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Way forward for risk assessment tools in Canada

T.S. Lyle and S.V. Hund

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T.S. Lyle[1] and S.V. Hund[1]

[1] Ebbwater Consulting, Unit 513–119 West Pender Street, Vancouver, British Columbia V6B 1S5

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Way Forward for Risk Assessment Tools in Canada
Final Report

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Ebbwater Consulting
Unit 513 - 119 West Pender St.
Vancouver, BC, V6B 1S5
www.ebbwater.ca

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Executive Summary

In the wake of the Alberta and Ontario floods of 2013, the federal government established the National Disaster Mitigation Plan (NDMP) in April 2015. The program has several priorities including providing support to provinces to identify, assess, plan for and mitigate high-risk flood areas and to collect disaster risk information. Similarly, the National Scale Geohazard Risk (NSGR) project has a mandate to support "research of best practices to reduce economic, social, and environmental losses from geohazards in Canada, through i) development and/or modification of tools to deliver targeted regional and national geohazard risk assessments, and ii) engagement of priority end users in development of product tools and methods with planners, emergency managers, and other responders, and decision makers for table-top exercise". Furthermore, as an endorsee of the United Nations post-2015 Hyogo Framework for Action Agreement (Sendai Framework)[1], the federal government seeks to meet the Sendai Priorities.

In early 2016, Ebbwater Consulting was retained by Natural Resources Canada (NRCan) to review and assess the existing risk management tools supported by NRCan, and to provide a strategic plan to ensure that risk assessment tools are available and meet the mandates of the NDMP, the NSGR, and the Sendai Priorities; providing the federal government with a Way Forward for Risk Assessment Tools in Canada.

Quantitative Risk Assessment as Best Practice for Risk Mitigation

Risk assessment, one that looks at consequences over time, is an invaluable instrument for decision makers, policy makers, and planners. It can be used to understand and mitigate present and future damages, to create risk management strategies that are both cost effective and community supported, and to help plan for long-term financial investments in risk mitigation. Tools that aid in the development of quantitative risk assessments are a key component of the successful adoption of quantitative risk assessment as best practice. Hazus Canada, which is currently supported by NRCan, is one such tool. It, along with other risk assessment tools were reviewed and evaluated as part of this project.

Hazus Canada Review

Hazus Canada, a risk assessment tool adapted from the U.S. version of the tool that is supported by FEMA, has been tested and used over the course of the last five years. Major studies for seismic and flood risk have been completed using the tool. Overall, although weaknesses were identified, Hazus Canada has provided some invaluable insights for the future of natural hazard risk assessments in Canada. Specifically:

1. The underlying inventory datasets were seen as a starting point for future regional/national scale assessments because of the consistency of the data.
2. The risk assessments completed using Hazus Canada have provided an opportunity to better understand the gaps for natural hazard risk assessment in Canada. Specifically the

underlying vulnerability datasets and the paucity of Canada-specific depth-damage curves for flood.

3. Finally, the consequence assessments completed with Hazus Canada also provided insights into the gaps and strengths in risk assessment and risk communication. Specifically, that dense standardized technical reporting cannot by itself be used to communicate risk and help decision makers. Hazus studies completed for the District of North Vancouver have helped the community understand and plan for seismic risk, and a regional study of M9.0 Cascadia earthquake has informed a cross-border, national and provincial earthquake exercise.

User Needs Assessment for Canada

At the outset of the project, it was recognized that user needs should define the way forward for risk assessment tools in Canada. Also, that risk assessment tools and methods should not be constrained by what is currently available, but rather by what the various professionals working in the field of risk management and mitigation need to make good decisions to reduce risk. To this end, this report interviewed almost 50 professionals across the country working in natural hazard risk mitigation. Key themes arising from this research were the need for:

- A **robust**, **accessible**, **easy-to-use** tool or methodology that could be consistently applied across the country.
- A **fine-scale** (property-level) tool that supports calculations for **multiple hazard**s, with a focus of **floods** and provides consequence information on **life safety** and **critical infrastructure**.
- A tool that supports **cumulative** calculations that aid in investment and long-range planning decisions.
- The development and support for a **user community** to increase capacity across Canada and support communities as they conduct **locally-specific risk assessments** based on local needs.

Risk Assessment Tool Evaluation

In order to provide some guidance to the NSGR on future efforts to support quantitative risk assessment in Canada, a number of alternatives to Hazus were evaluated. Each tool has been developed with a specific audience and user in mind, and so they have wide-ranging capabilities, strengths, and weaknesses. No evaluated tool comes close to meeting all the user needs defined as part of this project. However, most of the tools had a component that is relevant to the Canadian context and could be used as a model for the development of risk assessment tools in Canada. Recommendations related to how these components can be used in Canada are provided in this report.

