remove and replace electrical service panel.	1	unit	1500	$ 1,500	base_price
CDBS21	CD	B	S	none	52	28.84441	2.4	121.2266	21	1.5	Remove and replace windows.	3	window	250	$ 750	base_price*t_area/base_area
CDBS23	CD	B	S	M	52	28.84441	2.4	121.2266	23	2.1	Remove and replace all mechanical ductwork.	1	basement	1200	$ 1,200	base_price*t_area/base_area
CDBS24	CD	B	S	none	52	28.84441	2.4	121.2266	24	2.4	Inspect beams and floor joists.	2	hour	125	$ 250	base_price*t_area/base_area
CDMS01	CD	M	S	none	52	28.84441	2.7	129.8799	1	0.1	Remove existing flooring. Clean and sand subfloor sheathing. Install new flooring.	12	m2	65	$ 780	base_price*f_area/base_area
CDMS02	CD	M	S	none	52	28.84441	2.7	129.8799	2	0.1	Remove existing carpet. Clean and sand subfloor sheathing. Install new carpeting.	37	m2	90	$ 3,330	base_price*f_area/base_area
CDMS03	CD	M	S	none	52	28.84441	2.7	129.8799	3	0.1	Remove and replace baseboards.	68	linear m	4	$ 272	base_price*t_area/base_area
CDMS04	CD	M	S	none	52	28.84441	2.7	129.8799	4	0.1	Remove and replace all drywall to walls & ceilings.	212	m2	30	$ 6,360	base_price*t_area/base_area
CDMS05	CD	M	S	none	52	28.84441	2.7	129.8799	5	0.1	Remove and replace all poly vapour barrier.	67	m2	1	$ 67	base_price*t_area/base_area
CDMS06	CD	M	S	none	52	28.84441	2.7	129.8799	6	0.1	Remove and replace all insulation.	67	m2	2.5	$ 168	base_price*t_area/base_area
CDMS07	CD	M	S	none	52	28.84441	2.7	129.8799	7	0.1	Remove and replace all doors & hardware.	6	door	350	$ 2,100	base_price*t_area/base_area
CDMS08	CD	M	S	none	52	28.84441	2.7	129.8799	8	0.1	Remove and replace all wood casings and door jambs.	6	opening	90	$ 540	base_price*t_area/base_area
CDMS09	CD	M	S	none	52	28.84441	2.7	129.8799	9	0.1	Remove and replace all kitchen cabinets and counter tops.	1	kitchen	15000	$ 15,000	base_price*t_area/base_area
CDMS10	CD	M	S	none	52	28.84441	2.7	129.8799	10	0.1	Remove, clean and re-install bathroom toilet, sink and tub.	1	bathroom	500	$ 500	base_price
CDMS11	CD	M	S	none	52	28.84441	2.7	129.8799	11	0.1	Remove and replace bathroom cabinets.	1	cabinet	750	$ 750	base_price*t_area/base_area
CDMS12	CD	M	S	none	52	28.84441	2.7	129.8799	12	0.1	Clean and sanitize all structural components after demolition is completed.	4	hour	125	$ 500	base_price*t_area/base_area
CDMS13	CD	M	S	none	52	28.84441	2.7	129.8799	13	0.1	Clean and sanitize all exterior building finishes.	4	hour	125	$ 500	base_price*t_area/base_area
CDMS14	CD	M	S	none	52	28.84441	2.7	129.8799	14	0.1	Implement structural drying.	4	hour	75	$ 300	base_price*t_area/base_area
CDMS16	CD	M	S	none	52	28.84441	2.7	129.8799	16	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	main floor	6500	$ 6,500	base_price*t_area/base_area
CDMS17	CD	M	S	none	52	28.84441	2.7	129.8799	17	0.9	Remove and replace all windows.	10	window	800	$ 8,000	base_price*t_area/base_area
CDGS01	CD	G	S	none	50	28.28427	2.4	117.8823	1	0.1	Clean and sanitize concrete floor.	1	hour	125	$ 125	base_price*t_area/base_area
CDGS02	CD	G	S	none	50	28.28427	2.4	117.8823	2	0.1	Remove and replace all poly vapour barrier.	220	m2	1	$ 220	base_price*t_area/base_area
CDGS03	CD	G	S	none	50	28.28427	2.4	117.8823	3	0.1	Remove and replace all insulation.	220	m2	2.5	$ 550	base_price*t_area/base_area
CDGS04	CD	G	S	none	50	28.28427	2.4	117.8823	4	0.1	Remove and replace all man doors & hardware.	1	door	500	$ 500	base_price*t_area/base_area
CDGS05	CD	G	S	none	50	28.28427	2.4	117.8823	5	0.1	Clean and sanitize all structural components after demolition is completed.	2	hour	125	$ 250	base_price*t_area/base_area
CDGS06	CD	G	S	none	50	28.28427	2.4	117.8823	6	0.1	Clean and sanitize all exterior building finishes and overhead	2	hour	125	$ 250	base_price*t_area/base_area
CDGS07	CD	G	S	none	50	28.28427	2.4	117.8823	7	0.1	Implement structural drying.	4	hour	75	$ 300	base_price*t_area/base_area
CDGS09	CD	G	S	E	50	28.28427	2.4	117.8823	9	0.6	Remove and replace electrical outlets, switches, light fixtures and wiring back to the service panel.	1	garage	1000	$ 1,000	base_price*t_area/base_area
CDGS10	CD	G	S	none	50	28.28427	2.4	117.8823	10	0.9	Remove and replace all windows.	2	window	500	$ 1,000	base_price*t_area/base_area

Attachment D: Alberta Curves

Available upon request

Appendix E: SOFDA Study Inputs

SOFDA Study Inputs

A description of the Sunnyside/Hillhurst SOFDA model inputs

1. Introduction

This appendix documents the input files and parameters used to model flood risk in the Sunnyside/Hillhurst study area using the Stochastic Object-based Flood damage Dynamic Assessment model framework (SOFDA). For a complete description of SOFDA and an explanation of the inputs, see Appendix D. For a discussion of the application of this framework to Sunnyside/Hillhurst, see the main report.

2. Input Summary

In SOFDA, the user specifies input parameters and data files via the user Control File. Table 2-1 lists the control files used for each of the 5 scenarios investigated in this thesis and provides a summary of the key parameters varied between each.

Table 2-1: SOFDA control file summary for the 5 scenarios in this study.

Scenario	Tag	Control filename	Flood table code[a] (flood_tbl_nm)	Flood hazard zone code (fhr_nm)[b]	Re-development sub-Action list[c]
S01	01_FoSo	SOFDA003_01a.xls	2016_sc0	Fo	[a_newhse, a_nic, a_n_u, a_fhr1]
S02	02_FoS7	SOFDA003_02a.xls	2016_sc7	Fo	[a_newhse, a_nic, a_n_u, a_fhr1]
S11	11_FnSo	SOFDA003_11a.xls	2016_sc0	Fn	[a_newhse, a_nic, a_n_u]
S12	12_FnS7	SOFDA003_12a.xls	2016_sc7	Fn	[a_newhse, a_nic, a_n_u]
S72	72_Ft3S7	SOFDA003_72b.xls	2016_sc7	Ft3	[a_newhse, a_nic, a_n_u, a_fhz1, a_fhz2, a_fhz3]

a) See Section 4.2
b) See Section 4.2
c) See Section 10

With the exception of the parameters described in the previous table, all scenarios were modeled with identical ‘common’ input parameters and datasets. Table 2-2 summarizes these common elements by Control File section, and Attachment B provides an example Control File with these common elements.

Table 2-2: Summary of control file parameters and datasets used in this study.

Input name	**Code**	**Contributing dataset**[b]	**Reference**
Global parameters	gen		Table 3-1
Fdmg parameters	fdmg		
Alberta Curves	rfda_curve	IBI_2015RFDA_curves	Appendix D, Attachment D
Building Inventory	binv	IBI_2017CoC_binv_res	Section 4.1
Damage feature tables	dfeat_tbl	IBI_2015RFDA_dftbls	Appendix D, Attachment C
FHR table	fhr_tbl		Section 4.2
Dfunc parameters	dfunc		Section 6
House geometry	hse_geo		Section 0
Flood table parameters	flood_tbls		
Flood table	flood_tbl		Section 7
Flood object parameters	floods		Section 8
Simulation timeline	timeline		Section 9
Action parameters	actions		Section 10
Selector parameters	selectors		Section 11
Dynp parameters	dynp		Section 12
Output setup	outputs		Section 13

a) Publication restricted by a data sharing agreement.

b) See Appendix G, ‘datasets’ column.

3. Global Parameters

Table 3-1 provides the key global parameters common to all scenarios in this study. For a complete description, see Attachment B.

Table 3-1: Select SOFDA global parameter values for this study.

Parameter name	**Code**	**Value (mean)**	**Stochastic properties (uncertainty)**	**Sample period**
joist spacing	joist_space	0.3 m		
ARI of grid power failure	gpwr_ari	100	lognormal distribution	timestep
number of infills per timestep (N_i)	infil_cnt	150	normal distribution	simulation

4. Fdmg Parameters

On the Fdmg parameters tab, the user specifies file locations for the four main datafiles used by SOFDA:

1. *Alberta Curves*: see Appendix D;
2. *Damage Feature Tables*: see Appendix D;
3. *Building Inventory*: described below;
4. *FHZ Tables:* described below.

4.1. Building Inventory

The nine attributes in the building inventory were compiled from: 1) the 2017 Study's building inventory; 2) CoC Assessment data; and 3) the study survey results as described in the main report. Building Inventories in SOFDA are described in detail in Appendix D. The complete building inventory, with some attributes removed for privacy, is provided in Attachment A.

Basement Finish Height

The study survey results were used to estimate each House's basement finish height. Unlike the PLPMs, which were assigned stochastically at the start of each simulation, the basement finish height was calculated once — then applied as a discreet House attribute for all scenarios and simulations (for the first timestep).

To estimate this basement finish height, a statistical model of the study survey results (Figure 4-1) was built. This model divided the study results into three groups by year of construction (AYOC), then fitted a normal distribution to each group as shown in Figure 4-2. With this statistical model, the basement finish height of each house in the inventory was calculated and recorded in the building inventory provided in Attachment A.

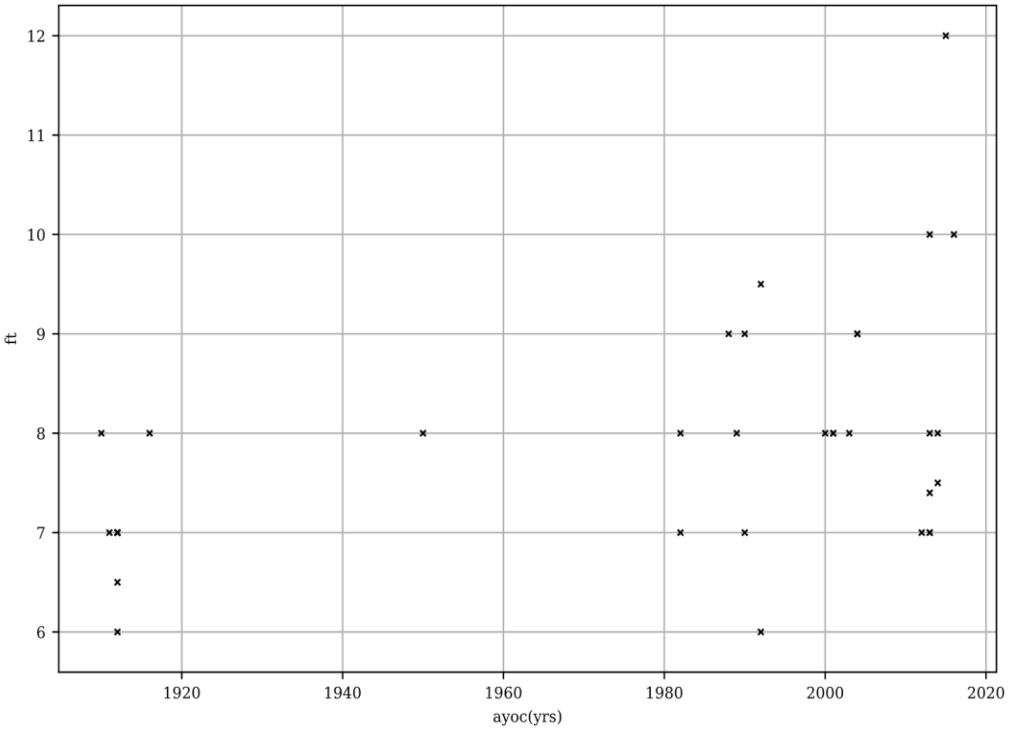


Figure 4-1: basement finish height and year of construction results from the study survey.

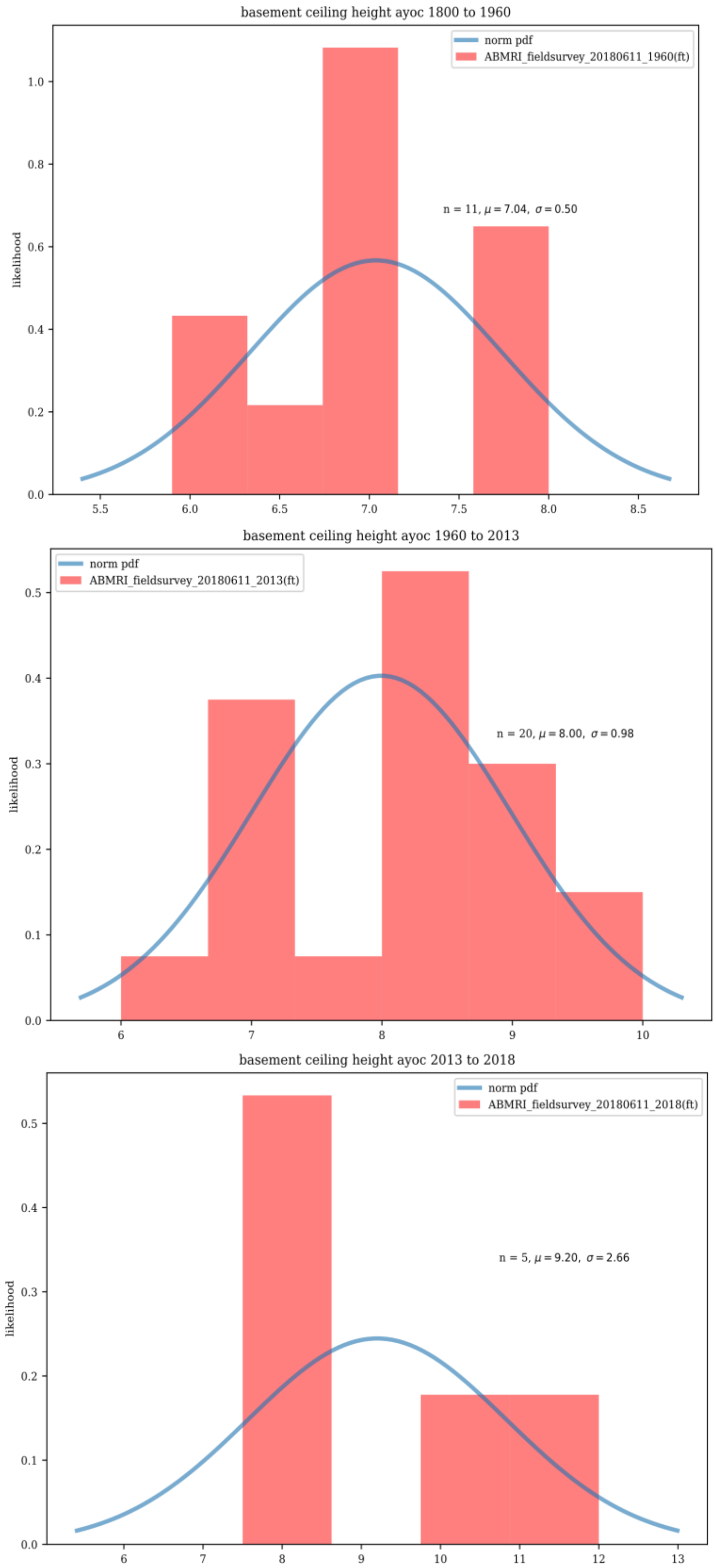


Figure 4-2: Basement finish height results and statistical model from study survey in feet.

4.2. FHZ tables

The FHZ tables used to simulate the two FHR options of this study (Ft3 and Fo) are summarized in the following table:

Table 4-1: Summary of flood hazard zone input datasets used in this study.

Name	Description	Contributing dataset[a]	Filename[b]
Fo	Current FHZ	GoA_AEP_FHZfringe_20150622	fhr_aoi01_20181004.xls
Ft3	Novel 3-tier FHZ	GLD_2017CoC_WSL_um (100-yr)	fhr_aoi01_20181004.xls

a) See Appendix G, 'datasets' column.
b) See Attachment E.

These FHZ tables are queried by the FHR sub-Actions described in Section 10.

5. Houses

As described in Appendix D, House objects are spawned in SOFDA from each row on the Building Inventory (Binv). Each House object then calculates its secondary geometry attributes from the floor area supplied in the Binv (gis_area) via the 'set_geo_dxcol' method and the user provided parameters on the 'hse_geo' tab. For this study, these secondary geometry were calculated by either assuming the House is a rectangle (and scaling from the area), or a simple value assumption as described on the following table:

Table 5-1: Description of house geometry calculation parameters (hse_geo) tab used in this study.

		Main floor	Basement	Garage
area	m^2	Use Binv value	Use Binv value	40
height	m	5	Use Binv value	5
per	m	*geo	*geo	*geo
inta[a]	m^2	*geo	*geo	*geo

*geo: Scaled from area assuming the House is a rectangle.
a.) Interior area (floor + walls)

6. Dfuncs

The parameterization of the Dfuncs is described in the main report.

7. Flood Tables

To simulate the two structural protection scenarios explored in this study, the flood tables described in the following table were used:

Table 7-1: Summary of flood table model input files used in this study.

Name[c]	**Description**	**Contributing dataset**[a]	**Filename**[b]
2016_sc0	Protection Scenario 0 (baseline) (P0)	GLD_2017CoC_WSL_sc0_gw	floodtbl_calgary2016_sc0_aoi01_20181004.xls
2016_sc7	Protection Scenario 7 (P7)	GLD_2017CoC_WSL_sc7_gw	floodtbl_calgary2016_sc7_aoi01_20181004.xls

a) See Appendix G, 'datasets' column.
b) See Attachment D.
c) Selected with global parameter 'flood_tbl_nm'

These flood tables were developed from the WSL predictions from two scenarios in the 2017 Study. This data was provided in the form of a hazard raster set. Each hazard raster set contains 24 rasters describing the flood WSL in the study area for the 12 event ARIs. A pair of rasters was provided for each ARI:

- full inundation in isolated areas (SW);
- groundwater infiltration in isolated areas (GW).

The GW rasters represent the scenario where structural protections are effective at preventing surface water from flooding low-lying areas that are disconnected from the river, yet below the simulated river WSL for that event. As this study assumed full performance of such structural protections, only the GW rasters were used to develop the flood tables. Some additional data cleaning and substitution was required to develop the complete flood tables. Attachment C provides the complete flood tables and a description of this data cleaning and substitution.

8. Flood Objects

The 12 events provided in the hazard layers are named, and assigned the corresponding ARI on the 'floods' tab of the control file, as shown in Attachment B.

9. Timeline

The timeline used to simulate flood risk for all scenarios in this study is provided in the following table:

Table 9-1: SOFDA model timeline for all scenarios. See text for description.

Timestep name	**Description**	**Command sequence (run_seq_d)**
t0	Calculate EAD on current inventory	[('Fdmg',['*run'])]
t1	Update inventory, Calculate new EAD	[('Udev',['a_redev']), ('Fdmg', ['*run'])]
t2	Update inventory, Calculate new EAD	[('Udev',['a_redev']), ('Fdmg', ['*run'])]

As described in the command sequence, for the first step, only the EAD is calculated using the basic Fdmg.run() method described in Appendix D. For the second and third steps, urban re-development is simulated before a new EAD is calculated. This urban re-development is simulated with the 'a_redev' Action described in the following section. Before this Action is called, the Dynp 'd_cntr' is used to stochastically assign the 'infil_cnt' for that timestep, as described in Section 12.

10. Actions

In SOFDA, Action objects bundle Dynp objects (and sometimes other Action objects) to simulate a unified change to the model. Further, Actions can use Selector objects to limit which objects the Action should modify. Actions are triggered intermittently by the schematization provided in the timeline tab of the Control File. Action objects are described in detail in Appendix D.

Urban Re-Development

For this study, all simulations employed the urban re-development Action named 'a_redev'. This Action: 1) selects the House objects for infilling (using the 's_pickn' Selector); 2) assigns parameters typical of a new house (using the 'a_newhse' sub-Action); then 3) applies FHRs (see next section; see main report for simple diagram). The spatial downscaling of the infill count ('infil_cnt') is achieved with the 's_pickn' Selector described in the following section. The 'a_newhse' sub-action includes some additional sub-actions to add stochastic uncertainty to key attributes. This Action is discussed further in the main report under the *Urban Re-Development Module (Udev)* section, and the parametrization is provided in Attachment B.

Applying FHRs

If the scenario includes some FHRs, these are applied following the execution of the 'a_newhse' sub-Action described above. This 'a_newhse' sub-Action passes the re-developed houses to the FHR sub-Action(s). This FHR sub-Action then applies the schematized flood rules based on the FHZ status of the House. In this way, the recently infilled house is modified to conform to the FHRs. The FHR sub-Actions for the three FHR options considered in this study are provided in the following table:

Table 10-1: Summary of urban re-development Action ('a_redev') by FHR option.

FHR option	FHR description	FHR sub-Action list[a]	Control File
Fn	No FHRs	N/A	Similar to Attachment B
Fo	Current FHZ	a_fhr1	Attachment B
Ft3	Novel 3-tier FHZ	a_fhz1, a_fhz2, a_fhz3	Attachment C

a) The complete 'a_redev' sub-Action list includes [a_newhse, a_nic, a_n_u]

11. Selectors

Selectors are SOFDA worker objects used to 'select' a sub-group of other model objects. This sub-group can then be used as part of some task of some other 'subscriber' object (e.g. Dynp, Action, Outputr). For the Fo scenarios, three Selectors are used (excluding those used for outputting) for: 1) selection of assets for downscaling of urban re-development ('s_pickn'); 2) selection of assets within the FHZ; and 3) selection of mechanical and electrical damage feature objects for FHR elevating (see Attachment B, 'selectors' tab). For the Ft3 scenarios, additional FHZ selectors are included for each of the three zones (see Attachment C).

11.1. Selection for Urban Re-development (s_pickn)

Common to all scenarios, the 's_pickn' selector identifies which assets are to be infilled — performing the downscaling portion of the urban re-development module. This Selector uses the special 'ranked_choice' function described in Appendix D, with a model.bucket_size parameter of 150 (see Attachment B). This provides a stochastic selection of the prioritization of assets based on their development-potential-ranking (described in next section). Where N_b is N_i + 150, this random bucket sampling follows these steps:

1) N_b assets with the highest development-potential-ranking are selected; then

2) from these, N_i are randomly selected for re-development.

This sub-set of House objects is then passed to the ‘a_newhse’ action for re-development.

11.1.1. Development-Potential-Ranking

For this study, the development potential for each house is assumed to be a direct function of the ratio of the assessed property value ($) to the parcel area ($m^2$). These base attributes were obtained from CoC property assessment data (Appendix G, dataset: ‘CoC_Ass_propass’). This property value-density attribute ($\$/m^2$) is calculated for each asset, then used to rank the assets from most- to least-likely to develop. This ranked list is stored in a .csv file (‘devpot_aoi02_20180916.csv’) used to load the ‘ranked_l’ object of the ‘ranked_choice’ function (of the Selector described above). This same ranked list is used for all scenarios in this study. This list is spatially displayed in Figure 11-1.

Figure 11-1: Development potential ranking for study area. Red parcels are most likely to develop while green parcels are least likely.

12. Dynamic Parameters (Dynp)

The Dynps utilized in this study are described on the ‘dynp’ tab in: Attachment B for the Fo scenarios, and Attachment C for the Ft3 scenarios. Key stochastic parameters are reproduced in the following figures. The basement finish height Dynp for new houses (d_bfh_n) is a piece of the statistical model described in section 4.1. Stochastic parameters for the remaining Dynps were developed from expert knowledge of what ‘seems reasonable’ (p.c. D. Sol).

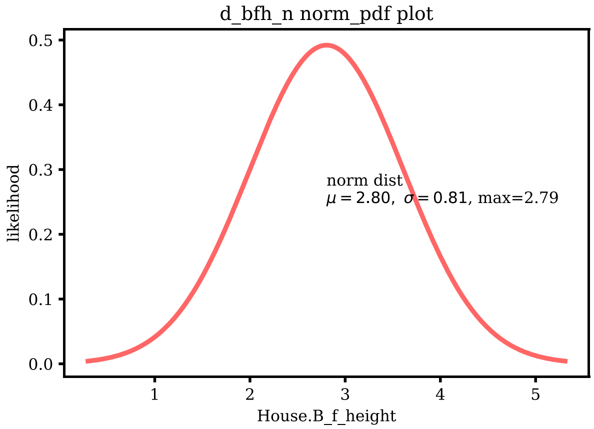


Figure 12-1: Probability distribution for the House basement finish height parameter.

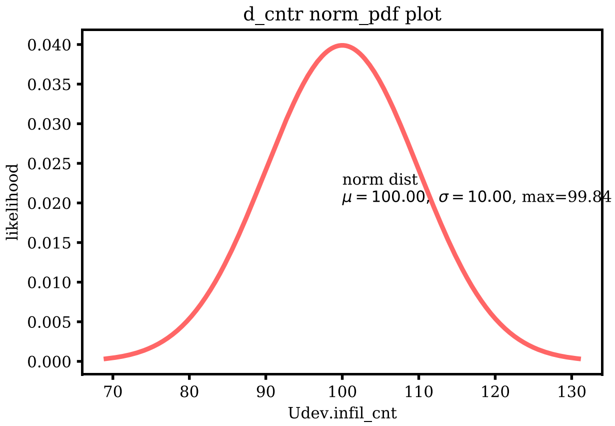


Figure 12-2: Probability distribution for the infill count parameter.