A Way Forward for Quantitative Risk Assessment in Canada

Quantitative natural hazard risk assessment in Canada is still more of an anomaly than the norm. It is, however, recognized as an incredibly important tool in risk mitigation; a comprehensive risk assessment tool can provide a better understanding of the impacts and consequences of impacts and consequences over time. This type of information is invaluable in understanding the trade-offs between mitigation actions (including no action), and allows for more transparent and robust decision making for risk reduction.

This research project has clearly shown that there is a need for a federally supported program to help lower-level governments prepare and use quantitative risk assessment. However, there is not necessarily a need to support a single risk assessment tool or software, as needs vary widely; hazards, vulnerabilities, and values are ultimately local. Rather, there is a need to create and support the building blocks of natural hazard risk assessment.

Development and Support for a High-Level, Publically Accessible Risk Assessment Tool

For many, a high-level risk assessment tool is an imperative first step. It can provide sufficient information to help prioritize funding for more detailed risk assessment (or, indeed, the collection of underlying data: flood-mapping, for example). In addition, high-level risk assessment tools can be educational in their own right, especially when used or viewed by the public or non-technical decision makers.

Standardized, Complete, and Accessible Hazard Information

The development of a base of information on the location and severity of natural hazards is a key recommendation of this project. At present, this information is sporadic and inconsistent. For example, it is well known that flood hazard mapping is lacking. Other hazards, like debris flows, are rarely considered at all. It is, therefore, imperative that the knowledge-base around natural hazards is increased, and that this data is stored in consistent manner in an accessible online database.

Standardized, Complete, and Accessible Vulnerability Information Collected at a Fine Scale

The development of a base of information on exposures and vulnerabilities (assets at risk) is a key recommendation of this project. At present, this information is sporadic and inconsistent. The original Hazus Canada program successfully started to develop a comprehensive and consistent database of some key assets at risk. This has successfully been used for regional studies, but was critiqued for its lack of usability at a municipal scale, especially in rural areas, and also for the quality of the results it can produce. Other very relevant information, such as the location of critical infrastructure, is often not collated or, alternately, not reported. Furthermore, much of the information that has been used for risk assessment in Canada was not originally designed for this purpose. Instead, data collected for other purposes (tax assessments, business licenses, etc.) are jerry-rigged, and are, therefore, prone to error. Recommendations are provided in this report to improve the collection and storage of vulnerability data in Canada.

Locally relevant and up-to-date fragility/damage curves

A key methodological piece in the calculation of impacts and consequences from a natural hazard event are curves or algorithms that can be applied to vulnerabilities for a given event to calculate expected losses. For flood impacts and consequences, these are generally described as damage curves, and for earthquakes, these are called fragility curves. For flood in particular, there is a paucity of information relevant to present-day Canada. Lacking any local up-to-date information, flood risk assessments in Canada have mostly relied on curves from FEMA (as used in Hazus Canada), which have not only produced erroneous results, but have also discouraged some users from conducting or publicising risk assessment results. Specific recommendations on improving this information for Canada are provided in this report.

Support for the growth of natural hazard risk assessment expertise and capacity across the country

Quantitative risk assessment is a relatively new field. This, combined with the fact that that hazard management has been relatively under-resourced in Canada in the last couple of decades, means that there is a capacity deficit in the country. There is a great need to improve this in the near term. The uptake of risk assessment for decision making will not increase unless the knowledge capacity for risk assessment is improved.

Conclusion

The Government of Canada has recognized that understanding and assessing the hazards and risk posed by natural disasters is the first step in any mitigation plan; these are clear cornerstones of the NDMP and the Sendai Framework. Quantitative risk assessment is seen as best practice in the understanding of natural hazard risk – especially with regards to long-range planning, land use decisions and infrastructure investments.

There is at present a deficit in capacity for quantitative risk assessment in Canada. This is partly due the lack of underlying datasets that inform quantitative risk assessment, and secondly due to the lack of professional capacity in this area, which stems from not having resourced or regulated risk assessment in Canada for the last couple of decades.

There is also a renewed interest in increasing capacity for risk assessment in Canada as evidenced by the 2015 NDMP. To Canada's advantage, many other nations have made great strides in this area in the last decade. There is now an opportunity for Canada to learn from others and to borrow research and knowledge from these groups.

The recommendations provided in this report are designed to help close the gap in risk assessment capacity in Canada by leaning on tools and research from the other nations. It is hoped that in future, once Canada has rejuvenated its risk assessment sector that the country can contribute back to the global understanding of disaster risk.