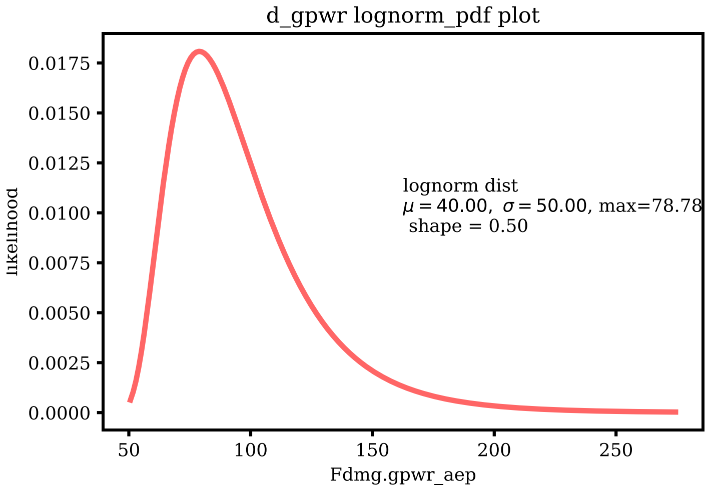


Figure 12-3: Probability distribution for the Flood grid power parameter

13. Outputs

The outputs used for this study are described in Attachment C.

Attachment A: Building Inventory

ID	ClAss	StruCt_Ty	area_GIS_	Bsmt-Prk	Height_m	integrated	~new cols >	~from assessment >	land_value	value	~val_area_r	devpot_rnk	ayoc	parcel_area	~stats model >	B_f_height
10300	C	A	48.55471	Y	0.7	1045.42554			$ 591,088	$ 520,500	1077.7	1	1910	482.954		3.6
8561	B	A	165.4689	Y	1.4	1045.59509			$ 701,193	$ 908,500	1083.5	2	1949	838.495		1.8
10155	C	A	96.87084	Y	0.7	1045.52014			$ 683,981	$ 755,000	1089.0	3	1950	693.275		3.6
10922	C	A	100.2087	Y	0.7	1047.40125			$ 1,121,626	$ 617,000	1107.3	4	1910	557.2		1.8
9368	C	A	74.59067	Y	0.7	1045.61292			$ 466,867	$ 490,500	1177.2	5	1910	416.65		1.984647
9952	C	A	68.9147	Y	0.7	1045.37952			$ 420,595	$ 428,500	1214.0	6	1944	352.958		3.6
10142	C	A	70.88806	Y	0.7	1045.93176			$ 606,627	$ 666,000	1228.7	7	1942	542.047		1.8
8199	C	A	91.77919	Y	0.7	1045.1582			$ 461,495	$ 465,500	1236.6	8	1928	376.442		3.6
9435	C	A	117.179	Y	0.7	1046.39465			$ 753,570	$ 826,500	1238.0	9	1911	667.628		1.8
8235	B	D	88.3622	Y	0.7	1045.10852			$ 478,581	$ 493,500	1248.9	10	1911	395.138		3.6
8787	B	D	96.29473	Y	0.7	1045.69421			$ 525,363	$ 566,000	1264.9	11	1920	447.46		2.07728
8789	B	D	94.58212	Y	0.7	1045.7655			$ 470,708	$ 489,500	1266.5	12	1914	386.495		2.478241
8110	C	A	95.15263	Y	0.7	1045.12549			$ 466,870	$ 531,000	1274.4	13	1912	416.653		1.8
9950	B	D	84.12727	Y	0.7	1045.39087			$ 556,398	$ 622,000	1287.7	14	1980	483.047		1.8
8188	C	A	55.21994	Y	0.7	1045.87817			$ 554,968	$ 539,500	1289.7	15	1941	418.301		1.8
8343	B	D	100.2441	Y	0.7	1045.19067			$ 585,454	$ 722,500	1295.0	16	1989	557.909		2.419798
9878	B	D	92.57423	Y	0.7	1045.07422			$ 498,948	$ 544,500	1303.5	17	1997	417.717		2.319394
8200	B	D	125.7143	Y	0.7	1045.29614			$ 523,954	$ 589,500	1322.2	18	1982	445.861		3.6
8284	C	A	96.07742	Y	0.7	1045.20166			$ 484,015	$ 531,500	1325.0	19	1920	401.131		2.852722
8387	C	A	106.8801	Y	0.7	1045.39319			$ 526,544	$ 648,500	1325.8	20	2016	489.132		1.8
8948	C	A	51.66428	Y	0.7	1047.02466			$ 624,141	$ 557,500	1333.3	21	1945	418.124		1.8
10287	A	D	186.76	Y	0.7	1045.42114			$ 732,105	$ 936,500	1344.6	22	1989	696.476		1.8
8814	B	D	126.0177	Y	0.7	1044.66528			$ 473,440	$ 524,000	1345.4	23	1913	389.489		3.6
9263	C	A	79.64381	Y	0.7	1046.60046			$ 658,028	$ 751,000	1347.8	24	1951	557.223		1.8
10028	C	A	85.19224	Y	0.7	1045.69812			$ 689,865	$ 759,500	1358.5	25	1915	559.093		3.6
10198	C	D	65.31623	Y	0.7	1047.00037			$ 530,674	$ 570,500	1363.9	26	1910	418.286		1.8
8435	C	A	97.85271	Y	0.7	1045.59302			$ 938,418	$ 809,500	1369.9	27	1930	590.898		1.8
9877	C	D	66.79423	Y	0.7	1044.96191			$ 368,162	$ 382,500	1373.3	28	1914	278.522		3.6
8329	C	A	78.38074	Y	0.7	1045.61182			$ 555,597	$ 577,500	1378.5	29	1945	418.933		1.8
9951	B	D	91.14783	Y	0.7	1045.4054			$ 490,826	$ 569,500	1393.5	30	1916	408.675		1.8
8255	C	A	124.7739	Y	0.7	1048.46289			$ 547,472	$ 729,000	1394.9	31	1925	522.602		1.8
9364	C	A	95.82667	Y	0.7	1045.00232			$ 466,191	$ 586,500	1410.4	32	1951	415.845		2.018827
10159	C	A	87.89836	Y	1.2	1046.1283			$ 772,557	$ 785,000	1412.6	33	1944	555.694		2.178957
8401	C	A	156.8728	Y	0.7	1046.13232			$ 795,617	$ 748,500	1417.4	34	1954	528.067		2.521017
8493	B	A	117.0514	Y	1	1045.99634			$ 561,133	$ 593,500	1421.4	35	1947	417.535		1.8
8922	C	A	75.49029	Y	0.7	1046.27698			$ 529,753	$ 594,000	1423.4	36	1921	417.318		3.6
8116	C	A	110.4829	Y	0.7	1045.26721			$ 696,532	$ 794,000	1425.5	37	1929	557		1.869254
9892	C	A	60.70466	Y	0.7	1045.45056			$ 498,333	$ 596,500	1430.4	38	1946	417.03		1.8
9735	C	A	109.3029	Y	0.7	1048.52197			$ 553,718	$ 649,500	1432.3	39	1911	453.457		1.8
8778	C	A	104.6522	Y	0.7	1045.28638			$ 560,660	$ 598,500	1435.0	40	1920	417.066		1.8
8075	C	A	82.74642	Y	0.7	1046.29297			$ 529,896	$ 601,000	1439.6	41	1950	417.469		2.950323
9561	C	A	88.66917	Y	0.7	1047.26599			$ 657,865	$ 802,000	1439.8	42	1948	557.039		1.8
10362	C	A	84.43804	Y	0.7	1045.63318			$ 554,071	$ 601,000	1439.9	43	1949	417.4		1.8
8673	C	A	76.06951	Y	0.7	1047.39563			$ 657,811	$ 807,500	1449.8	44	1948	556.978		1.8
9375	B	D	81.20529	Y	0.7	1047.15979			$ 751,082	$ 816,500	1464.9	45	1911	557.377		1.8
8279	C	A	110.5601	Y	0.7	1047.13818			$ 774,287	$ 816,500	1465.0	46	1923	557.354		1.8
9084	C	A	100.366	Y	0.7	1047.14954			$ 696,791	$ 816,500	1465.1	47	1951	557.282		1.8
8234	B	D	78.61363	Y	0.7	1045.17029			$ 404,967	$ 467,000	1476.7	48	1911	316.253		3.6
8790	C	A	95.96245	Y	0.7	1045.7052			$ 688,251	$ 824,000	1478.4	49	1929	557.349		2.109566
10154	C	D	79.83179	Y	0.7	1045.65576			$ 554,513	$ 620,500	1485.0	50	1913	417.844		3.6
10061	B	A	120.4213	Y	0.7	1048.18262			$ 547,661	$ 777,000	1486.1	51	1950	522.842		2.096825
10826	B	D	123.5239	Y	0.7	1049.46436			$ 870,717	$ 1,520,000	1488.9	52	1996	1020.917		2.398663
8328	B	D	82.49492	Y	0.7	1045.65295			$ 554,563	$ 622,500	1489.6	53	1911	417.894		3.6
9400	C	A	97.79416	Y	0.7	1046.03442			$ 609,976	$ 697,000	1493.5	54	1985	466.683		3.6
8949	C	D	71.74845	Y	0.7	1047.19092			$ 574,090	$ 624,500	1494.0	55	2016	418.008		3.6
8327	C	D	75.2512	Y	0.7	1045.30322			$ 345,667	$ 413,000	1494.5	56	1983	276.344		1.8
8492	B	D	80.35938	Y	0.7	1048.32751			$ 852,148	$ 1,050,000	1499.8	57	1913	700.103		1.8
10566	C	A	96.6461	Y	0.7	1046.35596			$ 845,970	$ 1,040,000	1500.0	58	1947	693.343		3.6
8170	C	D	69.41455	Y	0.7	1046.44556			$ 571,075	$ 559,000	1505.1	59	1920	371.409		1.8
8157	C	A	88.68622	Y	0.7	1045.66125			$ 553,855	$ 628,500	1506.5	60	1939	417.183		2.281128
8804	B	D	80.05152	Y	0.7	1045.89197			$ 755,601	$ 838,500	1508.4	61	2002	555.902		3.6
8518	B	D	134.0118	Y	0.7	1046.29236			$ 921,428	$ 922,500	1508.4	62	1993	611.57		1.8
8947	B	D	87.82123	Y	0.7	1046.22913			$ 593,604	$ 633,500	1512.8	63	1915	418.754		1.8
9135	B	D	96.60966	Y	0.4	1045.92285			$ 560,900	$ 631,500	1513.3	64	1979	417.304		1.954474
9048	C	A	98.9573	Y	0.7	1046.28638			$ 593,019	$ 634,500	1517.2	65	1925	418.204		3.6
8062	B	D	68.78721	Y	0.7	1046.15112			$ 594,219	$ 638,500	1522.7	66	1979	419.333		1.8
9868	C	D	63.77749	Y	0.7	1045.28967			$ 344,282	$ 425,500	1532.9	67	1912	277.587		3.6
9861	B	D	88.05354	Y	0.7	1045.80688			$ 756,979	$ 854,500	1533.4	68	1989	557.254		3.6
10285	C	A	82.28939	Y	0.7	1048.87476			$ 681,620	$ 858,000	1541.4	69	1947	556.63		3.6
8078	B	D	90.16612	Y	0.7	1045.56909			$ 433,506	$ 534,500	1543.4	70	1988	346.313		3.6
9823	B	D	101.8397	Y	0.7	1047.03003			$ 561,771	$ 645,500	1543.6	71	1910	418.168		3.6
8648	B	A	163.6715	Y	0.7	1049.08289			$ 845,595	$ 1,070,000	1544.2	72	1991	692.934		3.6
8133	B	D	97.33127	Y	0.7	1047.31152			$ 592,939	$ 647,000	1547.4	73	1910	418.129		3.135681
8145	C	A	102.8514	Y	0.7	1048.62354			$ 522,382	$ 701,000	1548.2	74	1925	452.794		1.991786
8174	C	A	112.2007	Y	0.7	1045.46191			$ 526,744	$ 571,000	1553.8	75	1927	367.492		1.8
10150	C	A	97.62687	Y	0.7	1045.96338			$ 592,709	$ 649,500	1554.2	76	1950	417.913		1.8
8478	B	D	82.0465	Y	0.7	1045.39026			$ 344,303	$ 432,000	1556.1	77	1911	277.61		1.974895
10162	C	A	107.9703	Y	0.7	1046.18005			$ 592,209	$ 651,500	1560.7	78	1911	417.443		3.6
8565	C	A	77.48114	Y	0.7	1045.32947			$ 280,534	$ 327,500	1565.5	79	1912	209.196		3.6
8608	B	A	88.62159	Y	1	1046.38745			$ 589,536	$ 698,500	1566.3	80	1945	445.949		1.8
8086	B	A	87.62305	Y	1.2	1045.98462			$ 733,542	$ 870,500	1567.6	81	1950	555.303		2.541172
8799	C	A	87.01446	Y	1.2	1045.69568			$ 591,527	$ 656,500	1575.1	82	2001	416.802		1.8
8571	C	A	64.24209	Y	0.7	1044.73254			$ 457,844	$ 449,000	1575.2	83	1910	285.035		1.8
9360	C	A	72.91066	Y	0.7	1046.10242			$ 408,830	$ 440,000	1581.0	84	1911	278.306		1.8
8045	C	A	107.1118	Y	0.7	1046.38647			$ 592,543	$ 660,500	1581.1	85	2008	417.757		2.73563
10044	B	D	114.6044	Y	0.7	1045.18738			$ 757,052	$ 886,500	1590.6	86	2007	557.326		3.6
10355	B	D	100.6043	Y	1	1044.97754			$ 590,555	$ 664,500	1597.8	87	1975	415.889		3.6
9441	B	D	78.7689	Y	0.7	1046.19556			$ 591,888	$ 667,000	1599.0	88	1908	417.141		2.139859
10304	C	A	65.81656	Y	0.7	1045.0332			$ 409,241	$ 447,000	1604.0	89	1912	278.679		3.6
9372	C	A	86.61942	Y	0.7	1048.37341			$ 429,761	$ 561,000	1607.2	90	2004	349.049		3.6
9387	B	D	67.63796	Y	1	1045.53857			$ 591,440	$ 670,500	1609.0	91	1995	416.72		3.6
8781	B	D	76.31841	Y	0.7	1044.73315			$ 368,120	$ 448,500	1610.5	92	1981	278.48		3.6
10181	C	D	65.95056	Y	0.7	1046.50134			$ 368,338	$ 449,500	1612.8	93	1912	278.7		1.8
10305	B	A	149.3459	Y	0.7	1045.37561			$ 687,900	$ 898,500	1613.2	94	2014	556.97		2.504759
8162	B	D	99.33699	Y	0.7	1046.27722			$ 590,921	$ 672,500	1615.7	95	1911	416.233		1.8
9002	C	A	66.53438	Y	0.7	1045.18469			$ 459,992	$ 450,000	1616.7	96	2000	278.353		3.6
9354	C	A	110.0365	Y	0.7	1046.05969			$ 529,967	$ 675,500	1617.8	97	1960	417.543		1.8
10264	C	A	80.74835	Y	0.7	1045.42688			$ 459,987	$ 452,500	1625.7	98	1915	278.349		3.358215
8950	C	A	78.96287	Y	0.7	1046.72583			$ 592,801	$ 681,500	1630.4	99	1970	417.999		3.6
8087	C	A	91.83145	Y	0.7	1047.23901			$ 605,261	$ 682,000	1631.7	100	1951	417.981		1.8

ID	ClAss	StruCt_Ty	area_GIS_	Bsmt-Prk	Height_m	integrated	~new cols >	~from assessment >	land_value	value	~val_area_r	devpot_rnk	ayoc	parcel_area	~stats model >	B_f_height
8352	C	A	89.60962	Y	0.7	1045.52869			$ 459,980	$ 454,500	1632.9	101	1915	278.343		1.8
10143	C	A	78.40609	Y	0.7	1045.86853			$ 408,627	$ 455,000	1636.0	102	1914	278.121		3.6
9900	C	A	95.17886	Y	0.7	1045.49658			$ 409,240	$ 456,000	1636.3	103	1912	278.678		3.6
8441	C	A	101.0119	Y	0.7	1048.81677			$ 595,514	$ 762,000	1639.0	104	1913	464.907		3.6
8198	C	A	102.8222	Y	0.7	1047.40796			$ 437,358	$ 459,000	1647.2	105	1912	278.663		3.6
8485	C	D	83.08831	Y	0.6	1047.30005			$ 542,235	$ 612,000	1648.9	106	1914	371.148		2.202897
8250	C	A	63.1004	Y	0.7	1045.1123			$ 408,647	$ 459,000	1650.2	107	1912	278.14		1.8
8710	C	A	76.64564	Y	0.7	1045.27893			$ 408,670	$ 460,000	1653.7	108	1912	278.16		1.8
8389	C	A	68.4849	Y	0.7	1045.06555			$ 409,242	$ 461,500	1656.0	109	1912	278.68		1.8
8085	C	A	83.32143	Y	0.7	1047.16357			$ 624,167	$ 694,500	1660.9	110	1914	418.147		1.8
10693	C	D	61.48586	Y	0.7	1046.80676			$ 501,407	$ 556,000	1662.9	111	1910	334.362		1.8
10062	B	D	165.8019	Y	0.7	1046.65588			$ 773,405	$ 926,000	1664.0	112	1957	556.507		1.8
8578	C	A	61.9373	Y	0.7	1047.41125			$ 437,372	$ 464,500	1666.8	113	1910	278.675		3.200251
8058	C	A	106.8334	Y	0.7	1046.56628			$ 542,446	$ 619,000	1666.9	114	1930	371.34		3.6
8432	C	A	74.26353	Y	0.7	1045.97461			$ 391,241	$ 465,000	1669.1	115	1920	278.588		2.69616
11044	C	A	86.68301	Y	0.7	1047.38171			$ 684,301	$ 874,000	1672.5	116	1949	522.562		2.286284
8424	C	A	75.81628	Y	0.7	1045.37292			$ 408,932	$ 466,000	1673.9	117	1912	278.398		3.6
9431	C	D	70.78449	Y	0.7	1045.48047			$ 408,736	$ 466,000	1674.9	118	1912	278.22		3.461372
9763	C	A	116.2262	Y	0.7	1046.53882			$ 542,633	$ 622,500	1675.6	119	1912	371.511		1.8
8101	C	A	80.29913	Y	0.7	1045.52527			$ 413,236	$ 465,500	1676.4	120	1912	277.674		1.8
10758	C	A	65.07121	Y	1	1047.63574			$ 437,081	$ 467,000	1677.3	121	1920	278.428		2.850407
8618	C	A	80.09772	Y	0.7	1046.40869			$ 571,071	$ 623,000	1677.4	122	1996	371.406		3.6
10399	C	A	67.32165	Y	0.7	1045.45496			$ 414,012	$ 467,000	1677.6	123	1915	278.37		3.6
10361	C	A	77.8133	Y	0.7	1045.51355			$ 409,270	$ 468,000	1679.2	124	1912	278.705		1.837609
10272	B	D	159.0394	Y	0.7	1046.76392			$ 828,229	$ 998,000	1680.6	125	1993	593.83		3.6
9100	C	A	96.27843	Y	0.7	1045.55945			$ 408,820	$ 468,500	1683.5	126	1912	278.297		2.561479
9381	C	A	93.75129	Y	0.7	1045.3584			$ 413,833	$ 468,500	1684.0	127	1912	278.209		1.8
8812	B	D	93.9912	Y	0.7	1047.38855			$ 592,768	$ 704,000	1684.3	128	2012	417.968		2.082325
9268	C	A	72.00767	Y	0.7	1045.48792			$ 408,849	$ 469,000	1685.1	129	1912	278.323		1.8
8788	B	D	91.46854	Y	0.7	1045.8042			$ 507,534	$ 720,500	1686.1	130	1980	427.329		1.8
9378	C	A	49.18507	Y	0.7	1045.84033			$ 409,068	$ 470,000	1687.5	131	1915	278.522		3.140131
8423	C	A	99.40604	Y	0.7	1045.48425			$ 409,240	$ 470,500	1688.3	132	1912	278.678		2.903963
8520	B	D	176.791	Y	0.7	1045.90039			$ 686,984	$ 939,000	1688.9	133	2013	555.982		1.8
9550	C	A	76.84667	Y	0.7	1045.33777			$ 409,240	$ 472,000	1693.7	134	1912	278.678		3.6
8330	C	D	86.80572	Y	0.7	1046.08093			$ 408,815	$ 471,500	1694.3	135	1912	278.292		1.8
8106	B	D	66.38038	Y	0.7	1045.61047			$ 555,179	$ 710,000	1696.5	136	1912	418.513		3.6
10310	C	A	75.49338	Y	0.7	1047.04822			$ 683,375	$ 885,000	1696.6	137	1951	521.62		3.6
8669	C	A	99.945	Y	1	1045.06311			$ 368,799	$ 474,000	1697.9	138	1979	279.165		1.8
8528	C	A	86.5039	Y	0.7	1045.18835			$ 413,722	$ 473,000	1700.8	139	1912	278.11		1.8
10026	C	A	66.00137	Y	0.7	1045.53308			$ 414,045	$ 475,500	1708.0	140	1915	278.399		3.6
10144	B	A	137.676	Y	0.7	1045.80261			$ 557,924	$ 829,000	1709.9	141	1929	484.814		1.8
8563	C	A	61.96741	Y	0.7	1045.35498			$ 279,971	$ 357,000	1711.1	142	1914	208.637		3.6
8402	C	A	68.7481	Y	0.7	1046.01526			$ 437,463	$ 477,500	1713.0	143	1913	278.752		1.8
9356	B	D	67.48171	Y	0.7	1045.59375			$ 409,238	$ 478,000	1715.3	144	1912	278.676		1.8
10919	C	A	73.09746	Y	0.7	1048.87183			$ 471,948	$ 585,000	1715.7	145	1941	340.959		1.8
8104	C	A	94.87873	Y	0.7	1045.495			$ 409,239	$ 478,500	1717.0	146	1979	278.677		1.8
8070	B	D	90.67618	Y	1	1045.60828			$ 590,456	$ 715,500	1720.8	147	2014	415.796		3.6
10030	C	A	84.59705	Y	0.7	1045.26709			$ 460,001	$ 479,500	1722.6	148	1950	278.36		2.941398
10058	C	A	95.93167	Y	0.7	1048.73853			$ 626,116	$ 800,500	1724.6	149	1911	464.175		3.6
9282	B	D	83.31965	Y	0.7	1047.00537			$ 391,194	$ 481,500	1728.6	150	1983	278.543		3.394728
8153	B	D	75.19939	Y	0.7	1045.47595			$ 344,315	$ 481,000	1732.6	151	2003	277.622		3.476906
10306	C	D	72.76073	Y	0.7	1045.54163			$ 409,001	$ 483,000	1734.5	152	1912	278.461		1.8
10377	C	A	63.3118	Y	0.7	1046.2207			$ 437,374	$ 483,500	1735.0	153	1912	278.677		1.8
9269	C	A	59.98666	Y	0.7	1045.89429			$ 408,868	$ 483,000	1735.3	154	1911	278.34		1.8
8556	B	D	99.36034	Y	0.7	1049.09644			$ 692,975	$ 989,000	1738.1	155	1985	569.028		3.6
9432	C	D	66.03893	Y	0.7	1045.66711			$ 409,535	$ 485,000	1738.7	156	1910	278.946		3.00096
9251	C	A	71.23933	Y	0.7	1045.57129			$ 413,853	$ 484,000	1739.6	157	1950	278.227		3.6
10360	C	A	76.57171	Y	0.7	1045.40662			$ 408,846	$ 484,500	1740.8	158	1910	278.32		1.8
9450	C	A	80.12774	Y	0.7	1045.08142			$ 408,868	$ 485,000	1742.5	159	1912	278.34		1.8
9737	C	A	112.4455	Y	0.7	1048.19299			$ 685,008	$ 912,000	1742.8	160	1914	523.282		1.8
10363	C	A	108.5543	Y	0.7	1046.54004			$ 542,487	$ 647,500	1743.5	161	1912	371.378		1.8
10146	C	A	80.62006	Y	0.7	1045.64709			$ 367,852	$ 486,000	1746.9	162	1958	278.21		1.8
8335	B	D	102.4848	Y	0.7	1048.7002			$ 648,156	$ 910,000	1748.3	163	1912	520.495		3.6
8391	C	D	77.10478	Y	0.7	1045.52539			$ 408,639	$ 486,500	1749.2	164	1912	278.132		1.8
10705	C	A	106.6366	Y	0.7	1048.82983			$ 560,051	$ 750,000	1750.8	165	1912	428.365		1.981724
9102	B	D	130.1857	Y	0.7	1045.31714			$ 590,708	$ 728,500	1751.1	166	1991	416.033		1.8
8541	B	D	79.77549	Y	0.8	1046.10974			$ 561,101	$ 731,500	1752.1	167	1912	417.503		3.6
9389	B	D	120.6132	Y	0.7	1048.52783			$ 605,020	$ 832,000	1752.2	168	1968	474.828		3.6
11024	C	A	91.44049	Y	0.7	1047.08252			$ 414,530	$ 489,000	1753.7	169	1981	278.834		2.107321
9281	C	A	84.38267	Y	0.7	1048.37952			$ 437,105	$ 488,500	1754.4	170	1918	278.448		1.8
10952	C	A	87.37561	Y	0.7	1047.27478			$ 414,469	$ 490,000	1757.7	171	1912	278.78		3.6
10463	B	D	70.11074	Y	0.7	1047.97876			$ 417,820	$ 461,000	1758.3	172	1914	262.19		2.628905
10020	C	A	87.37741	Y	0.7	1046.89709			$ 437,418	$ 490,500	1759.9	173	1927	278.714		3.6
10726	C	D	56.68931	Y	0.7	1046.87952			$ 437,341	$ 491,000	1762.1	174	1912	278.649		1.8
9944	C	A	108.9588	Y	0.7	1045.34204			$ 408,605	$ 490,500	1763.7	175	1988	278.101		1.8
8463	C	D	69.98794	Y	1	1045.99756			$ 473,958	$ 588,000	1763.8	176	1912	333.369		3.6
10259	C	A	84.65154	Y	0.7	1047.07239			$ 436,172	$ 491,000	1768.4	177	1910	277.656		3.389153
9383	C	D	77.82934	Y	0.7	1044.75305			$ 367,586	$ 492,500	1772.0	178	1958	277.942		3.6
10899	C	A	76.07897	Y	0.7	1047.12732			$ 414,500	$ 494,500	1773.6	179	1990	278.807		1.853764
8603	B	D	126.4686	Y	0.7	1048.56555			$ 766,871	$ 1,080,000	1775.5	180	2000	608.282		1.8
8786	B	D	97.80826	Y	0.7	1044.80664			$ 368,141	$ 495,500	1779.2	181	1978	278.501		3.6
10704	C	A	77.57773	Y	0.7	1046.36243			$ 437,393	$ 496,000	1779.7	182	1910	278.693		1.8
9936	C	A	67.75825	Y	0.7	1046.37817			$ 437,511	$ 497,500	1784.5	183	1932	278.793		1.968759
8917	C	D	59.1812	Y	0.7	1045.46094			$ 344,292	$ 495,500	1785.0	184	1911	277.598		1.8
9252	C	A	90.23736	Y	0.7	1046.40332			$ 516,563	$ 621,000	1785.0	185	1910	347.905		1.8
9982	B	D	88.48515	Y	0.7	1049.5459			$ 605,212	$ 848,500	1786.2	186	1980	475.029		3.158653
8921	C	A	76.37932	Y	0.7	1045.5719			$ 347,697	$ 497,500	1786.3	187	1945	278.51		1.8
8545	C	A	80.56513	Y	0.7	1048.58362			$ 454,407	$ 622,500	1786.7	188	1950	348.4		2.300853
8456	C	D	59.78873	Y	0.7	1046.91003			$ 437,404	$ 499,500	1792.2	189	1905	278.702		2.872054
8567	C	D	76.3421	Y	0.7	1045.35486			$ 279,982	$ 374,000	1792.5	190	1914	208.648		3.6
9000	C	A	96.1417	Y	0.7	1045.53503			$ 409,238	$ 500,500	1796.0	191	1912	278.676		1.8
9448	C	A	93.52163	Y	1	1044.97961			$ 369,055	$ 502,500	1798.3	192	1910	279.424		3.6
10178	B	D	128.2635	Y	0.7	1045.8197			$ 874,650	$ 967,500	1798.4	193	2011	537.977		1.8
9863	C	A	85.8836	Y	0.7	1045.36243			$ 409,242	$ 502,000	1801.3	194	1912	278.68		2.971806
10151	B	D	80.32108	Y	0.7	1045.66479			$ 499,022	$ 656,000	1806.9	195	1912	363.043		2.878277
8258	C	D	69.53997	Y	0.7	1046.43896			$ 436,862	$ 503,000	1807.8	196	1911	278.242		3.6
9219	C	D	48.08691	Y	0.7	1047.31018			$ 485,915	$ 641,000	1808.3	197	1911	354.479		2.189492
8474	C	A	73.22225	Y	0.7	1047.43176			$ 437,379	$ 504,000	1808.5	198	1912	278.681		2.706971
10728	C	A	58.4803	Y	0.7	1047.27014			$ 414,487	$ 504,500	1809.6	199	1998	278.796		3.355618
9288	B	D	129.9315	Y	0.7	1046.84924			$ 774,324	$ 1,010,000	1812.0	200	1982	557.389		3.6

ID	ClAss	StruCt_Ty	area_GIS_	Bsmt-Prk	Height_m	integrated	~new cols >	~from assessment >	land_value	value	~val_area_r	devpot_rnk	ayoc	parcel_area	~stats model >	B_f_height
8100	C	A	91.0569	Y	0.7	1045.78687			$ 408,795	$ 505,500	1816.6	201	2014	278.274		1.8
8333	C	A	84.45502	Y	0.7	1047.38428			$ 437,411	$ 506,500	1817.3	202	1905	278.708		3.6
9267	C	D	63.39593	Y	0.7	1045.46045			$ 409,239	$ 506,500	1817.5	203	1912	278.677		3.503825
9455	B	D	74.14135	Y	0.7	1046.48523			$ 391,292	$ 507,000	1819.6	204	1913	278.636		1.8
10662	C	A	106.1781	Y	0.7	1049.30103			$ 480,598	$ 636,500	1819.6	205	1911	349.799		3.351045
9076	B	D	103.0246	Y	0.4	1046.78979			$ 414,459	$ 507,500	1820.5	206	1974	278.771		3.6
8156	C	D	67.97364	Y	0.2	1046.93713			$ 436,998	$ 507,500	1823.2	207	1908	278.357		1.8
8908	B	D	73.74754	Y	1	1047.57837			$ 409,032	$ 499,500	1823.6	208	1982	273.914		3.6
8040	C	D	70.97827	Y	0.7	1045.52319			$ 413,248	$ 506,500	1824.0	209	1915	277.685		1.8
8066	B	D	124.9991	Y	0.7	1046.44226			$ 529,599	$ 761,000	1824.3	210	1911	417.157		3.6
9385	C	A	78.40547	Y	0.7	1046.77124			$ 437,440	$ 508,500	1824.3	211	1928	278.733		1.8
8105	C	A	84.14067	Y	0.7	1045.5083			$ 408,903	$ 509,000	1828.5	212	2013	278.372		3.001816
9104	B	D	84.83472	Y	0.7	1045.83521			$ 470,010	$ 613,000	1828.9	213	1912	335.177		1.8
8591	C	A	87.24834	Y	0.7	1046.83752			$ 437,350	$ 510,000	1830.2	214	1911	278.656		3.164564
8614	B	A	119.6816	Y	0.7	1048.69836			$ 615,276	$ 831,000	1832.5	215	1911	453.491		3.6
10077	B	D	108.6739	Y	0.7	1047.64612			$ 453,330	$ 639,000	1833.7	216	1912	348.481		2.968975
10040	C	A	76.3489	Y	0.7	1047.40833			$ 460,343	$ 511,000	1833.9	217	1914	278.636		1.8
8772	C	D	83.62833	Y	1.2	1047.62			$ 414,096	$ 511,000	1835.2	218	2015	278.445		1.8
10921	C	A	83.9398	Y	0.7	1047.73364			$ 435,359	$ 508,500	1836.0	219	1927	276.966		3.6
8092	C	A	96.63709	Y	0.7	1046.51709			$ 437,006	$ 512,000	1839.3	220	1910	278.364		2.319634
9093	B	D	100.2642	Y	0.7	1046.41943			$ 390,936	$ 512,000	1839.8	221	1980	278.298		3.6
10307	C	A	70.57582	Y	0.7	1046.04297			$ 436,366	$ 513,000	1846.5	222	1912	277.821		2.538173
10685	C	A	102.2916	Y	0.7	1047.33508			$ 438,533	$ 516,500	1846.9	223	1915	279.662		1.8
9373	C	D	62.53323	Y	0.7	1046.54236			$ 437,494	$ 515,000	1847.3	224	1914	278.779		1.8
8354	C	A	79.80914	Y	0.7	1046.49902			$ 492,580	$ 515,000	1848.2	225	1990	278.646		1.8
8404	C	A	69.75783	Y	0.7	1046.39551			$ 391,226	$ 515,500	1850.5	226	1912	278.574		1.8
10568	C	A	72.3922	Y	0.7	1047.12769			$ 460,673	$ 517,000	1853.7	227	1910	278.902		3.6
8931	C	A	93.18587	Y	0.7	1046.77075			$ 460,357	$ 517,000	1855.4	228	1911	278.647		3.456915
8280	C	A	73.49642	Y	0.7	1045.64209			$ 436,020	$ 515,000	1855.7	229	1912	277.527		3.6
9888	C	D	48.83668	Y	0.7	1047.79224			$ 437,093	$ 517,000	1856.8	230	1915	278.438		1.8
9744	B	D	83.16348	Y	0.7	1046.58728			$ 437,395	$ 517,500	1856.9	231	1917	278.695		2.851919
10576	A	D	148.2921	Y	0.7	1046.86401			$ 696,874	$ 994,500	1857.5	232	1994	535.403		1.8
9498	C	A	93.20301	Y	0.7	1046.92065			$ 534,173	$ 698,000	1858.4	233	1913	375.593		3.6
8166	C	A	71.45492	Y	0.7	1048.28088			$ 437,120	$ 518,000	1860.2	234	1918	278.461		1.8
10824	C	A	76.22709	Y	0.6	1046.82751			$ 414,331	$ 519,500	1864.3	235	1992	278.656		1.8
8237	C	D	88.64493	Y	0.7	1045.42798			$ 408,933	$ 519,500	1866.0	236	1986	278.399		2.735755
8454	C	A	85.42293	Y	0.7	1046.95679			$ 483,642	$ 658,000	1867.9	237	1911	352.27		1.8
9452	C	A	79.12833	Y	0.7	1046.33582			$ 391,238	$ 520,500	1868.4	238	1914	278.585		1.998428
10572	C	A	80.56593	Y	0.7	1047.32031			$ 414,476	$ 522,000	1872.4	239	1967	278.786		1.8
8919	B	D	53.70136	Y	0.7	1045.22131			$ 413,704	$ 521,000	1873.5	240	1912	278.094		3.6
10279	C	A	71.84993	Y	0.7	1045.27161			$ 460,007	$ 522,500	1877.0	241	1915	278.365		1.8
10396	C	A	69.08377	Y	0.7	1045.48315			$ 413,219	$ 522,500	1881.8	242	1912	277.659		1.8
9464	C	A	89.61501	Y	0.7	1047.42432			$ 437,348	$ 525,000	1884.1	243	1910	278.655		3.6
9280	C	D	67.79652	Y	0.7	1048.69421			$ 482,219	$ 662,000	1886.6	244	2000	350.889		3.6
8747	C	A	69.74837	Y	0.7	1046.66211			$ 438,398	$ 527,500	1887.0	245	1980	279.547		1.8
9094	C	A	65.88051	Y	0.7	1046.91382			$ 437,433	$ 526,500	1888.9	246	2007	278.727		3.6
9903	C	A	68.68984	Y	0.7	1045.79663			$ 436,272	$ 525,000	1890.3	247	1912	277.741		2.234453
8372	B	D	83.9639	Y	0.7	1045.54175			$ 439,591	$ 620,500	1892.3	248	1912	327.916		1.8
9355	B	D	55.68679	Y	0.7	1045.21216			$ 348,111	$ 528,000	1892.8	249	2013	278.952		3.282253
10897	C	D	56.74447	Y	0.7	1048.84082			$ 225,185	$ 342,000	1893.5	250	1914	180.619		1.930064
8501	B	D	82.7982	Y	0.7	1046.05603			$ 592,769	$ 791,500	1893.7	251	1996	417.969		3.6
8507	C	A	74.55495	Y	0.7	1046.7113			$ 469,631	$ 528,000	1894.5	252	1910	278.7		3.531392
9570	C	A	94.48993	Y	0.7	1047.18372			$ 446,581	$ 528,000	1894.7	253	1911	278.676		1.8
8771	C	A	54.83483	Y	0.7	1047.85168			$ 459,937	$ 527,500	1895.4	254	1997	278.308		1.805015
8179	B	D	111.8418	Y	1	1045.40247			$ 560,599	$ 790,500	1895.7	255	2011	417.005		1.8
9614	C	A	67.75782	Y	0.7	1045.41003			$ 413,756	$ 528,000	1895.9	256	1915	278.5		3.428699
10174	C	A	94.54868	Y	0.7	1048.84082			$ 479,831	$ 661,000	1896.3	257	1914	348.574		1.8
9869	C	A	79.02346	Y	0.7	1049.22705			$ 538,749	$ 721,500	1899.2	258	1930	379.889		3.6
8521	C	A	77.35614	Y	0.7	1046.23608			$ 437,863	$ 530,500	1900.8	259	1992	279.092		1.8
8488	C	A	162.5327	Y	0.7	1048.54761			$ 504,443	$ 662,000	1902.4	260	1929	347.983		3.6
9456	C	A	61.98682	Y	0.7	1046.43481			$ 460,359	$ 531,000	1905.6	261	1911	278.649		3.570535
8514	C	A	79.8	Y	0.7	1047.33313			$ 460,320	$ 531,500	1907.6	262	1914	278.617		3.6
10465	C	A	57.7528	Y	0.7	1046.80786			$ 437,005	$ 531,500	1909.4	263	1912	278.363		2.112902
9445	C	A	81.28011	Y	0.7	1045.35376			$ 408,373	$ 532,000	1914.4	264	1910	277.891		1.8
8295	C	A	88.43399	Y	0.7	1047.46729			$ 437,364	$ 534,000	1916.3	265	2012	278.668		1.8
8487	C	A	65.11316	Y	0.7	1046.67981			$ 492,580	$ 534,000	1916.4	266	1918	278.646		3.6
10265	B	D	138.3227	Y	0.7	1045.18835			$ 516,580	$ 1,070,000	1917.9	267	2013	557.914		3.6
10189	C	A	74.90136	Y	0.7	1047.15613			$ 437,388	$ 535,000	1919.7	268	1911	278.689		3.6
8593	C	D	64.16891	Y	0.8	1045.81299			$ 435,902	$ 534,000	1924.8	269	1910	277.427		3.6
9949	C	A	84.89817	Y	0.7	1046.64343			$ 460,348	$ 536,500	1925.4	270	1911	278.64		3.018427
10049	C	A	68.5904	Y	0.7	1047.1355			$ 460,670	$ 537,500	1927.2	271	1910	278.9		2.845711
10291	C	A	76.47984	Y	0.7	1045.53223			$ 436,256	$ 536,000	1930.0	272	1900	277.727		1.8
8630	C	A	101.6694	Y	0.7	1047.20837			$ 506,856	$ 676,000	1930.3	273	1914	350.204		2.550753
8059	C	A	92.39389	Y	0.7	1046.26599			$ 391,338	$ 538,000	1930.5	274	1920	278.68		1.8
8483	C	D	75.0775	Y	0.7	1047.02502			$ 437,371	$ 538,500	1932.4	275	1914	278.674		3.6
10657	C	A	87.10764	Y	0.7	1047.24365			$ 414,482	$ 539,000	1933.3	276	1925	278.791		1.8
8664	C	D	57.30163	Y	0.7	1046.85046			$ 437,393	$ 539,000	1934.0	277	1912	278.693		3.589697
8377	C	A	89.31848	Y	0.7	1047.3125			$ 506,715	$ 560,000	1935.3	278	1915	289.358		3.147477
8515	C	A	73.9457	Y	0.7	1046.31445			$ 436,826	$ 538,500	1935.6	279	1910	278.211		3.006612
8248	C	D	61.72915	Y	0.7	1044.82324			$ 460,377	$ 539,500	1936.0	280	1912	278.663		1.8
10903	C	A	83.35265	Y	0.7	1046.95898			$ 507,286	$ 679,000	1936.7	281	1926	350.6		1.8
8394	C	A	69.83357	Y	0.7	1046.43994			$ 437,370	$ 540,000	1937.8	282	1920	278.673		3.522482
8176	C	D	82.68527	Y	0.7	1046.71472			$ 469,555	$ 540,000	1938.0	283	1911	278.64		2.838307
8134	C	A	91.61073	Y	0.7	1046.47571			$ 437,006	$ 539,500	1938.1	284	1985	278.364		3.6
11039	C	A	82.03822	Y	0.7	1049.39001			$ 470,062	$ 614,000	1938.6	285	1911	316.725		1.8
9264	C	D	52.73353	Y	0.7	1046.61694			$ 460,359	$ 540,500	1939.7	286	1918	278.649		3.6
8972	C	A	87.3541	Y	0.7	1049.26758			$ 506,267	$ 680,000	1944.7	287	1911	349.662		1.8
10941	C	A	112.9234	Y	0.7	1046.80371			$ 508,508	$ 685,000	1947.5	288	1913	351.727		2.753969
8784	B	D	71.3338	Y	0.7	1044.71912			$ 368,130	$ 542,500	1948.0	289	2016	278.49		2.367661
10204	B	D	106.8655	Y	0.7	1048.75989			$ 587,968	$ 832,000	1949.1	290	1994	426.855		2.081564
10688	B	D	69.83958	Y	0.8	1046.91064			$ 414,527	$ 543,500	1949.2	291	1900	278.832		2.799369
8818	B	D	67.84588	Y	0.7	1046.47217			$ 475,071	$ 652,000	1949.7	292	1910	334.413		3.174676
8415	B	D	53.53053	Y	0.7	1046.92322			$ 391,284	$ 543,500	1950.6	293	1912	278.629		2.230161
8175	B	D	114.4781	Y	0.7	1046.71399			$ 391,210	$ 544,000	1952.9	294	1973	278.558		1.8
10348	C	D	72.5599	Y	0.7	1047.35327			$ 460,310	$ 545,000	1956.1	295	1914	278.609		3.6
8149	C	A	72.80562	Y	0.7	1046.18677			$ 437,830	$ 546,000	1956.5	296	1915	279.064		3.6
8344	C	A	88.84245	Y	0.7	1045.37634			$ 409,240	$ 546,000	1959.3	297	1913	278.678		1.8
10019	C	A	51.23429	Y	0.7	1047.1897			$ 414,493	$ 548,500	1967.4	298	1998	278.801		1.8
10160	C	A	70.86533	Y	0.7	1046.30615			$ 437,367	$ 548,500	1968.3	299	2013	278.671		1.8
10325	C	A	113.4549	Y	0.7	1046.84204			$ 460,684	$ 549,000	1968.4	300	1912	278.911		1.8

ID	ClAss	StruCt_T	area_GIS_	Bsmt-Prk	Height_m	integrated	~new cols >	~from assessment >	land_value	value	~val_area_r	devpot_rnk	ayoc	parcel_area	~stats model >	B_f_height
9430	B	D	97.23971	Y	0.6	1045.11829			$ 368,835	$ 550,000	1969.9	301	1980	279.202		2.629961
10394	C	A	112.5679	Y	0.7	1045.69885			$ 408,711	$ 549,000	1973.4	302	1996	278.198		3.25709
10145	C	A	90.15533	Y	0.7	1045.41956			$ 408,815	$ 550,000	1976.3	303	2013	278.292		1.8
9380	C	D	62.68888	Y	0.7	1045.5022			$ 367,866	$ 550,000	1976.8	304	1910	278.224		2.473272
8943	C	A	100.8136	Y	0.7	1046.3656			$ 437,390	$ 551,000	1977.1	305	1914	278.69		1.8
9521	B	D	115.8033	Y	0.7	1047.56946			$ 454,666	$ 689,500	1977.5	306	1927	348.665		1.8
10950	C	D	69.53813	Y	0.7	1046.91931			$ 438,305	$ 553,500	1980.5	307	1985	279.468		3.6
10741	C	A	86.43227	Y	0.7	1047.20789			$ 509,358	$ 699,000	1982.9	308	1991	352.511		3.6
10971	B	D	79.26746	Y	0.7	1047.57043			$ 507,690	$ 696,000	1983.1	309	1912	350.973		1.856491
8584	C	A	81.6293	Y	0.7	1047.09839			$ 460,384	$ 553,000	1984.4	310	1914	278.669		1.8
10744	C	A	95.00341	Y	0.7	1047.78088			$ 531,832	$ 691,500	1987.6	311	1913	347.909		1.8
10254	C	A	101.7565	Y	0.7	1048.19275			$ 478,067	$ 690,000	1989.2	312	1912	346.866		2.364533
8615	B	D	97.52697	Y	0.7	1047.05029			$ 437,156	$ 554,000	1989.3	313	1911	278.492		2.476794
9947	C	A	76.12413	Y	0.7	1047.44678			$ 437,387	$ 554,500	1989.7	314	2013	278.688		3.6
9602	B	D	72.59544	Y	0.7	1046.18347			$ 437,375	$ 554,500	1989.8	315	1998	278.678		3.6
10192	C	D	58.38329	Y	0.7	1047.00366			$ 460,664	$ 555,500	1991.8	316	1970	278.895		3.6
8744	B	D	83.60959	Y	0.7	1047.77087			$ 478,141	$ 692,500	1996.0	317	2003	346.938		2.780366
8376	C	A	75.39713	Y	0.7	1047.41223			$ 506,717	$ 579,500	2002.7	318	1915	289.359		3.6
10610	B	D	78.4708	Y	0.7	1048.823			$ 477,917	$ 694,500	2003.1	319	1997	346.721		2.699918
10376	C	A	90.79497	Y	0.7	1048.51172			$ 430,713	$ 606,000	2007.8	320	1917	301.829		2.003024
8158	C	A	100.678	Y	0.7	1046.13123			$ 391,324	$ 560,500	2011.4	321	2013	278.667		2.537197
11069	B	D	79.34875	Y	0.7	1047.29626			$ 506,299	$ 704,500	2014.6	322	1987	349.691		1.8
10545	B	D	89.80107	Y	0.7	1048.06763			$ 478,918	$ 701,000	2016.2	323	1912	347.69		2.369145
8338	C	A	90.91377	Y	0.7	1049.04956			$ 469,733	$ 639,000	2019.4	324	1912	316.429		1.8
8374	B	D	86.50749	Y	0.7	1046.31189			$ 460,455	$ 563,000	2019.9	325	1995	278.726		1.8
8172	B	D	92.61211	Y	0.7	1048.49194			$ 480,728	$ 706,000	2020.4	326	1911	349.443		1.8
9254	C	A	62.48859	Y	0.7	1046.79382			$ 460,453	$ 563,500	2021.7	327	2016	278.725		3.6
8676	B	A	98.61135	Y	0.6	1047.44922			$ 570,751	$ 750,500	2022.2	328	1914	371.128		1.8
10350	C	A	65.40216	Y	0.7	1047.29199			$ 460,458	$ 564,000	2023.5	329	1914	278.729		2.940495
9901	B	D	65.32885	Y	0.7	1045.54932			$ 408,876	$ 563,500	2024.5	330	1912	278.347		1.8
8183	C	A	89.68512	Y	0.7	1048.51746			$ 504,848	$ 705,500	2025.2	331	1931	348.355		2.764501
9562	C	A	81.43707	Y	0.7	1048.41455			$ 506,636	$ 709,500	2027.1	332	1991	350.001		2.810549
8339	C	A	79.54083	Y	0.7	1046.30554			$ 437,386	$ 565,000	2027.4	333	1995	278.687		3.6
8046	B	D	111.2986	Y	0.7	1048.55273			$ 504,390	$ 705,500	2027.7	334	2008	347.934		1.8
10266	C	A	69.17237	Y	0.7	1045.06763			$ 206,751	$ 282,500	2028.5	335	1912	139.263		3.246038
8400	B	D	82.53663	Y	0.7	1048.63049			$ 505,900	$ 709,000	2029.6	336	1911	349.324		3.6
9376	B	A	80.11957	Y	0.7	1046.22205			$ 437,452	$ 566,000	2030.5	337	1998	278.743		2.470491
8644	C	A	107.185	Y	0.7	1047.44385			$ 509,081	$ 715,500	2031.2	338	1927	352.255		2.749981
10731	B	D	99.27339	Y	0.7	1046.77649			$ 521,565	$ 739,000	2031.2	339	2000	363.82		1.8
8573	B	D	92.73026	Y	0.7	1045.05969			$ 408,647	$ 565,000	2031.4	340	1986	278.14		3.078504
9140	B	D	75.16734	Y	0.7	1046.65601			$ 502,955	$ 704,500	2032.5	341	1912	346.615		1.8
10673	C	D	63.98034	Y	0.7	1046.86108			$ 436,260	$ 564,500	2032.5	342	1910	277.731		3.6
9970	B	D	82.76451	Y	0.7	1048.36035			$ 480,170	$ 709,500	2033.5	343	1912	348.902		3.360807
8288	C	D	73.82084	Y	0.7	1047.07019			$ 437,418	$ 567,000	2034.3	344	1910	278.714		1.8
9937	B	D	72.89896	Y	0.7	1047.14185			$ 446,607	$ 567,000	2034.5	345	1911	278.698		3.6
9874	B	D	76.19872	Y	0.7	1044.83276			$ 368,152	$ 567,000	2035.8	346	1978	278.512		3.6
10733	B	D	78.96394	Y	0.7	1047.90637			$ 506,142	$ 712,000	2036.9	347	1912	349.546		3.6
8382	C	A	61.54421	Y	0.7	1047.44946			$ 483,035	$ 590,000	2039.0	348	1920	289.356		3.6
9504	C	D	75.60686	Y	0.7	1047.57117			$ 505,656	$ 712,000	2039.5	349	1913	349.099		1.8
10359	B	D	82.87861	Y	0.7	1045.21326			$ 408,649	$ 567,500	2040.3	350	1982	278.141		1.8
10609	C	A	91.93688	Y	0.7	1047.70313			$ 504,255	$ 711,000	2044.2	351	1990	347.81		3.6
8683	B	D	73.3963	Y	0.7	1046.26672			$ 437,383	$ 570,000	2045.3	352	1915	278.684		2.444176
8607	B	D	96.63075	Y	0.7	1048.76257			$ 505,044	$ 713,500	2047.1	353	1989	348.536		3.490525
10506	B	D	103.5465	Y	0.7	1047.38391			$ 506,843	$ 717,000	2047.4	354	1989	350.192		1.8
10607	C	A	115.7977	Y	0.7	1047.80261			$ 505,596	$ 715,000	2048.5	355	1911	349.044		2.533001
8598	C	D	69.08703	Y	0.7	1047.68066			$ 460,147	$ 570,500	2048.6	356	1912	278.478		3.6
10251	C	D	80.31344	Y	0.7	1047.69226			$ 507,413	$ 718,500	2048.7	357	1912	350.717		2.195366
9486	C	A	87.37024	Y	0.7	1048.95349			$ 503,884	$ 712,000	2049.1	358	1911	347.469		2.351922
8380	B	D	71.31535	Y	0.7	1047.3092			$ 506,713	$ 593,000	2049.4	359	1915	289.356		1.8
8746	B	A	129.7044	Y	0.7	1047.75232			$ 504,296	$ 713,500	2051.2	360	1982	347.848		1.8
8999	B	D	76.31478	Y	0.7	1045.39368			$ 348,112	$ 573,000	2054.1	361	1978	278.953		3.6
8118	B	D	105.771	Y	0.7	1046.151			$ 717,889	$ 946,000	2054.6	362	1988	460.426		1.8
8260	B	D	83.75326	Y	0.7	1045.43433			$ 408,646	$ 571,500	2054.7	363	1981	278.139		1.8
8375	B	D	62.89088	Y	0.7	1047.91089			$ 506,717	$ 595,000	2056.3	364	1915	289.359		1.8
11070	B	D	92.91157	Y	0.7	1047.97644			$ 505,230	$ 717,500	2057.6	365	1912	348.707		1.8
10186	C	A	82.0701	Y	0.7	1047.30676			$ 460,351	$ 574,000	2060.0	366	1914	278.642		1.8
10713	C	D	54.99659	Y	0.7	1046.85437			$ 438,661	$ 576,500	2060.6	367	1912	279.771		2.425688
8209	B	D	134.4065	Y	0.7	1045.12134			$ 561,814	$ 1,040,000	2062.6	368	2003	504.21		1.8
10655	C	A	85.63937	Y	0.7	1046.95544			$ 437,318	$ 575,500	2065.5	369	1920	278.629		2.806547
10013	C	D	62.72903	Y	0.7	1046.96729			$ 460,663	$ 577,000	2068.9	370	2015	278.894		2.173317
11029	C	A	101.6174	Y	0.7	1047.05322			$ 507,581	$ 728,000	2074.8	371	1912	350.872		1.8
9449	B	D	89.10648	Y	0.7	1045.20813			$ 408,627	$ 577,500	2076.4	372	1982	278.121		3.6
8410	C	A	75.43731	Y	0.7	1048.05762			$ 473,348	$ 664,000	2077.1	373	1911	319.68		1.8
8533	B	D	57.70779	Y	1	1045.90356			$ 500,288	$ 692,500	2077.3	374	2002	333.368		3.6
9851	B	D	95.73436	Y	0.7	1047.21716			$ 502,801	$ 720,000	2078.1	375	1978	346.473		2.020218
10660	C	A	105.9704	Y	0.7	1048.24915			$ 478,876	$ 723,000	2079.7	376	1991	347.649		3.6
10997	C	A	71.14732	Y	0.7	1046.9751			$ 461,495	$ 581,500	2080.0	377	2004	279.566		1.8
8740	C	D	101.3761	Y	0.7	1047.00916			$ 471,016	$ 661,500	2082.9	378	1912	317.582		1.8
8705	B	D	71.38842	Y	1	1045.3324			$ 368,982	$ 582,000	2083.4	379	1978	279.35		3.6
9497	C	A	99.70684	Y	0.7	1046.74475			$ 502,904	$ 723,000	2086.2	380	1986	346.568		3.6
8319	B	D	93.73923	Y	0.7	1048.78137			$ 504,196	$ 725,500	2086.2	381	1986	347.756		1.8
9546	B	D	83.18301	Y	0.7	1046.93896			$ 460,448	$ 582,000	2088.1	382	1978	278.721		3.6
9778	C	A	87.9737	Y	0.7	1049.48401			$ 446,552	$ 661,500	2088.6	383	1961	316.718		2.582096
9948	B	D	83.9514	Y	0.7	1047.03894			$ 437,379	$ 582,500	2090.2	384	1910	278.681		1.8
8824	B	D	107.1622	Y	0.7	1048.43164			$ 677,590	$ 1,080,000	2094.1	385	1982	515.74		1.8
10270	C	A	67.63027	Y	0.7	1046.08777			$ 436,350	$ 582,500	2096.8	386	2008	277.807		3.6
8633	B	D	65.77352	Y	0.7	1046.84204			$ 460,691	$ 586,000	2101.0	387	1912	278.917		1.8
9046	C	D	55.7616	Y	0.7	1046.68494			$ 576,422	$ 722,000	2101.2	388	1980	343.614		3.6
9605	C	A	81.04545	Y	0.7	1048.90222			$ 446,202	$ 665,000	2101.9	389	1991	316.387		1.926248
10375	B	D	94.63003	Y	0.7	1048.4552			$ 506,022	$ 734,500	2102.0	390	1991	349.436		2.721235
8617	B	D	66.87773	Y	0.7	1048.62427			$ 505,363	$ 733,500	2102.7	391	1911	348.829		1.8
9902	B	D	81.73843	Y	0.7	1045.82898			$ 408,888	$ 587,500	2110.6	392	1995	278.358		1.978238
8559	C	A	78.47036	Y	0.7	1045.203			$ 414,038	$ 588,000	2112.1	393	2002	278.393		1.8
10345	B	D	77.81764	Y	0.7	1045.29285			$ 347,757	$ 589,000	2114.3	394	1912	278.574		1.8
10894	C	D	73.11255	Y	0.7	1048.91626			$ 485,266	$ 699,500	2116.8	395	1914	330.457		3.6
9358	B	D	84.43269	Y	0.7	1045.78406			$ 409,950	$ 591,500	2117.6	396	1986	279.323		1.8
10358	B	D	84.88565	Y	1.2	1045.12817			$ 369,019	$ 592,000	2118.9	397	1984	279.387		3.6
9552	B	D	83.35087	Y	0.7	1045.65967			$ 409,519	$ 591,500	2120.6	398	1988	278.931		3.6
8346	B	D	82.34961	Y	0.7	1045.59326			$ 409,574	$ 594,000	2129.2	399	1992	278.981		3.6
10456	C	D	66.12634	Y	0.7	1046.70056			$ 460,689	$ 594,000	2129.7	400	2005	278.915		1.8

ID	ClAss	StruCt_Ty	area_GIS_	Bsmt-Prk	Height_m	integrated	~new cols >	~from assessment >	land_value	value	~val_area_r	devpot_rnk	ayoc	parcel_area	~stats model >	B_f_height
8109	C	A	74.18957	Y	0.7	1046.14282			$ 436,286	$ 592,000	2131.4	401	2007	277.753		3.6
8562	B	D	73.85096	Y	0.7	1045.24353			$ 389,049	$ 690,500	2134.3	402	2013	323.528		3.6
8261	C	A	97.2243	Y	0.7	1045.46338			$ 409,300	$ 595,000	2134.7	403	2014	278.732		1.8
8792	B	D	81.59868	Y	0.7	1045.79504			$ 408,950	$ 594,500	2135.3	404	1990	278.415		3.6
8643	B	D	70.94255	Y	0.7	1047.62622			$ 502,491	$ 740,000	2137.6	405	1914	346.189		1.8
8539	B	D	97.13456	Y	0.7	1048.56116			$ 505,403	$ 746,000	2138.4	406	1924	348.866		2.221156
9622	B	D	78.36416	Y	0.7	1047.26099			$ 506,991	$ 749,500	2139.4	407	1912	350.328		1.8
9099	B	D	86.67495	Y	0.7	1048.6687			$ 506,696	$ 749,000	2139.7	408	1912	350.057		1.8
10277	B	D	81.9497	Y	0.8	1046.03259			$ 413,856	$ 596,000	2142.1	409	1912	278.23		1.8
9072	B	D	65.58938	Y	0.7	1047.7605			$ 478,217	$ 743,500	2142.6	410	1912	347.011		3.6
11065	B	D	76.50805	Y	0.7	1046.70361			$ 503,006	$ 743,000	2143.3	411	2010	346.662		3.382169
10817	C	D	79.53417	Y	0.7	1047.11975			$ 508,802	$ 755,000	2144.9	412	1991	351.998		3.6
8742	B	D	97.10737	Y	0.7	1047.81006			$ 505,413	$ 748,500	2145.5	413	2010	348.875		3.314138
9623	C	A	118.5481	Y	0.7	1046.21375			$ 503,035	$ 745,500	2150.3	414	1978	346.688		1.8
10267	C	A	70.33763	Y	0.7	1045.21741			$ 206,751	$ 300,000	2154.2	415	1912	139.263		1.8
8566	B	D	84.77127	Y	0.7	1045.31409			$ 279,982	$ 449,500	2154.3	416	1989	208.648		3.6
8047	C	D	66.1878	Y	0.7	1048.77808			$ 481,215	$ 754,000	2154.8	417	1998	349.915		3.6
10732	C	A	101.0448	Y	0.7	1047.64526			$ 510,470	$ 762,000	2155.4	418	1963	353.537		2.204992
8996	B	D	60.82814	Y	0.7	1045.82129			$ 436,034	$ 598,500	2156.5	419	2004	277.539		3.362551
9091	C	A	84.32386	Y	0.7	1046.69678			$ 352,058	$ 450,000	2156.6	420	1910	208.665		1.8
9514	C	D	76.7899	Y	1	1047.75854			$ 414,009	$ 600,500	2157.2	421	1992	278.367		1.8
9255	C	D	61.79358	Y	0.7	1046.59106			$ 284,333	$ 426,500	2161.1	422	2000	197.353		3.6
10593	B	D	65.38553	Y	0.7	1047.57031			$ 414,216	$ 602,500	2163.0	423	1910	278.553		1.8
10309	B	D	72.75466	Y	0.7	1046.71082			$ 508,802	$ 762,500	2166.2	424	1991	351.998		2.097259
8544	B	D	78.79054	Y	0.7	1048.4541			$ 506,220	$ 757,500	2166.7	425	1982	349.618		1.8
9616	C	A	114.879	Y	0.7	1047.73022			$ 504,276	$ 754,500	2169.2	426	1999	347.829		1.83388
9569	C	D	59.59399	Y	0.7	1046.85754			$ 437,484	$ 605,500	2172.0	427	1914	278.77		1.8
10764	B	D	88.47258	Y	0.7	1047.53137			$ 502,879	$ 753,000	2172.9	428	1913	346.545		1.8
10819	B	D	62.8626	Y	0.7	1047.73535			$ 504,321	$ 756,000	2173.2	429	1911	347.871		2.663196
8249	B	D	96.63709	Y	1.6	1045.14758			$ 409,642	$ 606,500	2173.5	430	2016	279.043		3.6
8405	C	D	81.37193	Y	0.7	1048.58411			$ 469,827	$ 689,000	2176.8	431	1911	316.514		1.8
10349	C	D	59.75732	Y	0.7	1046.33423			$ 436,836	$ 606,000	2178.1	432	1912	278.22		1.8
8489	B	D	76.81219	Y	0.7	1048.88318			$ 506,415	$ 763,000	2181.3	433	1982	349.798		1.8
8371	B	D	85.9874	Y	0.7	1045.4751			$ 408,647	$ 607,000	2182.4	434	1981	278.14		3.6
8791	C	A	98.25464	Y	0.7	1045.85486			$ 408,683	$ 607,500	2183.9	435	1912	278.172		2.702258
8395	B	D	94.2839	Y	0.7	1048.67029			$ 505,004	$ 762,000	2186.5	436	1991	348.499		3.6
9941	C	D	55.68747	Y	0.7	1047.25415			$ 460,468	$ 609,500	2186.6	437	1991	278.737		3.405591
8916	B	D	83.62565	Y	0.7	1045.28809			$ 347,850	$ 609,500	2187.1	438	2016	278.674		2.104942
10366	B	D	74.15114	Y	0.7	1049.00269			$ 469,778	$ 692,500	2188.2	439	1974	316.47		1.8
10999	B	D	95.06038	Y	0.7	1047.08655			$ 502,698	$ 758,000	2188.4	440	1913	346.379		1.8
10569	C	D	68.44983	Y	0.7	1046.91724			$ 436,299	$ 608,000	2188.9	441	1912	277.764		1.8
9979	B	A	119.5325	Y	0.7	1048.8136			$ 478,920	$ 761,500	2190.2	442	1990	347.692		2.975129
8094	A	D	143.0751	Y	0.7	1048.53809			$ 604,990	$ 1,040,000	2190.4	443	1999	474.797		1.8
10164	C	D	60.35926	Y	0.7	1046.97083			$ 460,406	$ 610,500	2190.6	444	1910	278.687		1.8
10369	B	D	83.85054	Y	0.7	1048.54651			$ 480,020	$ 764,500	2192.1	445	1912	348.757		3.002969
8497	C	D	87.48767	Y	0.7	1048.86816			$ 469,812	$ 694,500	2194.3	446	1911	316.5		3.6
8568	B	A	93.88101	Y	0.7	1045.43433			$ 279,983	$ 458,000	2195.1	447	2015	208.649		3.6
9528	B	D	71.90529	Y	0.7	1046.80566			$ 436,337	$ 610,500	2197.7	448	2011	277.796		1.8
9008	B	D	128.0071	Y	0.7	1046.60083			$ 571,530	$ 819,000	2202.8	449	1985	371.804		3.6
10818	B	D	88.32181	Y	0.7	1047.73926			$ 505,777	$ 769,500	2203.5	450	1939	349.21		2.080878
8313	B	D	65.9422	Y	0.7	1046.51807			$ 508,949	$ 776,000	2203.7	451	2016	352.134		1.8
10268	C	A	69.55319	Y	0.7	1045.24524			$ 206,751	$ 307,000	2204.5	452	1922	139.263		3.6
9266	B	D	91.75847	Y	0.7	1045.31348			$ 348,113	$ 615,000	2204.7	453	1978	278.954		3.6
8379	C	A	120.7161	Y	0.7	1047.54285			$ 506,714	$ 638,000	2204.9	454	1983	289.357		3.6
10163	C	A	74.35046	Y	0.7	1047.2771			$ 437,399	$ 614,500	2204.9	455	2012	278.698		3.6
10455	B	D	69.98891	Y	0.6	1046.84863			$ 414,331	$ 614,500	2205.2	456	1900	278.656		1.8
10450	C	D	57.7695	Y	0.7	1046.55103			$ 460,676	$ 615,500	2206.8	457	1900	278.905		3.6
9899	C	D	51.66342	Y	0.7	1046.59326			$ 398,863	$ 544,000	2207.3	458	1914	246.45		1.8
9141	B	D	85.52935	Y	0.7	1047.01709			$ 502,903	$ 766,000	2210.3	459	2004	346.567		2.447027
8930	C	D	60.29402	Y	0.7	1047.375			$ 460,327	$ 617,500	2216.3	460	2015	278.623		2.504162
9145	C	A	76.11829	Y	0.7	1048.948			$ 469,921	$ 702,000	2217.3	461	1911	316.598		1.8
9555	C	D	59.90946	Y	0.7	1046.21277			$ 436,334	$ 617,000	2221.1	462	1912	277.794		3.6
8468	B	D	84.84633	Y	0.7	1047.02307			$ 437,425	$ 619,500	2222.7	463	1980	278.72		2.561134
8691	B	D	64.66709	Y	0.7	1048.7937			$ 479,868	$ 775,000	2223.1	464	1980	348.61		3.6
8616	C	D	74.54419	Y	0.7	1046.19299			$ 437,285	$ 620,500	2227.2	465	1912	278.601		1.8
11035	B	D	91.14873	Y	0.7	1048.02429			$ 506,082	$ 781,000	2234.7	466	2006	349.491		1.8
8084	B	D	68.62012	Y	0.7	1046.40479			$ 436,853	$ 622,500	2237.3	467	1911	278.234		1.8
8042	B	D	81.72232	Y	1	1045.3324			$ 368,945	$ 625,500	2239.4	468	2013	279.313		3.6
10080	B	D	68.28456	Y	1	1047.74097			$ 437,052	$ 623,500	2239.6	469	1963	278.403		3.6
10294	B	D	79.264	Y	0.7	1048.50562			$ 504,795	$ 780,500	2240.8	470	2004	348.307		3.6
10023	C	A	111.7277	Y	0.7	1049.04688			$ 506,430	$ 784,000	2241.2	471	1990	349.812		3.6
10180	B	D	95.51085	Y	0.7	1047.79321			$ 506,264	$ 784,000	2242.2	472	2011	349.659		1.8
10191	B	D	85.51325	Y	0.7	1047.29822			$ 509,634	$ 792,000	2245.1	473	1973	352.766		1.8
8262	C	D	78.91843	Y	0.7	1046.4386			$ 460,420	$ 626,500	2248.0	474	1910	278.698		3.6
9253	C	D	72.23226	Y	0.7	1046.86401			$ 437,439	$ 627,000	2249.5	475	2017	278.732		1.8
10352	B	D	73.29311	Y	0.7	1047.46899			$ 460,337	$ 627,000	2250.3	476	1914	278.631		3.344238
8543	C	A	106.4654	Y	0.7	1048.66602			$ 505,772	$ 786,500	2252.3	477	1913	349.206		3.6
8620	B	D	77.7351	Y	0.7	1045.26379			$ 409,097	$ 629,500	2259.9	478	1986	278.548		2.666958
8097	B	D	59.65864	Y	0.7	1048.71851			$ 431,306	$ 683,500	2260.4	479	1911	302.383		1.94348
9617	B	D	99.67048	Y	0.7	1048.90149			$ 477,841	$ 784,500	2263.1	480	1998	346.648		3.156225
8373	B	D	90.39997	Y	0.7	1045.57141			$ 409,482	$ 632,000	2266.1	481	1990	278.898		3.6
8399	B	D	136.0182	Y	0.7	1048.60706			$ 479,412	$ 790,000	2269.0	482	2000	348.168		3.6
10283	B	D	80.952	Y	0.7	1045.35583			$ 466,847	$ 946,000	2270.6	483	2002	416.626		2.05079
8821	B	D	81.64345	Y	0.7	1048.64282			$ 505,515	$ 792,500	2271.0	484	1912	348.969		2.214747
9519	B	D	99.44148	Y	0.7	1047.5481			$ 452,891	$ 788,000	2271.9	485	2004	346.851		1.8
8282	B	D	69.38706	Y	0.6	1045.73315			$ 435,948	$ 630,500	2272.4	486	1910	277.466		1.8
9010	C	D	69.86867	Y	0.7	1045.94763			$ 437,355	$ 633,500	2273.4	487	2014	278.661		1.8
8417	C	A	100.2141	Y	0.7	1048.84216			$ 439,819	$ 659,000	2273.6	488	2002	289.85		1.8
11030	B	D	73.60881	Y	0.7	1046.54102			$ 507,335	$ 799,500	2280.1	489	1983	350.645		1.8
8745	B	D	86.34811	Y	0.8	1046.86096			$ 437,521	$ 636,000	2281.2	490	1980	278.802		2.338161
8317	C	A	87.17459	Y	0.7	1046.88049			$ 460,437	$ 636,000	2281.9	491	2015	278.712		3.6
10182	C	D	66.60031	Y	0.7	1049.23999			$ 469,764	$ 724,000	2287.8	492	2013	316.457		1.8
10634	B	D	81.6609	Y	0.7	1046.56677			$ 437,393	$ 639,000	2292.8	493	1912	278.693		1.8
10983	B	D	92.87278	Y	0.7	1047.81055			$ 505,169	$ 799,500	2293.1	494	2002	348.651		2.328194
8437	B	D	82.39237	Y	0.7	1045.04858			$ 409,485	$ 640,000	2294.7	495	1996	278.9		3.6
9384	B	D	75.07405	Y	0.7	1046.80383			$ 437,448	$ 640,000	2296.0	496	1908	278.74		1.8
9560	B	D	72.31886	Y	0.7	1046.20667			$ 501,885	$ 640,000	2296.2	497	2006	278.718		3.6
9571	B	D	135.6015	Y	0.7	1048.80542			$ 636,524	$ 1,090,000	2297.2	498	2003	474.491		2.945456
9576	B	D	80.35627	Y	0.7	1045.27087			$ 410,012	$ 644,000	2305.1	499	1988	279.379		2.373933
8044	B	D	97.49447	Y	0.7	1045.48718			$ 409,300	$ 643,500	2308.7	500	1984	278.732		1.8

ID	ClAss	StruCt_Ty	area_GIS_	Bsmt-Prk	Height_m	integrated	~new cols >	~from assessment >	land_value	value	~val_area_r	devpot_rnk	ayoc	parcel_area	~stats model >	B_f_height
8419	B	D	77.09965	Y	0.7	1048.66992			$ 469,889	$ 733,000	2315.5	501	2006	316.569		2.77695
8572	B	D	91.40717	Y	1.6	1045.21558			$ 409,642	$ 646,500	2316.8	502	1982	279.043		1.8
8826	B	D	71.5977	Y	0.7	1046.9115			$ 460,415	$ 646,000	2318.0	503	1912	278.694		3.6
8178	B	D	102.0082	Y	1	1046.62878			$ 437,360	$ 647,000	2321.8	504	1977	278.665		1.8
8146	C	D	77.81295	Y	0.7	1046.82336			$ 460,422	$ 648,000	2325.1	505	2006	278.7		3.6
10459	B	D	100.7608	Y	0.7	1046.74756			$ 438,277	$ 650,500	2327.8	506	2006	279.444		1.8
8564	B	D	69.53145	Y	0.7	1045.354			$ 382,273	$ 682,500	2330.6	507	2016	292.846		3.173122
10252	B	A	104.8559	Y	0.7	1047.95776			$ 505,473	$ 815,000	2335.7	508	2010	348.931		1.8
8933	B	D	72.19332	Y	1.4	1044.89648			$ 368,762	$ 655,000	2346.6	509	1994	279.128		1.8
8670	B	D	91.20635	Y	0.7	1045.03503			$ 409,356	$ 655,000	2349.5	510	1992	278.783		1.8
8525	B	D	137.271	Y	0.7	1045.54126			$ 554,374	$ 982,000	2350.9	511	2013	417.704		3.148502
10093	B	D	91.25227	Y	0.7	1047.005			$ 502,594	$ 815,000	2353.6	512	1983	346.283		2.150553
8822	B	D	106.4837	Y	0.7	1048.49463			$ 505,823	$ 824,000	2359.3	513	1969	349.253		3.6
8289	C	D	69.13047	Y	0.7	1046.86609			$ 460,431	$ 658,000	2360.9	514	1914	278.707		2.582859
9433	B	D	100.941	Y	0.7	1046.229			$ 460,458	$ 658,500	2362.5	515	1989	278.729		3.6
10269	C	A	72.00398	Y	0.7	1045.27637			$ 206,751	$ 329,500	2366.0	516	2013	139.263		1.8
8605	B	D	65.31586	Y	0.7	1046.39783			$ 437,504	$ 661,500	2372.8	517	2013	278.787		2.170345
8403	B	D	78.64071	Y	0.7	1047.22815			$ 437,428	$ 662,500	2376.9	518	1914	278.723		1.8
8635	B	D	72.60459	Y	0.7	1046.58923			$ 460,680	$ 663,000	2377.1	519	2003	278.908		3.6
10687	C	D	59.34606	Y	0.7	1047.85754			$ 357,845	$ 473,500	2377.6	520	1914	199.154		2.008311
8464	B	D	109.4507	Y	0.7	1049.11755			$ 453,989	$ 719,000	2377.9	521	1987	302.368		3.6
8240	B	D	63.56445	Y	0.7	1046.41833			$ 390,940	$ 662,500	2380.5	522	1911	278.302		1.8
8920	B	D	72.60186	Y	0.7	1046.16028			$ 436,303	$ 663,000	2386.9	523	2017	277.767		3.6
11074	B	D	104.8047	Y	0.7	1049.08667			$ 559,181	$ 953,000	2387.2	524	1992	399.219		1.8
8065	B	D	65.50296	Y	0.7	1047.23401			$ 460,359	$ 666,500	2391.9	525	2006	278.649		1.8
9446	B	D	85.96145	Y	0.7	1045.16284			$ 409,959	$ 670,000	2398.6	526	1987	279.331		2.397082
8934	B	D	97.1681	Y	0.7	1045.0824			$ 409,595	$ 671,500	2406.8	527	1992	279		1.8
9214	B	D	105.7994	Y	0.7	1046.88794			$ 503,047	$ 835,000	2408.4	528	1987	346.699		1.8
11000	B	D	78.75356	Y	0.7	1046.7655			$ 502,962	$ 836,500	2413.3	529	1986	346.621		3.6
10193	B	D	97.75202	Y	0.7	1049.61658			$ 279,162	$ 581,000	2415.4	530	1992	240.54		2.598853
8316	B	D	75.24714	Y	0.8	1045.74536			$ 435,926	$ 672,000	2422.1	531	1910	277.447		1.8
8686	B	D	91.51795	Y	0.7	1045.35986			$ 408,217	$ 673,500	2424.9	532	1994	277.749		3.6
9977	B	D	86.21831	Y	0.7	1048.66235			$ 479,718	$ 845,000	2424.9	533	1994	348.464		3.102486
8707	B	D	72.57882	Y	0.7	1045.48926			$ 409,323	$ 676,500	2426.9	534	2002	278.753		1.8
10288	B	D	73.37614	Y	0.7	1046.72437			$ 437,464	$ 677,000	2428.7	535	1910	278.753		3.6
8805	B	D	108.4938	Y	0.7	1045.99426			$ 567,472	$ 1,020,000	2430.4	536	2013	419.686		3.6
8936	B	D	86.2389	Y	0.7	1045.77063			$ 409,641	$ 679,500	2435.1	537	1995	279.042		1.920025
10682	B	D	119.1737	Y	0.7	1049.26428			$ 637,095	$ 1,160,000	2441.8	538	1996	475.059		1.8
9575	B	D	83.30321	Y	0.7	1045.42798			$ 409,485	$ 683,500	2450.7	539	1996	278.9		1.8
10372	B	D	104.8532	Y	0.7	1048.65686			$ 505,643	$ 857,000	2455.0	540	1950	349.087		2.333048
8315	B	D	72.71147	Y	0.7	1046.87598			$ 437,361	$ 686,000	2461.7	541	2015	278.666		1.8
10968	B	D	83.15706	Y	0.7	1046.77893			$ 502,951	$ 853,500	2462.4	542	1986	346.611		1.8
8632	B	D	126.8852	Y	0.7	1047.91345			$ 504,168	$ 857,000	2464.6	543	2013	347.73		3.253491
8783	B	D	82.57441	Y	0.7	1046.75989			$ 437,454	$ 688,500	2470.0	544	1919	278.745		3.338305
10293	B	D	113.254	Y	1.2	1045.96606			$ 413,538	$ 687,000	2471.7	545	2013	277.945		3.6
8706	B	D	87.74589	Y	0.7	1045.18335			$ 409,485	$ 689,500	2472.2	546	1997	278.9		3.6
8621	B	D	82.91685	Y	0.7	1045.55542			$ 408,664	$ 690,500	2482.4	547	1996	278.155		3.6
10900	B	D	87.52765	Y	0.7	1046.66931			$ 487,917	$ 827,500	2486.0	548	1986	332.868		1.8
8408	B	D	88.30028	Y	0.7	1048.59644			$ 505,385	$ 868,500	2489.6	549	1912	348.85		1.8
9971	B	D	114.2854	Y	0.7	1048.48474			$ 504,745	$ 870,500	2499.6	550	2000	348.261		1.8
8569	B	D	87.20711	Y	0.7	1045.67371			$ 409,164	$ 697,500	2503.5	551	2003	278.609		2.169138
8406	B	D	93.20752	Y	0.7	1046.55603			$ 469,558	$ 699,000	2508.6	552	1911	278.642		3.6
9527	B	D	82.51328	Y	0.7	1046.97961			$ 460,695	$ 704,500	2525.8	553	1912	278.92		1.8
9943	B	D	90.30732	Y	0.7	1045.21179			$ 408,647	$ 703,000	2527.5	554	1986	278.14		3.6
9739	B	D	95.63391	Y	0.7	1046.15796			$ 391,305	$ 705,500	2531.9	555	1912	278.649		1.8
10734	B	D	101.2514	Y	0.7	1048.75208			$ 492,751	$ 855,500	2536.5	556	2003	337.271		3.6
8169	B	D	99.46601	Y	0.7	1048.50854			$ 480,057	$ 885,000	2537.3	557	1999	348.793		3.477995
9566	A	D	154.6243	Y	0.7	1048.39417			$ 616,170	$ 1,330,000	2543.5	558	1999	522.901		1.8
10725	C	D	61.68785	Y	0.7	1048.90466			$ 377,466	$ 602,000	2546.5	559	1914	236.399		3.6
10973	B	D	91.6837	Y	0.7	1047.67224			$ 504,232	$ 890,500	2560.5	560	1991	347.789		1.8
9257	B	D	58.48005	Y	0.7	1048.93066			$ 469,797	$ 812,000	2565.7	561	2000	316.487		2.369569
10637	B	D	111.3681	Y	0.7	1048.90198			$ 626,051	$ 1,200,000	2585.6	562	1997	464.11		1.8
8245	B	D	86.84334	Y	0.7	1048.802			$ 504,437	$ 903,000	2595.0	563	1991	347.977		1.8
10815	B	D	118.1992	Y	0.7	1047.06348			$ 502,540	$ 900,500	2600.8	564	1981	346.234		3.6
9822	B	D	123.8772	Y	0.7	1047.89978			$ 479,187	$ 905,500	2602.4	565	1991	347.95		1.8
10707	C	A	61.38779	Y	0.7	1046.53809			$ 259,959	$ 363,500	2610.2	566	1920	139.263		1.8
8122	B	D	79.31982	Y	0.7	1049.13			$ 469,750	$ 830,000	2622.9	567	1911	316.444		1.841985
10571	B	D	83.0497	Y	0.7	1048.03625			$ 506,203	$ 917,000	2623.0	568	2016	349.603		3.6
8962	B	D	113.4282	Y	0.7	1048.96985			$ 505,265	$ 919,000	2635.2	569	2006	348.739		2.841286
8043	B	D	91.12712	Y	0.7	1045.3075			$ 409,485	$ 736,000	2638.9	570	1997	278.9		3.6
9213	B	D	109.0341	Y	0.7	1047.24219			$ 507,138	$ 926,000	2642.2	571	1989	350.464		3.6
9503	C	D	61.21636	Y	0.7	1046.89709			$ 460,700	$ 739,500	2651.3	572	1912	278.924		3.513759
8671	B	D	94.04901	Y	0.7	1045.72827			$ 409,588	$ 744,500	2668.5	573	2004	278.994		3.6
10735	B	D	72.09908	Y	0.7	1049.15466			$ 390,338	$ 919,500	2670.6	574	2006	344.3		2.987761
9852	C	D	75.66312	Y	0.7	1046.91858			$ 502,940	$ 929,500	2681.8	575	1912	346.601		2.018185
8709	B	D	83.66937	Y	0.7	1045.04736			$ 408,649	$ 747,000	2685.7	576	2001	278.141		2.294952
10812	B	D	74.31287	Y	0.7	1049.49512			$ 481,088	$ 940,500	2688.7	577	1991	349.792		1.8
9262	B	D	116.1671	Y	0.7	1048.42847			$ 505,548	$ 940,500	2694.8	578	1996	349		2.206636
9462	B	D	84.49789	Y	0.7	1047.64929			$ 439,812	$ 781,500	2696.3	579	1981	289.844		1.8
9361	B	D	83.51412	Y	0.7	1048.79932			$ 453,744	$ 817,500	2705.6	580	1990	302.15		3.6
8490	B	D	119.7289	Y	0.7	1048.51965			$ 505,548	$ 946,500	2712.0	581	1997	349		1.8
9588	B	D	82.05122	Y	0.7	1046.99658			$ 460,227	$ 755,500	2712.3	582	2004	278.542		1.8
9051	B	D	121.2588	Y	0.7	1049.14709			$ 619,381	$ 1,330,000	2714.8	583	2002	489.915		3.6
8685	B	D	94.04359	Y	0.7	1045.1709			$ 409,224	$ 758,500	2721.9	584	2007	278.663		1.8
9940	B	D	78.85333	Y	0.7	1046.42224			$ 436,844	$ 757,500	2722.6	585	1911	278.227		1.8
9148	B	D	98.63858	Y	0.7	1049.2793			$ 454,217	$ 825,500	2728.3	586	1993	302.57		2.677133
10729	B	D	129.9773	Y	0.7	1046.83484			$ 507,433	$ 957,000	2728.5	587	2001	350.736		3.6
8425	B	D	79.3373	Y	0.7	1045.60742			$ 409,640	$ 769,500	2757.7	588	2009	279.041		1.8
8356	B	D	72.26655	Y	0.7	1049.0304			$ 464,214	$ 860,000	2761.0	589	1991	311.482		3.094042
8390	B	D	85.75298	Y	0.7	1045.27625			$ 409,069	$ 770,000	2764.6	590	2009	278.523		1.8
9053	C	A	68.22625	Y	0.7	1046.91382			$ 259,959	$ 385,500	2768.1	591	1912	139.263		1.8
~8803	B	D	94.68607	Y	0.7	1045.88892			$ 438,353	$ 746,500	2775.4	592	1989	268.972		
9505	C	D	78.54252	Y	0.7	1046.84778			$ 460,364	$ 776,500	2786.6	593	2005	278.653		2.214511
11034	B	D	89.87299	Y	0.7	1047.59668			$ 510,190	$ 985,500	2789.6	594	1997	353.279		2.877218
8542	B	D	118.4796	Y	0.7	1048.55872			$ 504,695	$ 973,500	2795.7	595	1996	348.215		1.833915
8290	A	D	92.01348	Y	0.7	1045.68005			$ 554,800	$ 1,170,000	2798.2	596	2013	418.132		2.901422
10094	B	D	119.6519	Y	0.7	1046.88806			$ 502,987	$ 973,500	2808.4	597	1996	346.644		2.142764
9734	B	D	93.43046	Y	0.7	1048.73938			$ 479,267	$ 996,500	2863.3	598	2010	348.028		2.3369
9938	B	D	98.77931	Y	0.7	1048.47717			$ 505,561	$ 1,000,000	2865.2	599	2000	349.012		1.8
9945	B	D	79.77291	Y	0.7	1045.49731			$ 469,834	$ 1,110,000	2879.1	600	2005	385.538		3.047751

ID	ClAss	StruCt_Ty	area_GIS_	Bsmt-Prk	Height_m	integrated	~new cols >	~from assessment >	land_value	value	~val_area_r	devpot_rnk	ayoc	parcel_area	~stats model >	B_f_height
9913	B	D	71.68221	Y	0.7	1046.97888			$ 437,625	$ 804,500	2884.6	601	1999	278.89		3.586355
8508	B	D	78.41407	Y	0.7	1045.72095			$ 408,725	$ 807,000	2900.7	602	2001	278.21		3.6
10011	B	D	77.59589	Y	0.7	1047.08667			$ 502,852	$ 1,010,000	2914.7	603	2004	346.52		3.6
8708	B	D	89.3095	Y	1.4	1044.97253			$ 368,725	$ 813,500	2914.8	604	2015	279.091		1.8
10095	B	D	93.13443	Y	0.7	1047.58069			$ 505,717	$ 1,020,000	2921.3	605	2001	349.155		3.6
9451	B	D	99.49145	Y	0.7	1045.61035			$ 409,217	$ 815,000	2924.7	606	2014	278.657		1.8
8434	B	D	103.073	Y	0.7	1048.65662			$ 505,256	$ 1,020,000	2924.9	607	2004	348.731		1.868698
8438	A	D	132.8459	Y	0.7	1046.27234			$ 593,128	$ 1,230,000	2940.4	608	2002	418.307		1.8
8311	C	D	66.23888	Y	0.7	1046.78943			$ 259,959	$ 409,500	2940.5	609	1912	139.263		1.8
9101	B	D	83.02099	Y	0.7	1045.901			$ 408,846	$ 821,500	2951.6	610	2004	278.32		1.8
8433	B	D	98.3708	Y	0.7	1048.62317			$ 453,732	$ 895,500	2963.9	611	1991	302.14		3.038962
10918	B	D	54.88885	Y	0.7	1048.33508			$ 308,834	$ 747,000	2964.9	612	1994	251.951		1.8
9142	B	D	135.9056	Y	0.7	1047.29834			$ 506,579	$ 1,040,000	2971.9	613	1990	349.949		1.8
8238	A	D	113.5996	Y	0.7	1045.52405			$ 498,729	$ 1,250,000	2994.2	614	2012	417.473		1.8
10057	C	D	66.89404	Y	0.7	1046.8562			$ 259,959	$ 417,500	2997.9	615	1912	139.263		1.8
10916	B	D	126.4789	Y	0.7	1049.12915			$ 558,938	$ 1,200,000	3007.6	616	1994	398.988		3.482157
8108	B	D	86.37229	Y	0.7	1045.74402			$ 408,725	$ 839,500	3017.5	617	2012	278.21		3.6
8297	B	D	97.0249	Y	0.7	1047.10596			$ 460,374	$ 843,500	3027.0	618	2001	278.661		3.6
8409	A	D	124.1478	Y	0.7	1048.34119			$ 505,627	$ 1,070,000	3065.3	619	1992	349.072		1.8
10393	B	D	86.37139	Y	0.7	1047.0343			$ 292,071	$ 517,000	3178.4	620	1982	162.66		1.8
9357	A	D	110.595	Y	0.7	1045.47766			$ 554,246	$ 1,330,000	3185.0	621	2012	417.576		3.6
10153	B	D	101.2059	Y	0.7	1045.66223			$ 409,502	$ 896,000	3212.4	622	1988	278.916		1.8
8347	C	A	78.30886	Y	0.7	1046.22205			$ 436,317	$ 899,000	3236.4	623	2014	277.779		1.8
8692	A	D	115.0039	Y	0.7	1048.7688			$ 479,124	$ 1,130,000	3248.2	624	1999	347.889		3.6
11067	B	D	137.333	Y	0.7	1047.14514			$ 502,891	$ 1,130,000	3260.7	625	1992	346.556		3.6
8057	B	D	90.65548	Y	0.7	1048.47498			$ 574,036	$ 1,350,000	3265.4	626	2016	413.422		1.8
10282	B	D	110.1623	Y	0.7	1045.19849			$ 347,857	$ 910,500	3267.2	627	2010	278.681		2.88644
9453	B	D	90.41526	Y	0.7	1045.73413			$ 446,254	$ 912,000	3275.8	628	2005	278.404		3.6
10065	B	D	128.5563	Y	0.7	1047.78284			$ 479,165	$ 1,140,000	3276.5	629	2002	347.929		2.705162
10371	B	D	77.09062	Y	0.7	1049.08081			$ 475,183	$ 1,060,000	3298.7	630	2014	321.334		3.6
11040	B	D	113.7534	Y	0.7	1048.83289			$ 504,687	$ 1,160,000	3331.4	631	1996	348.207		1.8
8482	B	D	55.40444	Y	0.7	1048.95203			$ 431,411	$ 1,010,000	3339.1	632	2013	302.481		3.6
9459	B	D	115.4395	Y	0.7	1047.99854			$ 505,291	$ 1,170,000	3354.7	633	1913	348.763		3.6
8935	B	D	102.6243	Y	0.7	1045.59534			$ 408,692	$ 934,000	3357.5	634	2014	278.18		1.8
8743	B	D	110.6447	Y	0.7	1047.79773			$ 504,188	$ 1,180,000	3393.3	635	2015	347.748		3.6
9791	A	D	115.7479	Y	0.7	1047.18091			$ 684,301	$ 1,780,000	3406.3	636	2012	522.562		3.6
10767	B	D	162.7331	Y	0.7	1047.80762			$ 505,046	$ 1,190,000	3414.3	637	1988	348.538		3.6
10659	A	D	92.30751	Y	0.7	1047.78235			$ 505,107	$ 1,200,000	3442.4	638	1997	348.594		3.6
8647	B	D	106.4993	Y	0.7	1047.73059			$ 504,341	$ 1,250,000	3593.1	639	2012	347.889		1.8
9502	A	D	117.6321	Y	0.7	1047.29736			$ 502,645	$ 1,250,000	3609.3	640	1999	346.33		2.608113
8526	A	D	80.87932	Y	0.7	1045.6			$ 469,215	$ 1,420,000	3689.6	641	2013	384.861		2.962178
8645	A	D	103.0465	Y	0.7	1047.79846			$ 556,421	$ 1,290,000	3693.5	642	2015	349.266		3.6
10972	B	D	117.0172	Y	0.7	1047.99072			$ 505,533	$ 1,290,000	3696.4	643	2009	348.986		2.453125
10295	B	D	85.29059	Y	0.7	1048.02783			$ 416,302	$ 1,070,000	3709.6	644	1981	288.44		1.8
8314	B	D	115.737	Y	0.7	1047.09631			$ 508,338	$ 1,310,000	3726.1	645	2008	351.57		3.6
8457	A	D	266.0434	Y	0.7	1048.17065			$ 819,546	$ 2,670,000	3751.8	646	2015	711.664		3.6
9218	B	D	93.52434	Y	0.7	1047.72595			$ 506,829	$ 1,350,000	3855.2	647	2013	350.179		1.8
9942	B	D	93.63088	Y	0.7	1048.84277			$ 462,333	$ 1,200,000	3873.5	648	2006	309.8		3.6
9563	A	D	105.2288	Y	0.7	1048.57056			$ 461,851	$ 1,200,000	3878.9	649	1997	309.37		3.6
9377	A	D	96.42221	Y	0.7	1045.78027			$ 408,655	$ 1,080,000	3882.8	650	2012	278.147		3.6
10444	A	D	195.2576	Y	0.7	1047.99255			$ 659,250	$ 2,110,000	3963.1	651	2007	532.407		1.8
8687	C	A	83.44186	Y	0.7	1045.36804			$ 408,882	$ 1,160,000	4153.5	652	2015	279.283		1.8

Attachment B: SOFDA Control File (Fo)

att_name	desc	att_value
~Session Control		
tag	short description for this simulation ensemble or scenario	01_FoSo
glbl_stoch_f	flag whether to use [TRUE] stochastic Dynps (default) or [FALSE] deterministic Dynps.	TRUE
mind	column label to match across all data sets (e.g. CPID)	CPID
~Simulation Control		
run_cnt	number of simulations to run --for deterministic runs: set to 1 --for stochastic (monte-carlo): set to many --for sensitivity analysis: set the maximum number of toggles to evaluate	**30**
~Sensitivity Analysis		
sensi_f	flag whether to run in sensitivity analysis mode --TRUE: ignores run_cnt. instead does 1 run for each value on each variable on the pars tab --FALSE: (default) execute with normal Dynp behavior	FALSE
delta_compare_col_nl	list of Outputr names to generate delta comparisons against the baseline	[od1a,od1c]
~Fdmg Control		
load_dfeats_first_f	flag whether to [TRUE] load all types of dfeats up front (improves performance), or [FALSE] each time called	TRUE
legacy_binv_f	flag to indicate that the binv is in legacy format (use indicies rather than column labels)	TRUE
hse_skip_depth	depth at which to skip calculating damage for a house (higher values improves performance)	-4
gis_area_max	value which to raise flag for building inventory footprint area error detection	3500
~Output Control		
write_fly_f	flag to write simulation results on the fly (useful for many simulations that may crash)	TRUE
log_separate_f	flag indicating whether each simulation should have its own log file (default=FALSE)	FALSE
output_dx_f	flag to include whether multi dimensional (w/ time steps) outputs should be generated (default=TRUE)	TRUE
write_sim_res_f	flag to write outputs of each simulation (default=TRUE)	FALSE
write_dt_dmg_dx	flag to write the raw damages on each flood/house for each timestep (default=FALSE)	FALSE
write_dt_dmg_sum	flag to write the damage totals for each damage type for each flood for each time step (default=FALSE)	FALSE
write_fdmg_sum_fly	flag to write damage totals for all sims, dts, and floods on the fly (useful for many simulations that may crash)	TRUE
~Scenario Control		
~Fdmg pars		
gpwr_aep	lowest aep that shuts down the grid power.(i.e.where sump pumps w/o generators work). affects the basement exposure grade function. generally re-assigned with a Dynp.	100
flood_tbl_nm	name of flood table to apply from the flood_tbls tab (for simulating different hazard scenarios)	**2016_sc0**
ca_ltail	code to calculate left tail y-axis intercept of EAD curve (near-impossible damage event). --**ltail**: left tail treatment code (low prob high damage) --**flat**: extend the max damage to the zero probability event (default) --**none**: don't extend the tail	flat
ca_rtail	code to calcualte right tail x-axis intercept of EAD curve (near-zero damage ARI)	3
area_egrd00	area exposure grade to apply for three different areas. control for areas depth decision algorhithim based on the performance of macro structures (e.g. dykes) and the area_prot_lvl of each house (see 'floods' tab).	dry
area_egrd01		dry
area_egrd02		dry
~Fdmg.House pars		
joist_space	default space to assume between top of basement ceiling and bottom of mainfloor	0.3
G_anchor_ht	default garage anchor height for anchor_ht_code = *hse (see 'dfunc' tab)	0.6
bsmt_egrd_code	global code for basement exposure grade (bsmt_egrd) algorhithim (for intermediate groundwater depth modification) --**plpm**: use logic based on your plpms to determine the bsmt_egrd (default) --**none:** exclude depth modification (equivalent to 'wet') --**'wet'=** set all Dfuncs to ignore bsmt_egrd; --**'damp'** = set all Dfuncs to modify intermediate groundwater depths per the damp_func_code;	plpm
damp_func_code	control code for bsmt_egrd = damp --**seep**: depth = 50% raw_depth --**spill**: depth = 0 until exceeding damp_spill_ht (set to 1/2 * bsmt_open_ht)	seep
bsmt_opn_ht_code	control code for bsmt_open_ht (for Dfuncs with bsmt_egrd = damp) bsmt_open_ht is the maximum height where bsmt_egrd = Dry sets depth = 0, and is 2x the damp_spill_ht --***min(2.0)**: take the minimum of height to grade and 2.0 --**some float**: use thsi float	*min(2.0)
~Fdmg.House.Dfunc pars		
dfeat_xclud_price	base_price below which dfeats will be excluded. a large value here improves performance, but underestimates lossess with the dfeats method (tests show $501 ~ 15% performance improvement and 5% total damage underestimation). Suggest 490.	490
~Udev pars		
fhr_nm	flooz hazard zone name to evaluate (see fdmg tab 'fhr_tbl' input file)	Fo
infil_cnt	number of properties to infill each year. generally re-assigned with a Dynp..	150
bucket_size	random bucket selection size parameter. Additional housese to add to the infil_cnt to generate a bucket for random selection. Utilized by the special Selector method 'get_random_pick_from_bucket'. --**0**: just take the top 'infil_cnt' from the list -->**0**: take a random 'infil_cnt' from the bucket #	150
~Debugging		
_parlo_f	flag to executle model in debugging mode (default=False) (see 'obj_test' tab)	FALSE
dbg_fld_cnt	for Fdmg.db_f = True, number of floods to include --'**all**': use all floods provided on 'floods' tab (default) --**int**: use this number (smaller values improve performance)	**all**

name	desc	headpath	tailpath
line ignored			relative path to data
rfda_curve	Model data file with Alberta Curve depth-damage values formatted for use in RFDA. legacy damage curves file for dfunc type='rfda'	fdmg/dfuncs	DamageCurves.xls
binv	Model data file with vulnerability data on each asset (e.g. main floor height, building type). The first 26 columns can be formatted for use in RFDA.	fdmg/binv	binv_ABMRI_aoi01_20181002.xls
dfeat_tbl	Model data file and tabs with damage feature data. Attachment C provides the default tables, developed from the original Alberta Curve damage feature tables. WARNING: be sure to edit each tab	fdmg/dfuncs	dfeat_tbl_20180902.xls
fhr_tbl	Model data file with FHZ and BFE on each asset for each FHR. CPID vs flood hazard levels and zones	fdmg/fhr	fhr_aoi01_20181004.xls

place_code	M	M	B	B	G	G
finish_code	f	u	f	u	f	u
area	gis_area	0	gis_area	0	0	40
height	5	0	*binv	0	0	5
per	*geo	0	*geo	0	0	*geo
inta	*geo	0	*geo	0	0	*geo

place_code	**dmg_code**	**dfunc_type**	**rat_attn**	**anchor_ht_code**
code for the floor or structure on the property generating the damage	code for damage type of the dfunc. C: contents S: Structural	type of damage function '**rfda**' = classic damage curves (requires 'rfda_curve' to be loaded). '**dfeats**' = build curves from teh damage features '**depdmg**' = standard format depth v damage curves from headpath/tailpath	attribute name to scale by for relative damage functions. BLANK or *none: no scaling, curves are absolute. Otherwise: py_eval (e.g. 'self.gis_area', or 'parent.value')	how the anchor_ht is determined for the dfunc ***rfda_pars** = legacy anchors (basement: from rfda_pars (generally 2.7); garage: -.6). requries rfda_pars to be loaded ***hse:** DEFAULT. uses parents geometry values to
M	C	rfda	self.parent.gis_area	*hse
M	S	dfeats	*none	*hse
B	C	rfda	self.parent.gis_area	*hse
B	S	dfeats	*none	*hse
G	S	dfeats	*none	*dem

name	desc	wetnull_code	wetdry_tol	damp_build_code	headpath	tailpath
line ignored		how to treat null values found in the 'wet' tab **take_wet:** use the values from the 'wet' tab.	tolerance for wsl_dry - wsl_wet. (e.g. '0.1' allows wet this much higer than dry... and sets wet = dry for these values)	how to generate the damp wsl **average**: add delta/2 to the 'wet' wsl **random(RATIO)**: randomly select the passed ratio of houses to apply 'wet' to, all others get 'dry'.		relative path to data
~area_prot_lvl						
2016_sc0	2016 Calgary - Scenario 0. all area_prot_lvl = 1	take_dry	0.1	average	flood tables	floodtbl_calgary2016_sc0_aoi01_20181004.xls
2016_sc7	2016 Calgary - Scenario 7. all area_prot_lvl = 2	take_dry	0.1	average	flood tables	floodtbl_calgary2016_sc7_aoi01_20181004.xls
stop						

name	**ari**
	annual recurrance interval
~area_prot_lvl	
0005flood	5
0008flood	8
0010flood	10
0020flood	20
0035flood	35
0050flood	50
0075flood	75
0100flood	100
0200flood	200
0350flood	350
0500flood	500
1000flood	1000

name	desc	run_seq_d
t0	Calculate EAD on current inventory	[('Fdmg',['*run'])]
t1	Update inventory, Calculate new EAD	[('Udev',['a_redev']), ('Fdmg', ['*run'])]
t2	Update inventory, Calculate new EAD	[('Udev',['a_redev']), ('Fdmg', ['*run'])]

name	desc	pclass_n	sel_n	act_n_l	dynp_n_l
		objects class name on which this is applicable	selector name to trigger this action on	list of actions to bundle in with this one (these are activated first) WARNING: inherited actions must come first here	list of pars to include in this action (activated after the bundled Actions)
~Redevelopment					
a_newhse	infill the parcles	House			[d_area_n, d_anch_n, d_ayoc_n, d_bfh_n, d_type_n]
a_nic	baseline PLPMs apply the bkflowv_f sumpump_f genorat_f to each house.(new houses only)	House			[ic01, ic02, ic03]
a_n_u	uncertainties	House			[d_area_nu, d_anch_nu]
a_fhr1	flood hazard land use regs on new builds in the FLOODFRINGE	House	s_fhz01		[d_fhr1a, d_fhr1d, d_fhr1e]
a_redev	infill the selected parcels. apply the initial conditions apply FHRs	House	s_pickn	[a_newhse, a_nic, a_n_u, a_fhr1]	

name	desc	pclass_n	obj_bool_exe	spcl_f_exe_str	headpath	tailpath	upd_sim_lvl
		objects class name on which this is applicable WARNING: Can not select objects with a selector dependency (Action, OUtputrs, Dynps)	pick set based on object booleans: e.g. 'obj.name == 'myname'. WARNING: no check on attribute validity	string for executing a special selector function. NOTE: These need to be self calls	headpath to a list of object names		lower level calc phase at which to update the selector explicit = 'none' periodic: 0: Session: never upate 1: Simulation 2: Timestep 3: Model 4: object level (NA)
~by House ID							
~Redevelopment							
s_pickn	pick the to 10 houses from the bid_rank_ser. NOTE: this only works if all teh houses are loaded	House		self.ranked_choice(n ='udev')	selectors/dev_pot	devpot_aoi02_2018091	none
~Flood hazard zones							
s_fhz01	those houses in the fhz100 FRINGE	House	obj.fhz == 1				0
~fhz rules							
s_dfeat_ME	mechanical & Electrical dfeatures	Dmg_feat	(obj.cat_code == 'M') or (obj.cat_code == 'E')				none
~Outputting							
s_hAD	houses of type hAD	House	obj.hse_type == 'AD'				none
s_new	new houses	House	obj.ayoc == session.year				none
s_fhznew	those new houses in the fhz100	House	(obj.fhz == 1) & (obj.ayoc ==				none

name	desc	pclass_n	att_name	sel_n	value_assign_str	change_type	dist_pars_l	min	max	correlate_an	upd_sim_lvl
unique identifier for thsi par	NOTE: many of these are not utilized when the default damage model is applied ('rfda')	objects class name on which this is applicable	attribute name on which to apply this dynamic parameter. BLANK: no dyn object updates	apply a (secondary) selector explicit selector blank = no secondary selection	controls how the value is assigned. see hp.synp.calibrate_valf. **'scipy.stats.NAME'** =some scipy distribution **STRING or FLOAT**: apply as a constant **EQUATION**: 1) 'new_val=...' (valf_simpl) with local variables 'att_name, obj, old_att_val, session 2) 'obj.custom_func()' (valf_set_exec)	control how the dynp value modifies the att_value 'delta': the dynp is added tot he value 'replace': the dynp value replaces the object value.	distirbution parameters. for 'scipy.stats.NAME'. expects []. 'norm': l[0] = loc, l[1] = scale	for 'scipy.stats.NAME'. NONE: Simple distribution, uncontained NUMERIC: Simple distribution, contained STRING: binary with min/max labels. (min taken for base during sensi)	see 'min'	correlated attribute name	step to apply the dynp '**NONE**': called excplicitly ('actions') **0:** Session **1**: Simulation **2:** Tstep **3:** Model **NOTE**: calling 'None' and assigning to an Action that only
~Fdmg General Pars											
d_gpwr	grid power aep	Fdmg	gpwr_aep		scipy.stats.lognorm	replace	[40, 50, .5]	51	1001		2
~NEW HOUSES							150	15			
d_cntr	Number of houses redeveloped per action	Udev	infil_cnt		scipy.stats.norm	replace	[150,15]	50	250		2
~a_nic											
ic01	apply the bkflowv_f	House	bkflowv_f		scipy.stats.norm	replace	[.5, .2]	yes	no		1
ic02		House	sumpump_f		scipy.stats.norm	replace	[.5, .2]	yes	no		1
ic03		House	genorat_f		scipy.stats.norm	replace	[.25, .2]	yes	no		1
~a_newhse											
d_area_n	maximze new parcel area	House	gis_area		new_val = obj.parcel_area*0.45 - 50	replace					none
d_anch_n	anchor elevation function	House	anchor_el		new_val = obj.dem_el + 0.6	replace					none
~d_value_n	house value change	House	value		scipy.stats.norm	delta	[200000, 10]	50000	1000000		none
d_ayoc_n	set the year to current	House	ayoc		new_val = session.year	replace					none
d_bfh_n	New B_f_height for rebuilds (see ic06)	House	B_f_height		scipy.stats.norm	replace	[2.80416, 0.8107]	1.8	3.6		none
d_type_n	set the new building type. THIS SHOULD BE LAST	House	hse_type		AD	replace					none
~a_n_u											
d_area_nu	infil area uertainty	House	gis_area		scipy.stats.norm	delta	[0, 1]	-10	10		none
d_anch_nu	anchor elevation uncertainty	House	anchor_el		scipy.stats.norm	delta	[0, .2]	-0.5	0.5		none
~FHZ regs											
~a_fhr1											
d_fhr1a	(P3D3.60.1).New houses in the FF require sewer backup valves.	House	bkflowv_f		TRUE	replace					none
d_fhr1d	(P3D3.60.1). New houses in the FF must have the 1st floor above the BFE	House	anchor_el		new_val = max(old_val, obj.bfe)	replace					none
~d_fhr1d_u	anchor elevation uncertainty	House	anchor_el		scipy.stats.norm	delta	[0, .2]	-0.5	0.5		none
d_fhr1e	(P3D3.60.1). New houses in the FF must have all M&E above BFE	Dmg_feat		s_dfeat_ME	obj.set_new_depth(obj.hse_o.bfe)						none

name	**desc**	**pclass_n**	**out_attn**	**sel_n**	**sim_stats_exe**
unique identifier. not really used, instead a codename is generated based ont he dimensions of the data.		objects class name selected for writing to the outputs library. Simulation and Session outputting NOT IN.	attribute name to collect and store data on. (model parts may use these to generate stats)	selector name (see 'selectors' tab). helps pick which objects are included for outputting. BLANK: include all objects int he class NOTE: the pclass_n must match WARNING: Only allow Selectors that don't update.	py string to execute on the outputr's final data set for summary into the Session. 'data', 'df', and 'ar', are exposed. should return a float ***none:** exclude reporting this outputr in the session summary ***raw:** only valid for 1D. report without a stat. ***dxraw**: report raw value for each time step. examples: np.mean(data) np.sum(data) np.count_nonzero(~pd.isnull(data))
~Damage Estimate Results					
od1	total EAD	Fdmg	ead_tot		np.mean(data)
~granular (fancy)					
~od3	write full results for the flood	Fdmg	res_fancy		*none
od4	aep for this flood	Flood	aep		*none
od5	total ground water damage	Flood	dmg_gw		np.sum(data)
od6	total surface water damage	Flood	dmg_sw		np.sum(data)
od7	total damage for this flood	Flood	total		np.sum(data)
od8	Basement Structural damage	Flood	BS		np.sum(data)
od9	Basement Contents	Flood	BC		np.sum(data)
od10	Mainfloor Structural	Flood	MS		np.sum(data)
od11	Mainfloor Contents	Flood	MC		np.sum(data)
~Vulnerability state					
ov1		House	bkflowv_f		np.sum(data)
ov2		House	gis_area		np.mean(data)
ov3		House	vuln_el		np.mean(data)
ov4		House	anchor_el		np.mean(data)
ov5	maximum possible damage on a house (combines all Dfuncs)	House	max_dmg		np.sum(data)
~Vulnerability state (in the FHZ)					
ovf1		House	bkflowv_f	s_fhz01	np.sum(data)
ovf2		House	gis_area	s_fhz01	np.mean(data)
ovf3		House	vuln_el	s_fhz01	np.mean(data)
ovf4		House	max_dmg	s_fhz01	np.sum(data)
~ Vulnerability Grades (area)					
~ Vulnerability Grades (local/basement)					
ovb1	mimum aep flood with power	Fdmg	gpwr_aep		np.mean(data)
ovb2	number of floods with power	Fdmg	fld_pwr_cnt		np.sum(data)
ovb3	basement exposure grade count	Fdmg	bwet_cnt		np.sum(data)
ovb4	basement exposure grade count	Fdmg	bdamp_cnt		np.sum(data)
ovb5	basement exposure grade count	Fdmg	bdry_cnt		np.sum(data)
~Exposure state					np.sum(data)
oe1	number of houses with any flood damage	Flood	hdmg_cnt		np.sum(data)
oe2	average house depth for this flood	Flood	hdep_avg		np.mean(data)
oe3	avearge water surface level	Flood	wsl_avg		np.mean(data)
~Urban development (Udev)					
ou1	total house count	House	hse_type		np.count_nonzero(data)
ou2	AD house count	House	hse_type	s_hAD	np.count_nonzero(~pd.isnull(data))
ou3	new houses count	House	hse_type	s_new	np.count_nonzero(~pd.isnull(data))
ou4	new houses in teh FHZ	House	hse_type	s_fhznew	np.count_nonzero(~pd.isnull(data))

Attachment C: SOFDA Control File (Ft3)

name	desc	pclass_n	obj_bool_exe	spcl_f_exe_str	headpath	tailpath	upd_sim_lvl
		objects class name on which this is applicable WARNING: Can not select objects with a selector dependency (Action, OUtputrs, Dynps)	pick set based on object booleans: e.g. 'obj.name == 'myname'. WARNING: no check on attribute validity	string for executing a special selector function. NOTE: These need to be self calls	headpath to a list of object names		lower level calc phase at which to update the selector. 0: Session: never upate 1: Simulation 2: Timestep 3: Model 4: object level (NA)
~by House ID ~Redevelopment							
s_pickn	pick the to 10 houses from the bid_rank_ser. NOTE: this only works if all teh houses are	House		self.ranked_choice(n ='udev')	selectors/dev_pot	devpot_aoi02_2018091	none
~Flood hazard zones							
s_fhz1	those houses in the fhz100 FRINGE	House	obj.fhz == 1				0
s_fhz2	those houses in the fhz100 FRINGE	House	obj.fhz == 2				0
s_fhz3	those houses in the fhz100 FRINGE	House	obj.fhz == 3				0
~fhz rules							
s_dfeat_ME	mechanical & Electrical dfeatures	Dmg_feat	(obj.cat_code == 'M') or (obj.cat_code == 'E')				none
~s_bsmt	basements	Dfunc	obj.place_code == 'B'				none
s_conts	contesnts	Dfunc	(obj.dmg_code == 'C') and (obj.place_code == 'B')				none
s_strut	structural	Dfunc	(obj.dmg_code == 'S') and (obj.place_code == 'B')				none
s_fin	finishings	Dmg_feat	(obj.cat_code == 'F') or (obj.cat_code == 'E')				none
~Outputting							
s_hAD	houses of type hAD	House	obj.hse_type == 'AD'				none
s_new	new houses	House	obj.ayoc == session.year				none
s_fhz1new	those new houses in the fhz100 FRINGE	House	(obj.fhz == 1) & (obj.ayoc ==				none
s_fhz2new	those new houses in the fhz100 FRINGE	House	(obj.fhz == 2) & (obj.ayoc ==				none
s_fhz3new	those new houses in the fhz100 FRINGE	House	(obj.fhz == 3) & (obj.ayoc ==				none

name	**desc**	**pclass_n**	**sel_n**	**act_n_l**	**dynp_n_l**
		objects class name on which this is applicable	selector name to trigger this action on	list of actions to bundle in with this one (these are activated first) WARNING: inherited actions must come first here	list of pars to include in this action (activated after the bundled Actions)
~Redevelopment					
a_fhrA	all plpms	House			[d_fhrA_b, d_fhrA_c, d_fhrA_a]
a_fhrB	unfinished basements	Dfunc			[d_fhrB_a, d_fhrB_b]
a_newhse	infill the parcles	House			[d_area_n, d_anch_n, d_ayoc_n, d_bfh_n, d_type_n]
a_nic	baseline PLPMs apply the bkflowv_f sumpump_f genorat_f to each house.(new houses only)	House			[ic01, ic02, ic03]
a_n_u	uncertainties	House			[d_area_nu, d_anch_nu]
a_fhz1	unfinished basement all PLPMs short basement	House	s_fhz1	[a_fhrB, a_fhrA]	[d_fhr_e]
a_fhz2	all PLPMs short basement	House	s_fhz2	[a_fhrA]	[d_fhr_e]
a_fhz3	ff above bfe	House	s_fhz3		[d_fhr_a]
a_redev	infill the selected parcels. apply the initial conditions apply FHRs	House	s_pickn	[a_newhse, a_nic, a_n_u, a_fhz1, a_fhz2, a_fhz3]	

name	desc	pclass_n	att_name	sel_n	value_assign_str	change_type	dist_pars_l	min	max	correlate_an	upd_sim_lvl
unique identifier for thsi par	NOTE: many of these are not utilized when the default damage model is applied ('rfda')	objects class name on which this is applicable	attribute name on which to apply this dynamic parameter. BLANK: no dyn object updates	apply a (secondary) selector explicit selector blank = no secondary selection	controls how the value is assigned. see hp.synp.calibrate_valf. **'scipy.stats.NAME'** =some scipy distribution **STRING or FLOAT**: apply as a constant **EQUATION**: 1) 'new_val=...' (valf_simpl) with local variables 'att_name, obj, old_att_val, session 2) 'obj.custom_func()' (valf_set_exec)	control how the dynp value modifies the att_value 'delta': the dynp is added tot he value 'replace': the dynp value replaces the	distirbution parameters. for 'scipy.stats.NAME'. expects []. 'norm': l[0] = loc, l[1] = scale	for 'scipy.stats.NAME'. NONE: Simple distribution, uncontained NUMERIC: Simple distribution, contained STRING: binary with min/max labels. (min taken for base during	see 'min'	correlated attribute name	step to apply the dynp '**NONE**': called excplicitly ('actions') **0:** Session **1**: Simulation **2:** Tstep **3:** Model **NOTE**: calling 'None' and
~Fdmg General Pars											
d_gpwr	grid power aep	Fdmg	gpwr_aep		scipy.stats.lognorm	replace	[40, 50, .5]	51	1001		2
~NEW HOUSES							150	15			
d_cntr	Number of houses redeveloped per action	Udev	infil_cnt		scipy.stats.norm	replace	[150,15]	50	250		2
~a_nic											
ic01	apply the bkflowv_f	House	bkflowv_f		scipy.stats.norm	replace	[.5, .2]	yes	no		1
ic02		House	sumpump_f		scipy.stats.norm	replace	[.5, .2]	yes	no		1
ic03		House	genorat_f		scipy.stats.norm	replace	[.25, .2]	yes	no		1
~a_newhse											
d_area_n	maximze new parcel area	House	gis_area		new_val = obj.parcel_area*0.45 - 50	replace					none
d_anch_n	anchor elevation function	House	anchor_el		new_val = obj.dem_el + 0.6	replace					none
~d_value_n	house value change	House	value		scipy.stats.norm	delta	[200000, 10]	50000	1000000		none
d_ayoc_n	set the year to current	House	ayoc		new_val = session.year	replace					none
d_bfh_n	New B_f_height for rebuilds (see ic06)	House	B_f_height		scipy.stats.norm	replace	[2.80416, 0.8107]	1.8	3.6		none
d_type_n	set the new building type. THIS SHOULD BE LAST	House	hse_type		AD	replace					none
~a_n_u											
d_area_nu	infil area uertainty	House	gis_area		scipy.stats.norm	delta	[0, 1]	-10	10		none
d_anch_nu	anchor elevation uncertainty	House	anchor_el		scipy.stats.norm	delta	[0, .2]	-0.5	0.5		none
~FHZ regs											
d_fhr_a	ff above bfe	House	anchor_el		new_val = max(old_val, obj.bfe)	replace					none
d_fhr_e	minimize B_f_height	House	B_f_height		1.8	replace					none
~a_fhrA	*all plpms*										
d_fhrA_a	require backflow valves	House	genorat_f		TRUE	replace					none
d_fhrA_b	require backflow valves	House	bkflowv_f		TRUE	replace					none
d_fhrA_c	require backflow valves	House	sumpump_f		TRUE	replace					none
~a_fhrB	*unfinished basements*										
d_fhrB_a	reduced contents in	Dfunc	rat_attn	s_conts	self.parent.gis_area*0.5	replace					none
d_fhrB_b	no finishings or electircal	Dmg_feat	base_price	s_fin	0	replace					none

Attachment D: Flood Tables

Available upon request

Attachment E: FHZ Tables

CPID	fhz	bfe
168586	1	1046.7
168780	1	1047
168877	1	1047.3
169265	999	0
169362	999	0
169459	999	0
169653	999	0
169750	1	1047
171981	1	1046.7
548729	1	1047
10168490	1	1046.7
10168587	1	1046.7
10168684	1	1047
10168781	1	1047
10168878	999	0
10169266	999	0
10169363	999	0
10169557	999	0
10171982	1	1046.7
20168491	1	1046.7
20168588	1	1046.7
20168685	1	1047
20168879	999	0
20169267	999	0
20169364	999	0
20169461	999	0
20169558	999	0
20169655	999	0
20169752	1	1047
20171983	1	1046.7
20547761	1	1046.7
30168492	1	1046.7
30168589	1	1046.7
30168686	1	1047
30168880	999	0
30168977	999	0
30169074	1	1046.7
30169268	999	0
30169365	999	0
30169462	999	0
30169559	999	0
30169656	999	0
30171984	1	1046.7
30547762	1	1046.7
40168493	1	1046.7
40168590	1	1046.7
40168687	1	1047
40168881	1	1047.3
40169269	999	0
40169366	999	0
40169463	999	0
40169560	999	0
40169754	999	0
40171985	1	1046.7
40523319	1	1047
50168494	1	1046.7
50168591	1	1046.7
50168882	999	0
50168979	999	0
50169270	999	0
50169367	999	0
50169464	999	0
50169561	999	0
50169755	999	0
50171986	1	1046.7
50505084	999	0
50523320	1	1047
60168592	1	1046.7
60168689	1	1047
60168883	999	0
60169271	999	0
60169368	999	0
60169465	999	0
60169562	999	0
60169659	999	0
60169756	1	1047
60171987	1	1046.7
70168593	1	1046.7
70168690	1	1047
70168884	999	0
70169272	999	0
70169369	999	0
70169660	999	0
80161513	999	0
80168497	1	1046.7
80168594	1	1046.7
80168691	1	1047
80168788	1	1047.3
80168885	1	1047.3
80169273	999	0
80169370	999	0
80169467	999	0
80169661	999	0
80171989	1	1046.7
90168595	1	1046.7
90168692	1	1047
90168789	1	1047.3
90168983	999	0
90169274	999	0
90169371	999	0
90169468	999	0
90169662	999	0
96065009	999	0
96065010	999	0
96065080	1	1047
96065081	1	1047
96066520	1	1047
96073051	1	1047
96073052	1	1047
96073268	1	1046.7
96073269	1	1046.7
96075138	999	0
96077526	1	1046.7
96077527	1	1046.7
96078910	999	0
96078911	1	1047.3
96081785	1	1046.7
96081786	1	1046.7
96094372	1	1047
96094373	1	1047
96094374	1	1047
96094375	1	1047
96094376	1	1047
96094377	1	1047
96095195	1	1046.7
96098629	999	0
96106773	999	0
96108304	1	1047
96111506	1	1046.7
96111507	1	1046.7
96112046	1	1047
96112047	1	1047
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96112978	1	1047
96114442	999	0
96116303	1	1046.7

CPID	fhz	bfe
96116304	1	1046.7
96118821	999	0
96119243	999	0
96119244	999	0
96119245	999	0
96119246	999	0
96120771	999	0
96121853	999	0
96125715	999	0
96127821	1	1047
96129158	999	0
96130873	1	1047.3
96132945	999	0
96132946	999	0
96133158	999	0
96133159	999	0
96137953	1	1047
96140790	1	1047
96141179	999	0
96141192	999	0
96142251	999	0
96142409	999	0
96146858	999	0
96146862	999	0
96147948	1	1046.7
96147949	1	1046.7
96149211	1	1047
96152540	999	0
100168499	1	1047
100168596	1	1046.7
100168693	1	1047
100168790	1	1047.3
100168887	1	1047.3
100169275	999	0
100169372	999	0
100169469	999	0
100169663	999	0
100169760	1	1047
110168500	1	1047
110168597	1	1046.7
110168791	1	1047.3
110168888	1	1047.3
110168985	999	0
110169179	999	0
110169276	999	0
110169373	999	0
110169470	999	0
110169664	999	0
120168501	1	1047
120168598	1	1046.7
120168889	1	1047.3
120168986	999	0
120169180	999	0
120169277	999	0
120169374	999	0
120169471	999	0
120169568	999	0
120169762	1	1046.7
120171993	1	1046.7
130168502	1	1047
130168599	1	1046.7
130168696	1	1047
130168890	999	0
130169181	999	0
130169278	999	0
130169375	999	0
130169472	999	0
130169763	999	0
130171994	1	1046.7
130532446	1	1047
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140168600	1	1046.7
140168794	1	1047.3
140168891	999	0
140168988	999	0
140169182	999	0
140169279	999	0
140169376	999	0
140169473	999	0
140169667	999	0
140171995	1	1046.7
140532447	1	1047
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150169474	999	0
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170168506	1	1047
170168603	1	1046.7
170168700	1	1047
170168797	1	1047.3
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170169282	999	0
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170169476	999	0
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170555827	999	0
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180169089	1	1046.7
180169186	999	0
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190168605	1	1046.7
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190168993	999	0
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190169187	999	0
190169284	999	0

CPID	fhz	bfe
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190169478	999	0
190169575	1	1047
190169672	999	0
190528960	1	1047
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200168606	1	1046.7
200168800	999	0
200168897	999	0
200169091	1	1046.7
200169188	999	0
200169285	999	0
200169382	999	0
200169479	999	0
200169576	1	1047
200169673	999	0
200528961	1	1047
210168510	1	1047
210168607	1	1046.7
210168801	999	0
210168898	999	0
210168995	999	0
210169189	999	0
210169286	999	0
210169383	999	0
210169480	999	0
210169577	1	1047
210169674	999	0
220168511	1	1047
220168608	1	1046.7
220168705	1	1047
220168802	999	0
220168899	999	0
220169190	999	0
220169287	999	0
220169384	999	0
220169481	999	0
220169578	1	1047
220169675	999	0
220169772	999	0
230168609	1	1046.7
230168706	1	1047
230168803	999	0
230168900	999	0
230168997	999	0
230169191	999	0
230169288	999	0
230169385	999	0
230169482	999	0
230169676	999	0
230506169	999	0
240168513	1	1046.7
240168610	1	1046.7
240168707	1	1047
240168804	999	0
240168901	999	0
240169192	999	0
240169289	999	0
240169483	999	0
250168514	1	1046.7
250168611	1	1046.7
250168708	1	1047
250168805	999	0
250168902	999	0
250168999	999	0
250169193	999	0
250169290	999	0
250169484	999	0
250169581	1	1047
250557872	999	0
260168515	1	1046.7
260168612	1	1046.7
260168709	1	1047
260168806	999	0
260168903	999	0
260169000	999	0
260169194	999	0
260169291	999	0
260169388	999	0
260169485	999	0
260169582	1	1047
260169776	999	0
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260539055	1	1047
270168516	1	1046.7
270168613	1	1046.7
270168710	1	1047
270168807	999	0
270168904	999	0
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590168839	3	1047.752

CPID	fhz	bfe
590168936	2	1047.732
590169033	3	1048.493
590169227	3	1049.652
590169324	3	1049.183
590169518	3	1048.974
590169809	2	1048.837
590506399	1	1047.394
600168646	2	1047.403
600168743	2	1047.481
600168840	3	1047.737
600168937	2	1047.732
600169034	3	1048.468
600169131	3	1049.508
600169228	3	1049.653
600169519	2	1048.931
600169810	2	1048.877
600506400	1	1047.398
610168647	2	1047.402
610168744	2	1047.487
610168841	3	1047.728
610168938	2	1047.766
610169035	3	1048.456
610169132	3	1049.524
610169520	2	1048.926
610169811	2	1048.872
610506401	1	1047.397
610555677	3	1049.281
620168745	2	1047.494
620168842	3	1047.722
620168939	2	1047.8
620169036	3	1048.443
620169133	3	1049.465
620169230	3	1049.655
620169327	3	1049.445
620169812	2	1048.867
630168649	2	1047.4
630168843	3	1047.713
630168940	2	1047.8
630169134	3	1049.346
630169231	3	1049.656
630169813	2	1048.862
640168650	2	1047.432
640168844	3	1047.698
640168941	2	1047.834
640169135	3	1049.438
640169232	3	1049.656
640169329	3	1049.446
640169426	3	1048.448
640169523	2	1048.911
640169814	2	1048.857
640527841	3	1048.487
650168651	2	1047.432
650168748	2	1047.535
650168845	3	1047.683
650168942	2	1047.87
650169136	3	1049.423
650169233	3	1049.83
650169330	3	1049.447
650169427	3	1048.517
650169524	2	1048.906
650169815	2	1048.851
660168652	2	1047.43
660168749	2	1047.454
660168846	3	1047.683
660168943	2	1047.906
660169137	3	1049.468
660169234	3	1049.836
660169331	3	1049.447
660169428	3	1048.676
660169525	2	1048.901
660169816	2	1048.844
670168653	2	1047.428
670168750	2	1047.454
670168847	3	1047.668
670168944	2	1047.906
670169138	3	1049.463
670169235	3	1049.836
670169332	3	1049.448
670169429	3	1048.759
670169526	2	1048.891
670169817	2	1048.829
670528717	3	1049.632
680168654	2	1047.425
680168751	2	1047.458
680168848	3	1047.668
680168945	2	1047.788
680169139	3	1049.459
680169236	3	1049.575
680169333	3	1049.448
680169430	3	1048.785
680169527	2	1048.886
680169818	2	1048.821
690168655	2	1047.424
690168752	2	1047.462
690168946	2	1047.849
690169237	3	1049.489
690169334	3	1049.449
690169431	3	1048.812
690169528	2	1048.881
690169625	3	1047.705
690169819	2	1048.813
700168656	2	1047.423
700168753	2	1047.475
700169141	3	1049.458
700169238	3	1049.836
700169335	3	1049.45
700169432	3	1048.838
700169529	2	1048.876
700169820	2	1048.813
710168560	2	1047.401
710168657	2	1047.422
710168754	2	1047.484
710168851	3	1047.721
710169142	3	1049.442
710169239	3	1049.633
710169336	3	1049.45
710169433	3	1048.861
710169530	3	1048.744
710169627	2	1047.389
710169724	2	1047.38
710169821	2	1048.805
710566648	2	1047.437
710577124	3	1047.495
720168561	2	1047.391
720168658	2	1047.421
720168755	2	1047.488
720168852	3	1047.754
720168949	2	1047.962
720169240	3	1049.375
720169337	3	1049.451
720169434	3	1048.901
720169531	3	1048.736
720169822	2	1048.798
720566649	2	1047.435
730168465	1	1047.164
730168562	2	1047.369

CPID	fhz	bfe
730168659	2	1047.42
730168756	2	1047.495
730168853	3	1047.765
730168950	2	1047.675
730169144	3	1049.425
730169338	3	1049.452
730169435	3	1048.961
730169532	3	1048.729
730566650	2	1047.439
740168466	1	1047.16
740168563	2	1047.369
740168660	2	1047.418
740168757	2	1047.498
740168854	3	1047.752
740168951	2	1047.691
740169048	3	1048.443
740169339	3	1049.452
740169533	3	1048.72
740169727	3	1047.755
740566651	2	1047.438
750168564	2	1047.371
750168661	2	1047.418
750168758	2	1047.501
750168855	3	1047.746
750168952	2	1047.703
750169340	3	1049.454
750169437	3	1049.02
750169534	3	1048.71
750169728	3	1047.979
750169825	3	1049.451
760168565	2	1047.372
760168662	2	1047.417
760168759	2	1047.508
760168856	3	1047.731
760168953	2	1047.72
760169147	3	1049.69
760169244	3	1049.356
760169438	3	1049.04
760169535	3	1048.7
760169632	2	1047.384
770168566	2	1047.324
770168663	2	1047.416
770168760	2	1047.511
770168857	3	1047.722
770168954	2	1047.753
770169148	3	1049.669
770169245	3	1049.349
770169342	3	1049.289
770169439	3	1049.06
770169536	3	1048.679
770169633	2	1047.384
770169730	3	1048.97
780168567	2	1047.324
780168664	2	1047.415
780168761	2	1047.514
780168955	2	1047.787
780169149	3	1049.644
780169246	3	1049.341
780169343	3	1049.289
780169440	3	1049.08
780169537	3	1048.668
780169634	1	1047.385
780169731	3	1049.799
790168665	2	1047.414
790168762	2	1047.521
790168859	3	1047.801
790168956	2	1047.787
790169150	3	1049.798
790169247	3	1049.334
790169344	3	1049.29
790169441	3	1049.101
790169538	3	1048.657
790169635	1	1047.384
790169732	3	1049.278
800168472	1	1047.285
800168569	2	1047.398
800168666	2	1047.414
800168763	2	1047.528
800168957	2	1047.821
800169151	3	1049.829
800169248	3	1049.326
800169345	3	1049.29
800169539	3	1048.646
800169733	3	1049.284
810168473	1	1047.285
810168570	1	1047.234
810168667	2	1047.412
810168958	2	1047.821
810169152	3	1049.716
810169249	3	1049.318
810169346	3	1049.316
810169540	3	1048.635
810169637	1	1047.383
810527179	3	1048.004
820168474	1	1047.281
820168668	2	1047.411
820168765	2	1047.44
820168959	2	1047.854
820169153	3	1049.7
820169250	3	1049.311
820169347	3	1049.317
820169541	3	1048.964
820169638	1	1047.383
820509041	1	1047.353
830168475	1	1047.277
830168572	1	1047.23
830168766	2	1047.627
830168960	2	1047.888
830169154	3	1049.702
830169348	3	1049.317
830169542	3	1048.69
830527181	3	1048.052
830577815	2	1047.428
840168573	1	1047.226
840168670	1	1047.394
840168767	2	1047.632
840169155	3	1049.716
840169349	3	1049.318
840169640	1	1047.38
840527182	3	1048.13
840577816	2	1047.431
850168477	1	1047.269
850168574	1	1047.222
850168671	1	1047.397
850168768	2	1047.637
850168865	3	1047.667
850169156	3	1049.663
850169253	3	1049.293
850169350	3	1049.318
850527183	3	1048.104
850548717	2	1047.428
860168478	1	1047.264
860168575	1	1047.218
860168672	1	1047.401
860168769	2	1047.663
860168866	3	1047.695

CPID	fhz	bfe
860169157	3	1049.702
860169254	3	1049.285
860169351	3	1049.318
860527184	3	1048.078
870168479	1	1047.26
870168576	1	1047.21
870168673	2	1047.412
870168770	2	1047.692
870168867	3	1047.695
870169158	3	1049.44
870169255	3	1049.285
870169352	3	1049.319
870169643	1	1047.376
870169740	2	1047.393
870527185	3	1048.179
880168480	1	1047.26
880168674	2	1047.419
880168771	2	1047.692
880168868	3	1047.723
880169159	3	1049.44
880169256	3	1049.278
880169353	3	1049.319
880169450	3	1049.089
880169644	1	1047.375
880169741	1	1047.256
880527186	3	1048.156
890168675	2	1047.422
890168772	2	1047.721
890168869	3	1047.723
890169160	3	1049.474
890169257	3	1049.27
890169451	3	1049.084
890169645	1	1047.382
890169742	3	1047.658
890527187	3	1048.13
890532813	3	1048.981
900168482	1	1047.293
900168579	1	1047.194
900168676	2	1047.43
900168773	2	1047.739
900168870	3	1047.755
900169258	3	1049.262
900169452	3	1049.084
900169646	1	1047.387
900532814	3	1049
910168483	1	1047.368
910168580	1	1047.286
910168677	2	1047.436
910168774	2	1047.75
910168871	3	1047.818
910169259	3	1049.255
910169356	3	1049.32
910169453	3	1049.078
910169647	1	1047.386
910169744	3	1049.848
910518944	3	1049.443
910550178	3	1048.593
920168484	1	1047.363
920168581	1	1047.309
920168678	2	1047.426
920168872	3	1047.935
920169163	3	1049.588
920169260	3	1049.247
920169357	3	1049.184
920169454	3	1049.073
920169745	3	1049.849
920518945	3	1049.299
920550179	3	1048.668
920568706	1	1047.273
930168485	1	1047.363
930168582	1	1047.309
930168679	2	1047.429
930168873	3	1047.682
930169164	3	1049.411
930169261	3	1049.239
930169358	3	1049.185
930169455	3	1049.068
930169649	3	1047.788
930518946	3	1049.443
930568707	1	1047.273
940168583	1	1047.332
940168680	2	1047.431
940168874	3	1047.709
940169262	3	1049.232
940169359	3	1049.185
940169456	3	1049.062
940169650	3	1047.713
950168487	1	1047.359
950168584	1	1047.363
950168681	2	1047.434
950168778	2	1047.709
950168875	3	1047.709
950169263	3	1049.224
950169360	3	1049.187
950169457	3	1049.057
950169651	3	1047.683
950169748	1	1047.387
960168488	1	1047.359
960168585	1	1047.363
960168779	2	1047.691
960168876	3	1047.739
960168973	3	1047.923
960169361	3	1049.187
960169458	3	1049.052
960169652	3	1047.683
960169749	1	1047.386
960599443	2	1047.717
960599637	3	1047.706
960600765	2	1047.732
960602962	3	1047.664
960604963	1	1047.202
960604964	1	1047.206
960606909	3	1047.952
960608968	3	1048.405

Appendix F: Sensitivity Analysis

SOFDA Sensitivity Analysis

F1. Introduction

To evaluate flood risk under dynamic vulnerability, the novel Stochastic Object-based Flood damage Dynamic Assessment model (SOFDA) is developed and leveraged to explore flood risk in the Sunnyside/Hillhurst study area (see Appendix D, *SOFDA Users Manual,* for a detailed description of SOFDA). To support framework development, two sensitivity analysis (SA) are conducted and described here. The purpose of these are to:

- *identify parameters with small influence:* To improve performance, parameters with small influence can be applied to SOFDA as deterministic (rather than stochastic) parameters with only a small impact on model results.
- *identify parameters with high uncertainty and sensitivity*: To improve the current and future projects, research resources should be prioritized on parameters which have a significant influence on model results and which are difficult to measure.
- *create confidence in the model function:* As SOFDA is a novel framework, SA provide a useful qualitative demonstration and testing opportunity.

F2. Method

For a complete description of the sensitivity analysis mode in SOFDA, see Appendix D. For this SA, the base model (see main report) was executed in SA mode to quantify the results sensitivity to key parameters.

F2.1. Sensitivity Metrics

For this SA, estimated annual damage (EAD) results compared in two ways were leveraged to quantify the sensitivity of the focus parameters:

- **EAD baseline delta at the start (**EAD_0**)**: This is the risk in the first year (before redevelopment) compared against the baseline. This quantifies how much the focus parameter influences risk estimates. This metric is not influenced by vulnerability dynamics.
- **EAD baseline delta change (**EAD_d**):** This is the risk change (last year minus first year) compared against the baseline (delta of a delta). This quantifies how much this parameter influences the simulation of risk over time?

F2.2. Focus Parameters

In SOFDA, focus parameters are implemented as Dynp objects — SOFDA worker objects that change some other model object attribute values (e.g the Dynp 'd_begr' sets the 'bsmt_egrd' parameter on all House objects). For each of these focus parameters, SOFDA builds a set of deterministic simulations based on the user provided extremes — holding all other Dynps at their mean value. For example, the Dynp "d_begr" was parameterized with 'dry', 'damp', and 'wet', extremes which lead SOFDA to build three deterministic simulations with Dynp as the focus parameter.

The focus parameters relevant to the base model can be grouped by model application:

- *Initial conditions*: parameters/structural attributes that adjust key attributes of the building inventory (e.g. basement vulnerability grade (BVG), B_f_height,). These mostly influence EAD_0;
- *Fdmg behavior*: parameters/structural attributes that influence the damage model function throughout the simulation. These mostly influence EAD_0;
- *Udev behavior*: parameters/structural attributes that influence how new houses are infilled (e.g. infil_cnt). These only influence EAD_d;
- *FHZ behavior*: really a subset of Udev behavior, these influence how the FHZ regs are applied to new houses. These only influence EAD_d.

For the main SA, 25 model parameters and attributes were selected for investigation based (see Attachment A). These included all those dynps necessary to execute the timeline of the base model and additional dynps applied to quantify the uncertainty of key parameters. The complete table of dynp values from the user control file is provided in Attachment B. From these, and the selected parameter extremes, 43 focus simulations (and one baseline) were evaluated.

F3. Results and Discussion

The complete results of the 44 simulations are provided in Attachment A.

F3.1. Static Risk Sensitivity (EAD_0)

This section discusses those parameters with the most and least influence on the risk prediction in the first year (EAD_0).

F3.1.1. Most Influential

The following provides the results of those focus simulations with the largest EAD_0. This list represents those parameters with the most influence on the initial risk prediction — before the influence of vulnerability dynamics.

Table 3-1: SA results showing the six simulations with the highest EAD_0.

dynp	description	focal value	EAD_0	EAD_0
			base delta	base delta
			relative	rank
			first	first
d_fprob	flood probability multiplier	1.6	0.443	1
d_bfh	basement finish height uncertainty	3.6	0.362	2
d_anch_u	anchor elevation uncertainty	-0.5	0.294	3
d_bfh	basement finish height uncertainty	1.8	-0.272	4
d_begr	basement exposure grade uncertainty	dry	-0.249	5
d_anch_u	anchor elevation uncertainty	0.5	-0.247	6

The rank 1 parameter, d_fprob, scales up the flood frequencies by 40%. This parameter can be used to simulate changes in exposure from factors like climate change. Considering this acts as a global modifier on all flood damages (during EAD integration), it is unsurprising that the model predicts a large positive correlation with EAD.

Grouping by behavior, rank 2, 3, 5, and 6 (d_bfh and d_anch_u) relate to how 'high' the houses are. As expected, the model predicts that asset flood risk is very sensitive to its height and negatively correlated — higher assets have less damage.

Finally, the rank 6 parameter, d_begr, toggles all basement vulnerability grades (BVG) to 'dry'. This simulates all houses as invulnerable to intermediate depth basement flood damage. As expected, such a large change invulnerability results in a relatively large risk reduction.

F3.1.2. Least Influential

Excluding those parameters which only influence model dynamics, Table 3-2 shows the results of the five parameters with the least influence on the EAD_0 prediction.

Table 3-2: SA results showing the five simulations with the lowest EAD_0.

dynp	description	focal value	EAD_0	EAD_0
			base delta	base delta
			relative	rank
d_bopht_u	basement open height uncertainty	0.5	-0.042	14
d_begr	basement exposure grade uncertainty	damp	-0.039	15
d_dampfc	depth fuction code for bsmt_egrd (damp	seep	0.035	16
d_ltail	EAD left tail integration code	none	-0.014	17
d_gpwr	minimum aep to disable grid power	51	0.000	18

Grouping by behavior, the following relate to how basement damages are calculated by different subsets:

- Rank 14 (d_bopht_u) only influences basement Dfuncs with BVG = dry (about 12% of assets);
- Rank 15 (d_begr) sets all 'dry' (12%) and 'wet' (46%) BVGs to 'damp' — the two effects cancelling;
- Rank 16 (d_dampfc) only influences BVG = damp by changing the depth calculation algorithm for shallow basement floods.

Rank 17 (d_ltail) governs how the EAD integration treats the left of the damage plot for the calculation of the near-impossible damage event. The insignificance of this parameter suggests that high-frequency flood damage is more significant than low-frequency for this model.

Rank 18 (d_gpwr) governs how many of the floods have grid power. This influences the calculation of houses with BVG = damp or dry for modelling the assumption that sump pumps in those assets without backup power will fail. Considering this parameter extreme resulted in only one additional flood object being simulated with a power failure (75 ARI), this result suggests that the number of dry and damp houses only getting basement damages in the 75flood is insignificant.

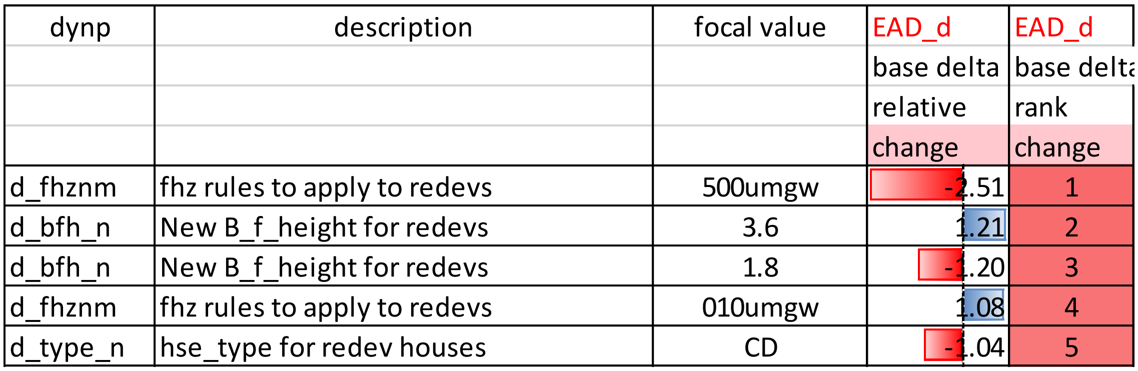
F3.2. Dynamic Risk Sensitivity (EAD_d)

This section discusses those parameters with the most and least influence on the risk accumulation prediction (EAD_d). This metric measures model performance with respect to vulnerability dynamics — rather than EAD_0, which measures performance with respect to static vulnerability. As SOFDA conceptualizes time-dynamics through changes in vulnerability brought about by infilling, the focal simulations discussed here explore the sensitivity of different parameterizations for re-development.

F3.2.1. Most Influential

Table 3-3 provides results for the five simulations with the most influence on the dynamic risk prediction (EAD_d).

Table 3-3: SA results showing the five simulations with the highest EAD_d.



dynp	description	focal value	EAD_d base delta relative change	EAD_d base delt rank change
d_fhznm	fhz rules to apply to redevs	500umgw	-2.51	1
d_bfh_n	New B_f_height for redevs	3.6	1.21	2
d_bfh_n	New B_f_height for redevs	1.8	-1.20	3
d_fhznm	fhz rules to apply to redevs	010umgw	1.08	4
d_type_n	hse_type for redev houses	CD	-1.04	5

Similar to the static risk sensitivity described above, rank 2 and 3 (d_bfh_n) — which control the basement height for infills — results suggest that flood risk is very sensitivity to asset height.

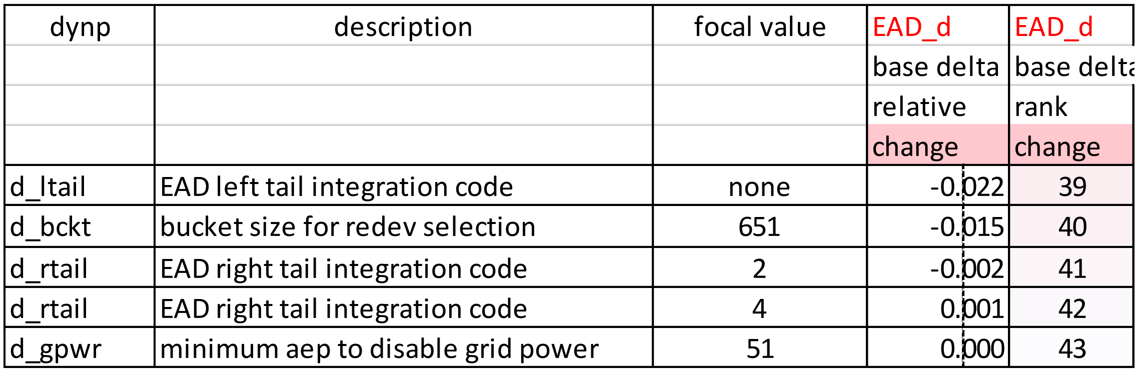
Rank 1 and 4 (d_fhznm) are flat toggles of the primary research question: *what benefits to Flood Hazard Regulations (FHRs) provide?* These control which redeveloped houses have FHZs applied, and how severe those FHZs are (how elevated things in the floodproofed house need to be). As expected, implementing a 500-yr FHZ reduces damages dramatically (compared against the current ~ 35-yr FHZ), while relaxing to a 10-yr FHZ increases damages.

The rank 5 simulation (d_type_n) investigates the influence of house type for infills. The base model assumption is that new houses are generally large and expensive — best parametrized as hse_type = ‘AD’. This SA simulation result shows that replacing this hse_type value with ‘CD’ significantly reduces risk. This matches intuition; if the current study area were replaced with smaller, less valuable houses — vulnerability and therefore risk would decrease.

F3.2.2. Least Influential

Table 3-4 shows those simulations with the smallest EAD$_d$. These represent those parameters with the least influence on the dynamic results of the model.

Table 3-4: SA results showing five simulations with the lowest EAD$_d$.



dynp	description	focal value	EAD_d base delta relative change	EAD_d base delt rank change
d_ltail	EAD left tail integration code	none	-0.022	39
d_bckt	bucket size for redev selection	651	-0.015	40
d_rtail	EAD right tail integration code	2	-0.002	41
d_rtail	EAD right tail integration code	4	0.001	42
d_gpwr	minimum aep to disable grid power	51	0.000	43

The two parameters explored in the rank 42, 41, and 39 simulations (d_ltail, d_rtail) control the assumption for the extreme flood damage calculation used in the EAD integration algorithm. The near-impossible event assumption (d_ltail) is discussed above. The insignificance of zero-damage event assumption (d_rtail) suggests that — absent other parameter dynamics — the difference in the shape of the right tail of the EAD curve does not change significantly between the baseline and the focal simulation. Because the shape of the right tail is a function of: 1) the d_rtail parameter; and 2) the next lowest damage estimate (for this case 5 ARI) — and only #1 is modified here — the difference calculated between the baseline's first/last timestep and the focal simulation's first/last timestep is nearly identical. This is limitation of the SA and it is expected that this parameter would be more significant if the 5 ARI damage prediction were also varied.

The rank 43 parameter is discussed above (d_gpwr) and the rank 40 parameter (d_bckt) is discussed below.

F3.3. Spatial Selection Sensitivity

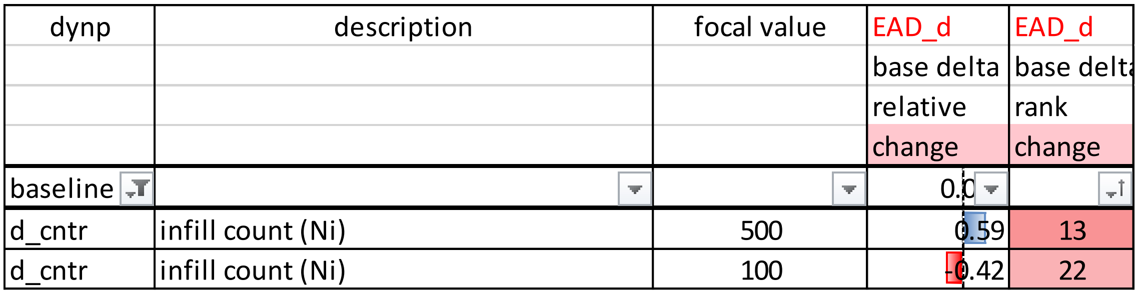
As discussed in the main report, SOFDA simulates urban re-development with the following steps:

1) rank the development potential of the 651 assets in the study area;

2) identify the number of assets which should be redeveloped for this time step (N_i);
3) apply the spatial selection algorithm to select the set of assets which should be redeveloped based on the infill count (N_i) and the development potential rankings;
4) apply the infill algorithms to the selected assets.

Sensitivity to step #2 (infill count) was explored in the first SA with the focal simulation 'd_cntr' (Table 3-5). Results suggest a moderate sensitivity to the number of houses re-developed. Many elements of step #4 are also discussed above (e.g. d_type_n, d_bfh_n, d_area_n). Dynamic risk sensitivity to Step #3 — the spatial selection algorithm — is explored here with a second SA. In other words, this sensitivity analysis is conducted to answer the question: *does it matter which houses infill?*

Table 3-5: SA results for the infill count paramter.



dynp	description	focal value	EAD_d base delta relative change	EAD_d base delt rank change
baseline			0.0	
d_cntr	infill count (Ni)	500	0.59	13
d_cntr	infill count (Ni)	100	-0.42	22

The random bucket sampling spatial selection algorithm was utilized in this SOFDA model is described in Appendix D[1]. To investigate the sensitivity of the spatial selection, extremes for this algorithm's 'bucket_size' parameter were simulated. This parameter controls the size of the bucket from which the random sample is taken. Because this function is stochastic, three scenarios were parameterized with 20 simulations (on a reduced inventory of 400) — each with a different bucket_size used to select the 100 Houses for infilling:

- *Scenario 1.1a (green; bucket_size = N_i; 1x):* This scenario is deterministic as it randomly selects 100 from the top 100 most likely to develop House objects.
- *Scenario 1.2a (red; bucket_size = 200; 2x)*: This scenario randomly selects 100 from the 200 most likely to develop House objects.

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[1] First, Nb assets with the highest development potential ranks are selected, where Nb is Ni plus a bucket size parameter (150 for this study). From these Nb assets, Ni are randomly selected for re-development. See Appendix D discussion of the 'ranked_choice' function for more details.

- *Scenario 1.3a (blue; bucket_size = 400; 4x)*: This scenario uses the maximum bucket size of 400 to randomly select 100, ignoring the development potential rankings.

F3.3.1. Results and Discussion

The EAD$_d$ results for the three scenarios are provided on Figure 3-1. These results show that the larger bucket size, the more flood risk is accumulated. In other words, when development is restricted to those assets at the top of the development potential rank — the vulnerability reductions of the FHRs drive down flood risk.

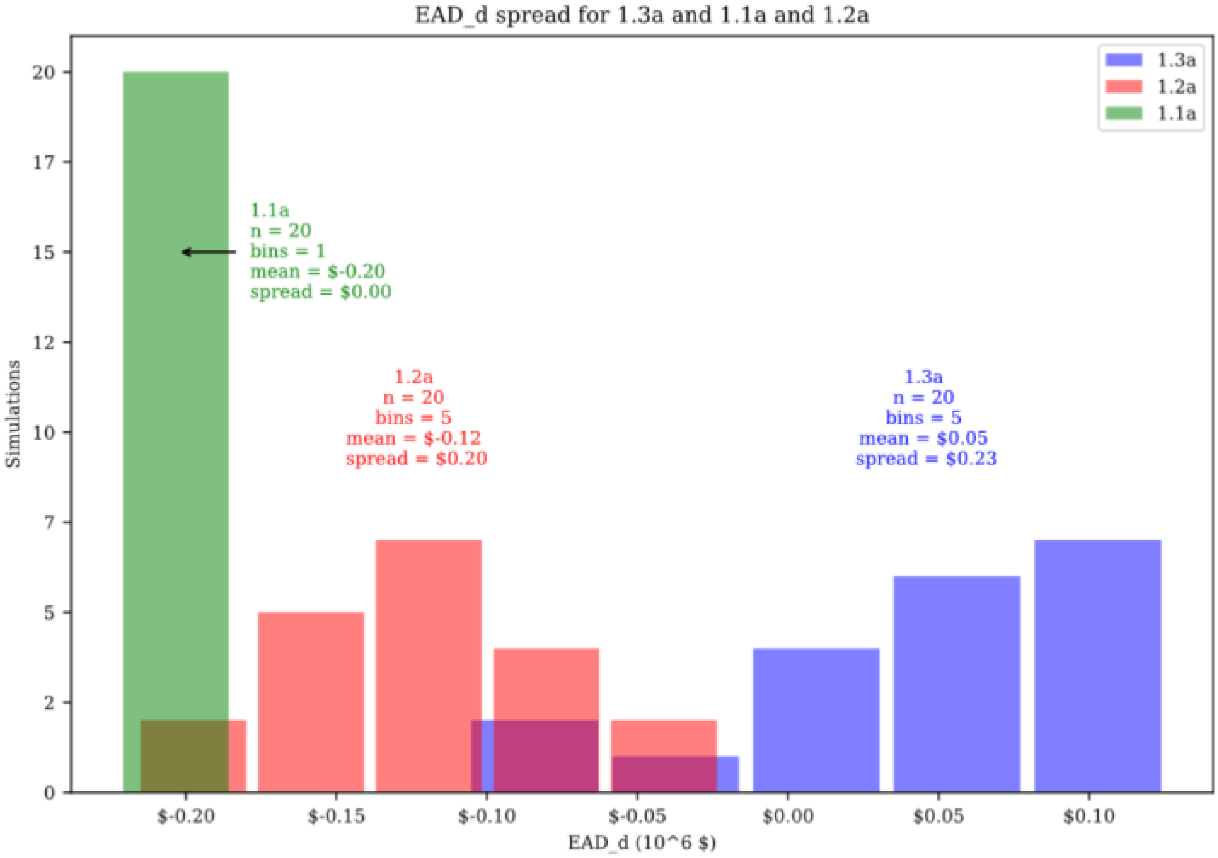

Figure 3-1: Spatial selection EAD$_d$ results histograms for the three bucket size scenarios. Scenario 1.1a is deterministic and therefore has no spread.

This result is driven by the local context of the study area: those homes most likely to develop are also those with the most influence on the vulnerability dynamics. This is further explained in the main report. The bias of the development potential ranking for those houses in the FHZ is demonstrated on Figure 3-2. This shows that in the scenario which only selects those 100 assets at the top of the development potential ranking — 77 are in the FHZ. If the bucket is enlarged to 400 (1.3a; blueish), the most extreme simulation was very unlucky and only 45 new homes were replaced with floodproofed ones (the other 55 were redeveloped outside the FHZ and therefore without floodproofing).

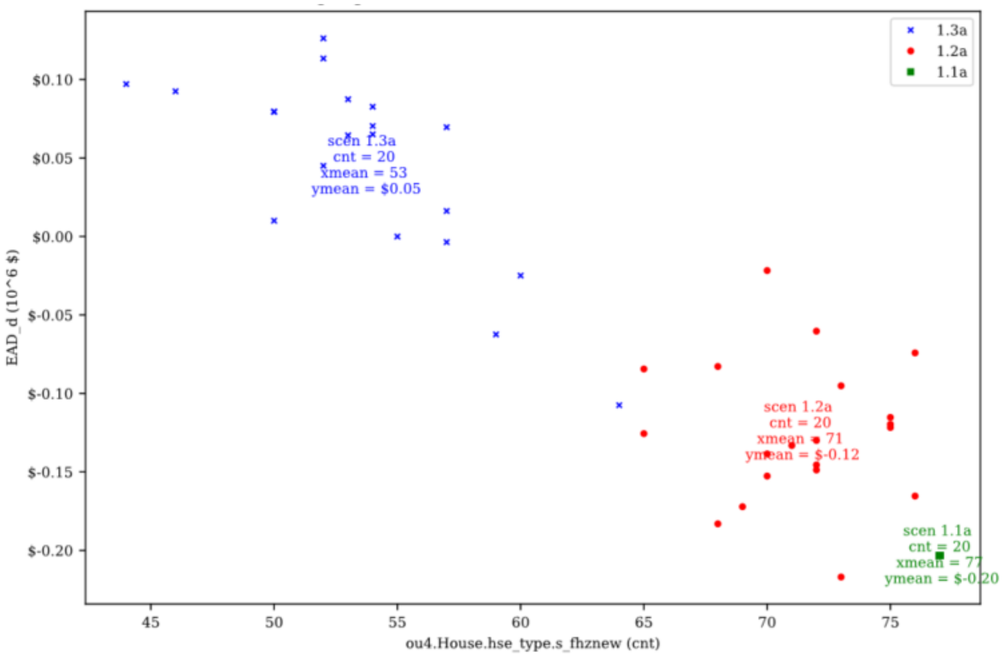

Figure 3-2: Spatial selection ensemble results scatter plot for EAD_d vs number of House objects selected within the FHZ on three scenarios. Scenario 1.1a is deterministic and therefore has no spread.

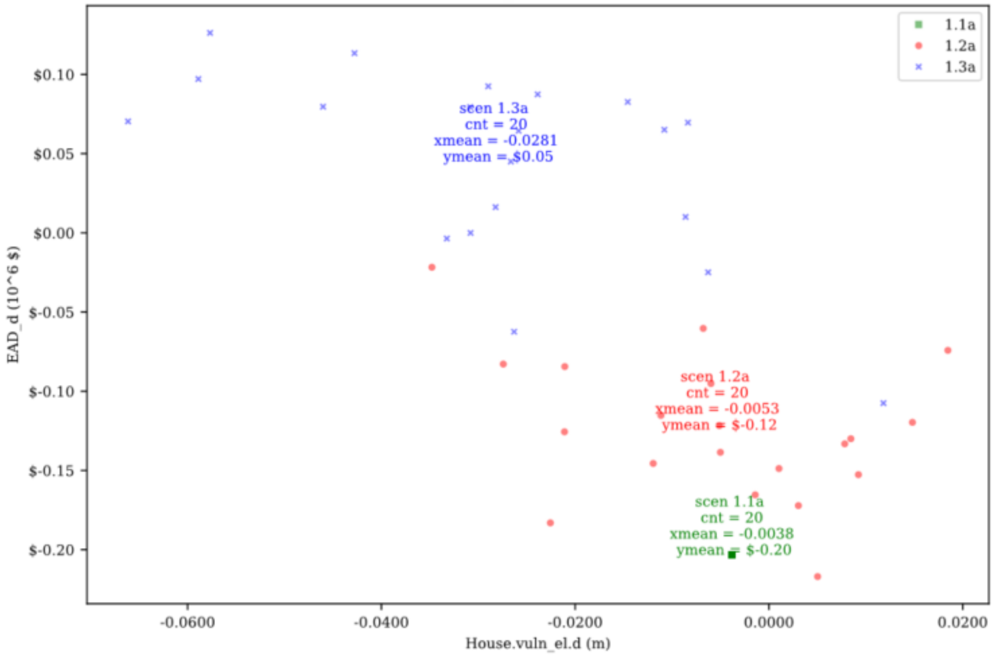

Figure 3-3: Spatial selection ensemble results scatter plot for EAD_d vs average vulnerability elevation delta on three scenarios.

F4. Conclusion

The SA discussed here instigated valuable troubleshooting, de-bugging, and model confidence building. More directly, the results suggest making the following parameters static in the model to conserve computation resources:

- The EAD integration parameters (Fdmg.rtail = 3 yr, Fdmg.ltail = None);
- House object basement open height (House.bsmt_opn_ht = House.dem_el);
- Dfunc object BVG = damp control code (Dfunc.damp_func_code = spill).

Finally, the SA results suggest future flood risk research should invest the most data collection effort into establishing the main and basement floor elevations.

Attachment A: Results Table

dynp	description	focal value	EAD_d base delta relative change	EAD_d base delta rank change	EAD_0 base delta relative first	EAD_0 base delta rank first	EAD first	EAD last		House gis_area first	House gis_area last	House vuln_el first	House vuln_el last	House anchor_el	House anchor_el	House bkflowv_f first	House bkflowv_f last	Fdmg fld_pwr_c first	Fdmg bwet_cnt first	Fdmg bdamp_cn first	Fdmg bdry_cnt first	Fdmg bwet_cnt last	Fdmg bdamp_cn last	Fdmg bdry_cnt last	Flood hwet_cnt first	Flood hwet_cnt last	Binv hnew_cnt	Binv hAD_cnt first	Binv hAD_cnt last	Udev bucket_siz last	Fdmg gpwr_aep first
focus		**OUTPUTR**	**od1c_rdlt**	**od1c_dlt_rnk**	**od1a_rdlt**	**od1a_dlt_rnk**	**04-od1a-Fdmg-aad_tot-raw**	**05-od1b-Fdmg-aad_tot-raw**	**06-od1c-Outputr-raw**	**10-ov2a-House-gis_area-sum()**	**11-ov2b-House-gis_area-sum()**	**12-ov3a-House-vuln_el-mean()**	**13-ov3b-House-vuln_el-mean()**	**14-ov4a-House-anchor_el-mean()**	**15-ov4b-House-anchor_el-mean()**	**16-ov5a-House-bkflowv_f-sum()**	**17-ov5b-House-bkflowv_f-sum()**	**24-ob3a-Fdmg-fld_pwr_cnt-sum()**	**26-ob4a-Fdmg-bwet_cnt-sum()**	**27-ob5a-Fdmg-bdamp_cnt-sum()**	**28-ob6a-Fdmg-bdry_cnt-sum()**	**29-ob4b-Fdmg-bwet_cnt-sum()**	**30-ob5b-Fdmg-bdamp_cnt-sum()**	**31-ob6b-Fdmg-bdry_cnt-sum()**	**33-oe1a-Flood-hwet_cnt-sum()**	**34-oe1b-Flood-hwet_cnt-sum()**	**36-ou1-Binv-hnew_cnt-sum()**	**37-ou2a-Binv-hAD_cnt-sum()**	**38-ou2b-Binv-hAD_cnt-sum()**	**39-ou3-Udev-bucket_size-mean()**	**44-oc4a-Fdmg-gpwr_aep-raw**
baseline			0.000		0.000		$ 8,946,740	$ 10,920,132	1973392	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_fhznm	fhz rules to apply to redevs	500umgw	-2.51	1	0	19	$ 8,946,740	$ 5,966,074	-2980666	57255.14	65528.83	1044.614	1045.343	1047.508	1048.37	252	418	7	3627	3198	987	2345	4973	494	6760	6279	304	20	317	0	96
d_bfh_n	New B_f_height for redevs	3.6	1.21	2	0.000	20	$ 8,946,740	$ 13,307,142	4360402	57255	65529	1044.614	1044.227	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	7167	304	20	317	0	96
d_bfh_n	New B_f_height for redevs	1.8	-1.20	3	0.000	21	$ 8,946,740	$ 8,557,735	-389004	57255	65529	1044.614	1045.057	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6494	304	20	317	0	96
d_fhznm	fhz rules to apply to redevs	010umgw	1.08	4	0	22	$ 8,946,740	$ 13,058,179	4111440	57255.14	65528.83	1044.614	1044.464	1047.508	1047.454	252	239	7	3627	3198	987	4314	3004	494	6760	7037	304	20	317	0	96
d_type_n	hse_type for redev houses	CD	-1.04	5	0.000	23	$ 8,946,740	$ 8,859,643	-87096.3	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	17	0	96
d_begr_nu			-0.85	6	0.000	24	$ 8,946,740	$ 9,235,173	288433.8	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	2248	1528	4036	6760	6553	304	20	317	0	96
d_fhr1d_u			0.81	7	0.000	25	$ 8,946,740	$ 12,515,465	3568725	57255	65529	1044.614	1044.450	1047.508	1047.440	252	306	7	3627	3198	987	3577	3741	494	6760	7024	304	20	317	0	96
d_bfh	basement finish height uncertainty	3.6	-0.80	8	0.362	2	$ 12,181,973	$ 12,580,588	398614.8	57255	65529	1043.608	1044.051	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	7406	7278	304	20	317	0	96
d_fhr1d			0.68	9	0.000	26	$ 8,946,740	$ 12,262,226	3315487	57255	65529	1044.614	1044.463	1047.508	1047.454	252	306	7	3627	3198	987	3577	3741	494	6760	7001	304	20	317	0	96
d_area_n			-0.65	10	0.000	27	$ 8,946,740	$ 9,641,890	695150.4	57255	57255	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_anch_u	anchor elevation uncertainty	-0.5	-0.63	11	0.294	3	$ 11,575,721	$ 12,301,360	725639.7	57255	65529	1044.114	1044.324	1047.008	1047.315	252	306	7	3627	3198	987	3577	3741	494	7062	7092	304	20	317	0	96
d_fprob	flood probability multiplier	1.6	0.60	12	0.443	1	$ 12,914,446	$ 16,077,380	3162934	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_cntr			0.59	13	0.000	28	$ 8,946,740	$ 12,087,988	3141248	57255	66770	1044.614	1044.537	1047.508	1047.596	252	303	7	3627	3198	987	3916	3662	234	6760	7086	503	20	516	0	96
d_fhr1d_u			-0.58	14	0.000	29	$ 8,946,740	$ 9,784,291	837551.1	57255	65529	1044.614	1044.738	1047.508	1047.729	252	306	7	3627	3198	987	3577	3741	494	6760	6833	304	20	317	0	96
d_bfh	basement finish height uncertainty	1.8	0.57	15	-0.272	4	$ 6,509,946	$ 9,617,773	3107827	57255	65529	1045.408	1045.022	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6232	6646	304	20	317	0	96
d_anch_u			0.54	16	-0.247	6	$ 6,732,711	$ 9,777,803	3045091	57255	65529	1045.114	1044.864	1048.008	1047.854	252	306	7	3646	3186	980	3594	3727	491	6418	6744	304	20	317	0	96
d_anch_nu			-0.53	17	0.000	30	$ 8,946,740	$ 9,868,399	921659.4	57255	65529	1044.614	1044.729	1047.508	1047.719	252	306	7	3627	3198	987	3577	3741	494	6760	6786	304	20	317	0	96
d_type_n			-0.52	18	0.000	31	$ 8,946,740	$ 9,887,620	940880.9	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	17	0	96
d_anch_nu			0.48	19	0.000	32	$ 8,946,740	$ 11,875,037	2928297	57255	65529	1044.614	1044.500	1047.508	1047.491	252	306	7	3627	3198	987	3577	3741	494	6760	7013	304	20	317	0	96
d_begr_nu			0.44	20	0.000	33	$ 8,946,740	$ 11,795,753	2849014	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	5848	1528	436	6760	7056	304	20	317	0	96
d_fhr1a			0.44	21	0.000	34	$ 8,946,740	$ 11,795,753	2849014	57255	65529	1044.614	1044.594	1047.508	1047.585	252	118	7	3627	3198	987	5645	1673	494	6760	7056	304	20	317	0	96
d_cntr			-0.42	22	0.000	35	$ 8,946,740	$ 10,087,150	1140411	57255	63594	1044.614	1044.612	1047.508	1047.545	252	289	7	3627	3198	987	3415	3563	834	6760	6814	104	20	118	0	96
d_begr	basement exposure grade uncertainty	dry	-0.35	23	-0.249	5	$ 6,718,410	$ 8,007,214	1288804	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	0	0	7812	0	0	7812	6064	6165	304	20	317	0	96
d_fhr1e			0.33	24	0.000	36	$ 8,946,740	$ 11,565,445	2618706	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_fhznm			-0.27	25	0	37	$ 8,946,740	$ 10,379,446	1432707	57255.14	65528.83	1044.614	1044.604	1047.508	1047.594	252	358	7	3627	3198	987	3005	4313	494	6760	6860	304	20	317	0	96
d_area_nu			-0.24	26	0.000	38	$ 8,946,740	$ 10,442,550	1495811	57255	62529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_area_nu			0.24	27	0.000	39	$ 8,946,740	$ 11,396,808	2450068	57255	68529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_area_u			0.21	28	-0.096	10	$ 8,083,847	$ 10,478,564	2394717	50745	62019	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_area_u			-0.21	29	0.096	11	$ 9,808,086	$ 11,360,911	1552825	63765	69039	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_begr	basement exposure grade uncertainty	damp	-0.21	30	-0.039	15	$ 8,601,122	$ 10,165,012	1563890	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	0	7812	0	0	7812	0	6653	6719	304	20	317	0	96
d_fprob			-0.20	31	-0.148	7	$ 7,624,171	$ 9,201,049	1576878	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_dampfc	depth fuction code for bsmt_egrd (damp)	seep	0.13	32	0.035	16	$ 9,257,263	$ 11,481,196	2223933	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6976	7172	304	20	317	0	96
d_anch_n			-0.13	33	0.000	40	$ 8,946,740	$ 10,670,880	1724141	57255	65529	1044.614	1044.620	1047.508	1047.611	252	306	7	3627	3198	987	3577	3741	494	6760	6898	304	20	317	0	96
d_bckt		375	0.11	34	0.000	41	$ 8,946,740	$ 11,137,604	2190865	57255	65287	1044.614	1044.582	1047.508	1047.577	252	298	7	3627	3198	987	3664	3592	556	6760	6945	304	20	317	375	96
d_begr			0.11	35	0.131	8	$ 10,116,091	$ 12,305,113	2189022	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	7812	0	0	7812	0	0	7152	7252	304	20	317	0	96
d_gpwr			-0.08	36	0.000	42	$ 8,946,740	$ 10,752,546	1805807	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	**12**	3192	3348	1272	3192	3348	1272	6760	6844	304	20	317	0	1001
d_bopht_u	basement open height uncertainty	0.5	-0.06	37	-0.042	14	$ 8,571,948	$ 10,431,561	1859613	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6663	6836	304	20	317	0	96
d_bopht_u			0.05	38	0.049	13	$ 9,381,593	$ 11,447,269	2065676	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6893	7028	304	20	317	0	96
d_ltail	EAD left tail integration code	none	-0.022	39	-0.014	17	$ 8,821,896	$ 10,750,904	1929008	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_bckt	bucket size for redev selection	651	-0.015	40	0.000	43	$ 8,946,740	$ 10,889,864	1943124	57255	64631	1044.614	1044.574	1047.508	1047.575	252	313	7	3627	3198	987	3473	3721	618	6760	6909	302	20	316	651	96
d_rtail	EAD right tail integration code	2	-0.002	41	0.130	9	$ 10,113,688	$ 12,082,491	1968803	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_rtail	EAD right tail integration code	4	0.001	42	-0.065	12	$ 8,363,266	$ 10,338,952	1975687	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	7	3627	3198	987	3577	3741	494	6760	6928	304	20	317	0	96
d_gpwr	minimum aep to disable grid power	51	0.000	43	0.000	18	$ 8,947,047	$ 10,920,132	1973084	57255	65529	1044.614	1044.594	1047.508	1047.585	252	306	**6**	3714	3168	930	3621	3725	466	6760	6928	304	20	317	0	51

dynp																														
focus	**01-d_bckt-Udev-bucket_size**	**04-d_begr-House-bsmt_egrd**	**05-d_anch_u-House-anchor_el**	**06-d_bopht_u-House-bsmt_opn_ht**	**07-d_area_u-House-gis_area**	**08-d_js_u-House-joist_space**	**09-d_bfh-House-B_f_height**	**11-d_fhznm-Udev-fhz_nm**	**13-d_cntr-Udev-infil_cnt**	**15-ic01-House-bkflowv_f**	**16-ic02-House-sumpump_f**	**17-ic03-House-genorat_f**	**18-d_begr_nu-House-bsmt_egrd**	**20-d_area_n-House-gis_area**	**21-d_area_nu-House-gis_area**	**22-d_anch_n-House-anchor_el**	**23-d_anch_nu-House-anchor_el**	**24-d_value_n-House-value**	**25-d_ayoc_n-House-ayoc**	**26-d_bfh_n-House-B_f_height**	**27-d_type_n-House-hse_type**	**30-d_fhr1a-House-bkflowv_f**	**31-d_fhr1d-House-anchor_el**	**32-d_fhr1d_u-House-anchor_el**	**33-d_fhr1e-Dmg_feat-none**	**36-d_rtail-Fdmg-ca_rtail**	**37-d_gpwr-Fdmg-gpwr_aep**	**39-d_fprob-Fdmg-fprob_mult**	**40-d_ltail-Fdmg-ca_ltail**	**41-d_dampfc-Dfunc-damp_func_code**
baseline	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fhznm	0	*skip	*skip	*skip	*skip	*skip	*skip	500umgw	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_bfh_n	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	3.6	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_bfh_n	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	1.8	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fhznm	0	*skip	*skip	*skip	*skip	*skip	*skip	010umgw	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_type_n	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	CD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_begr_nu	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	dry	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fhr1d_u	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	-0.5	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_bfh	0	*skip	*skip	*skip	*skip	*skip	3.6	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fhr1d	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=old	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_area_n	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=old	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_anch_u	0	*skip	-0.5	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fprob	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1.6	*skip	*skip
d_cntr	0	*skip	*skip	*skip	*skip	*skip	*skip	current	500	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fhr1d_u	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.5	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_bfh	0	*skip	*skip	*skip	*skip	*skip	1.8	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_anch_u	0	*skip	0.5	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_anch_nu	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.5	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_type_n	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	BA	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_anch_nu	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	-0.5	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_begr_nu	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	wet	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fhr1a	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	FALSE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_cntr	0	*skip	*skip	*skip	*skip	*skip	*skip	current	100	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_begr	0	dry	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fhr1e	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	*skip	3.0	96.65742265	1	*skip	*skip
d_fhznm	0	*skip	*skip	*skip	*skip	*skip	*skip	035umgw	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_area_nu	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	-10	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_area_nu	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	10	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_area_u	0	*skip	*skip	*skip	-10	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_area_u	0	*skip	*skip	*skip	10	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_begr	0	damp	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_fprob	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	0.8	*skip	*skip
d_dampfc	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	seep
d_anch_n	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	*skip	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_bckt	375	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_begr	0	wet	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_gpwr	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	1001	1	*skip	*skip
d_bopht_u	0	*skip	*skip	0.5	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_bopht_u	0	*skip	*skip	-0.5	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_ltail	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	none	*skip
d_bckt	651	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	96.65742265	1	*skip	*skip
d_rtail	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	2	96.65742265	1	*skip	*skip
d_rtail	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	4	96.65742265	1	*skip	*skip
d_gpwr	0	*skip	*skip	*skip	*skip	*skip	*skip	current	300.0	FALSE	FALSE	FALSE	*skip	new_val=obj	0.0	new_val=obj	0.0	200000.0	new_val=obj	2.80416	AD	TRUE	new_val=ma	0.0	obj.set_new	3.0	51	1	*skip	*skip

Attachment B: SOFDA Control File Dynp Tab

name	desc	pclass_n	att_name	sel_n	value_assign_str	change_type	dist_pars_l	min	max	correlate_an	upd_sim_lvl	freeze_att_f	~sensi comment	sensi1	sensi2	sensi3
~DEBUG SENSI ANAL												FALSE				
d_bckt	bucket size for redev selection	Udev	bucket_size		0	replace					1	FALSE	look at ranges to see if bucket size matters. baseline with no bucket size	375	651	
~Initial Conditions												FALSE				
~a_ic_u (initial condition uncertainties)												FALSE				
d_begr	basement exposure grade override	House	bsmt_egrd		*skip	replace					1	TRUE	uncertainty bounds	dry	damp	wet
d_anch_u	anchor elevation uncertainty	House	anchor_el		*skip	delta					1	FALSE	uncertainty bounds	-0.5	0.5	
d_bopht_u	basement open height uncertainty	House	bsmt_opn_ht		*skip	delta					1	FALSE	uncertainty bounds	-0.5	0.5	
d_area_u	area uncertainty	House	gis_area		*skip	delta					1	FALSE	uncertainty bounds	-10	10	
d_js_u	joist_space uncertainty	House	joist_space		*skip	delta					1	FALSE	uncertainty bounds			
d_bfh	basement finish height global sensitivity	House	B_f_height		*skip	replace					1	FALSE	uncertainty bounds	1.8	3.6	
~NEW HOUSES							300	30				FALSE				
d_fhznm	fhz rules to apply	Udev	fhz_nm		current	replace					1	FALSE		010umgw	035umgw	500umgw
~d_bckt	bucket size for redev selection	Udev	bucket_size		0	replace					1	FALSE	look at ranges to see if bucket size matters. baseline with no bucket size	375	651	
d_cntr	Number of houses redeveloped per action	Udev	infil_cnt		scipy.stats.norm	replace	[300,30]	100	500		1	FALSE	look at min/max	*min/max		
~a_ic												FALSE				
ic01	apply the bkflowv_f	House	bkflowv_f		scipy.stats.logistic	replace	[447000, 301711.28]	no	yes	value	none	FALSE	ignore. depdendt on bsmt_egrd			
ic02		House	sumpump_f		scipy.stats.logistic	replace	[447000, 341415.78]	no	yes	value	none	FALSE	ignore. depdendt on bsmt_egrd			
ic03		House	genorat_f		scipy.stats.logistic	replace	[447000, 699137.00]	no	yes	value	none	FALSE	ignore. depdendt on bsmt_egrd			
d_begr_nu	basement exposure grade on infils	House	bsmt_egrd		*skip	replace					none	TRUE	yes. This is a secondary attribute, therefore teh baseline run is a dummy 'skip' dynp	dry	wet	
~a_newhse												FALSE				
d_area_n	maximze new parcel area	House	gis_area		new_val = obj.parcel_area*0.45 - 50	replace					none	FALSE	consider alternates?. For now, just use numerical uncertainty (see below)	new_val=old_val		
d_area_nu	infil area ucertainty	House	gis_area		scipy.stats.norm	delta	[0, 1]	-10	10		none	FALSE	see above	*min/max		
d_anch_n	anchor elevation function	House	anchor_el		new_val = obj.dem_el + 0.6	replace					none	FALSE	consider alternates?. For now, just use numerical uncertainty (see below)	new_val=	*skip	
d_anch_nu	anchor elevation uncertainty	House	anchor_el		scipy.stats.norm	delta	[0, .2]	-0.5	0.5		none	FALSE	see above	*min/max		
d_value_n	house value change	House	value		scipy.stats.norm	delta	[200000, 10]	50000	1000000		none	TRUE	no...we are using a delta so this would be too difficult for such an insignif par			
d_ayoc_n	set the year to current	House	ayoc		new_val = obj.model.year	replace					none	TRUE	n/a			
d_bfh_n	New B_f_height for rebuilds (see ic06)	House	B_f_height		scipy.stats.norm	replace	[2.80416, 0.8107]	1.8	3.6		none	TRUE	yes.	*min/max		
d_type_n	set the new building type. THIS SHOULD BE LAST	House	hse_type		AD	replace					none	TRUE	testing this serves as a proxy for the sensitivy tot he accuracy of teh dfeat_tbles	BA	CD	
~FHZ regs												FALSE				
~a_fhr1												FALSE				
d_fhr1a	(P3D3.60.1).New houses in the FF require sewer backup valves.	House	bkflowv_f		TRUE	replace					none	TRUE	yes. during sensi runs, ic01 is static (always False)	FALSE		
d_fhr1d	(P3D3.60.1). New houses in the FF must have the 1st floor above the BFE	House	anchor_el		new_val = max(old_val, obj.fhzlvl_ser[obj.model.udev.fhz_nm])	replace					none	FALSE	yes. also test numerical uncertainty below.	new_val=old_val		
d_fhr1d_u	anchor elevation uncertainty	House	anchor_el		scipy.stats.norm	delta	[0, .2]	-0.5	0.5		none	FALSE	see above	*min/max		
d_fhr1e	(P3D3.60.1). New houses in the FF must have all M&E above BFE	Dmg_feat		s_dfeat_ME	obj.set_new_depth(obj.hse_o.fhzlvl_ser[obj.model.udev.fhz_nm])						none	FALSE	mostly we are testing with the below	*skip		
~d_fhr1e_u	M&E uncertainty	Dmg_feat	depth	s_dfeat_ME	scipy.stats.norm	delta	[0, .5]	-1	1		none	FALSE	see above	*min/max		
~Fdmg General Pars												FALSE				
d_rtail	EAD right tail integration code	Fdmg	ca_rtail		scipy.stats.norm	replace	[3, .1]	2	4		1	FALSE	none=5 (generally). considering 2 alternates	*min/max		
d_gpwr	grid power aep	Fdmg	gpwr_aep		scipy.stats.lognorm	replace	[40, 50, .5]	51	1001		2	FALSE		*min/max		
~Fdmg sensi analy												FALSE				
d_fprob	flood probability multiplier	Fdmg	fprob_mult		1	replace					1	TRUE		0.8	1.6	
d_ltail	EAD left tail integration	Fdmg	ca_ltail		*skip	replace					1	FALSE	just looking at 1 alternate. default = flat	none		
d_dampfc	depth fuction for bsmt_egrd = damp	Dfunc	damp_func_code		*skip	replace					1	FALSE	1 alterante. default = 'spill' (see dfunc tab)	seep		

Appendix G: Study Datasets

Where the data sharing agreement allows, these datasets are available upon request.

dataset	description	format	originator	transmittal
CoC_Ass_ARFI_2013	Postal survey of properties likely directly damaged by the 2013 Flood requesting information on flood damage. Survey was conducted in September 2013 to assess impacts to the CoC's annual property assessment.	.xls	CoC Assessment	2018 02 26 - Abe - AFRI
CoC_Ass_ARFI_2014	As a follow up to the 2013 survey, this was mailed to the same properties and had similar questions.	.xls	CoC Assessment	2018 02 26 - Abe - AFRI
CoC_Ass_propass	Harmonization of 6 CoC Assessment property assessment database slices. This database is continuously updated by CoC Assessment and contains a mix of property inspections, remote sensing data, and in-house model predictions. For data-analysis without a temporal component, the latest available entry for a property is used.	.xls	CoC Assessment	various
CoC_Dev_2013flood_impacted	Description of properties impacted by the 2013 Flood. "accurate data collection was not a high priority in the days following the flood. Most properties had just a quick exterior assessment of the building (known as "rapid damage assessment"), with no follow-up unless a permit inspection was required. "	.xls	CoC Planning	2017 03 22 - File transfer from Kevin
CoC_Dev_2013flood_permits	Data on permits deemed to be related to the 2013 Flood recovery.	.xls	CoC Planning	2017 03 22 - File transfer from Kevin
CoC_ISS_bldgs_das2017	Digital Aerial Survey building outlines from 2017.	.shp	CoC Planning	2018 05 01 - Nichole - bldg outlines
CoC_PDA_scenser_2016	GIS results from GeoDemographics scenario series forecast from 2014, updated with 2016 values.	.xls	CoC Geodemographics	2017 09 12 - Scenario Series from Patrick
CoC_WR_2017CoC_Hyd_ins	Details of boundary conditions for the 2017 Study HEC-RAS model scenarios.	.xls	CoC Water Resources	2018 03 16 - David
CoC_WR_DEM_2013_20170815	2013 Digital Elevation Model provided by CoC to IBI Group for the 2015 Study.	.tif	???	2017 08 15 - Dropbox from David (DEM)
CoC_WR_flood_201306_inun	Flood extents extrapolated from aerial imagery flown Saturday June 22, 2013 from 8:00 AM to 9:30 AM MDT (~28 hrs after the peak)	.shp	CoC Water Resources	2017 09 19 - File transfer from Bill
GLD_2017CoC_WSL_sc0_gw	Raster set of surface water levels for inundated areas and ground water levels for other areas for 12 events. For 2017 Study scenario 0.	.tif	Golder	2017 07 30 - FTP2 from David
GLD_2017CoC_WSL_sc0_in	Polygons designating surface water flooding and area protection type. For 2017 Study scenario 0.	.shp	Golder	2017 07 30 - FTP2 from David
GLD_2017CoC_WSL_sc0_sw	Raster set of surface water levels in all areas. For 2017 Study scenario 0.	.tif	Golder	2017 07 30 - FTP2 from David
GLD_2017CoC_WSL_sc7_gw	Raster set of surface water levels for inundated areas and ground water levels for other areas for 12 events. For 2017 Study scenario 7.	.tif	Golder	2017 10 17 - Dropbox from David
GLD_2017CoC_WSL_sc7_in	Polygons designating surface water flooding and area protection type. For 2017 Study scenario 7.	.shp	Golder	2017 10 17 - Dropbox from David
GLD_2017CoC_WSL_sc7_sw	Raster set of surface water levels in all areas. For 2017 Study scenario 7.	.tif	Golder	2017 10 17 - Dropbox from David
GLD_2017CoC_WSL_um	Raster set of surface water levels for inundated areas and ground water levels for other areas for 12 events. For 2017 Study scenario unmitigated.	.tif	Golder	2017 07 30 - FTP2 from David
GoA_AEP_FHZfringe_20150622	GIS polygon of regulatory flood fringe from Alberta Environment and Parks	.shp	GoA AEP	2017 05 14 - FTP from David
GoA_AEMA_DRP_2013_private-c	Spreadsheet of private claims paid out by the Alberta Disaster Recovery Program by forward sorting area.	.xls	GoA AEMA	2017 11 16 - Email from Mary
IBI_2015RFDA_curves	Spreadsheet formatted for use in RFDA with Alberta Curve tables.	.xls	IBI Group	2017 07 29 - FTP from David
IBI_2017CoC_binv_res	Residential inventory table for all 10713 floodprone residential assets within the city.	.xls	IBI Group	2017 07 29 - FTP from David