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List of Acronyms

AHRA	All-Hazards Risk Assessment
APEGBC	Association of Professional Engineers and Geoscientists of BC
CAD	Computer Aided Design
CI	Critical Infrastructure
CRHNet	Canadian Risk and Hazards Network
DFAA	Disaster Financial Assistance Arrangements
DRDC	Defence Research and Development Canada
FEMA	Federal Emergency Management Agency (United States)
GBS	Global Building Stock
GC	Government of Canada
GIS	Geospatial Information System
GSC	Geological Survey of Canada
MASAS	Multi-Agency Situational Awareness System
NDMP	National Disaster Mitigation Plan
NEMS	National Emergency Management System
NRCan	Natural Resources Canada
NSGR	National Scale Geohazards Risk
PSC	Public Safety Canada
P/T	Province/Territory
QRA	Quantitative Risk Assessment
RIBA	Royal Institute of British Architects
UDF	User-Defined Facility
UN-ISDR	United Nations Office for International Strategy for Disaster Risk Reduction
USACE	United States Army Corps of Engineers

1 Introduction

In the wake of the Alberta and Ontario floods of 2013, the federal government established the National Disaster Mitigation Plan (NDMP) in April 2015. The program has several priorities including providing support to provinces to identify and mitigate high-risk flood areas and to collect disaster risk information. Similarly, the National Scale Geohazard Risk (NSGR) project has a mandate to support "research of best practices to reduce economic, social, and environmental losses from geohazards in Canada, through i) development and/or modification of tools to deliver targeted regional and national geohazard risk assessments, and ii) engagement of priority end users in development of product tools and methods with planners, emergency managers, and other responders, and decision makers for table-top exercise". Furthermore, as an endorsee of the United Nations post-2015 Hyogo Framework for Action Agreement (Sendai Framework)[1], the federal government seeks to meet the Sendai Priorities. Of particular relevance to this work are:

> **Sendai Priority 1:** Understanding disaster risk: to identify existing risk by utilizing an all-hazards approach and improved understanding of disaster risk in all dimensions (hazard characteristics, exposure and vulnerability of people, assets, and environment).
>
> **Sendai Priority 3:** Investing in disaster risk reduction for resilience: Focus attention on promotion of the mainstreaming of disaster risk assessments into land-use policy development and implementation, including urban planning, and the use of guidelines and follow-up monitoring and assessment tools informed by anticipated demographic and environmental changes.

In early 2016, Ebbwater Consulting was retained by Natural Resources Canada (NRCan), who are the owners of the NSGR project, to review and assess the existing risk management tools supported by NRCan, and to provide a strategic plan to ensure that risk assessment tools are available and meet the mandates of the NDMP, the NSGR, and the Sendai Priorities; providing the federal government with a Way Forward for Risk Assessment Tools in Canada. This project was completed in a relatively short period of time (11 weeks from the start of contract to final reporting) and, therefore, has some limitations:

- The report provides research, analysis, and recommendations commensurate with the time and resources available, and should not be considered exhaustive.
- The report does not provide specific recommendations on methods or tools that could be used to prioritize funding applications for the current NDMP program (Stream 1: Risk Assessment) as this is outside the scope of this work.
- As per the mandate of the NSGR, this report focuses on tools for risk assessment for natural hazards, with a focus on geohazards.

The report provides background information on risk assessment, specifically quantitative risk assessment for geohazards in Section 2. Further background information on risk assessment methods for flood are provided in Appendix A. This is followed by a review of Hazus Canada, a risk assessment tool that has been supported by NRCan for the last five years, in Section 3. Section 4 outlines identified user needs for risk assessment tools, based on interviews with 47 professionals from across the country. This is followed by descriptions and evaluations of eight risk assessment tools, including Hazus Canada, in Section 5. The evaluations are based on metrics developed from the outcomes of the user needs interviews. Finally, in Section 6, recommendations are provided on a way forward for quantitative risk assessment tools.

This document has been written in parallel with two other related works: T*he National Principles, Best Practices and Guidelines - Flood Mapping*[46] and the *Revised Application Guide: Recommendations for the National Disaster Mitigation Program*[47]. As much as possible given the timing constraints, effort has been made to align this document with the parallel reports.

A glossary of terms is provided at the end of the document.

2 Risk Assessment for Natural Hazards

It is well-documented that preparation and planning ahead for a disaster will greatly reduce cost and suffering during and after a disaster event[2]. Understanding and assessing the hazards and risk posed by natural disasters is the first step in any mitigation plan (Figure 1). This is confirmed by the recent Sendai Framework, which has **understanding disaster risk** as Priority 1[1]. You cannot manage or reduce risk without first identifying and assessing it.

Figure 1: Natural hazard risk planning process

2.1 What is Natural Hazard Risk?

A solid grounding in the understanding of the term risk is key to understanding the components of a risk assessment. Risk is a function of both the likelihood of an event occurring, and the consequences if that event occurs (Figure 2). Consequence is defined as a function of the hazard (where and how big is the event?), and vulnerability (what's in the way and how susceptible is it?). Vulnerability can be further described as a function of exposure (what's in the way?), resilience (how will the system resist and recover?), and mitigation (what measures are in place to reduce damage?).

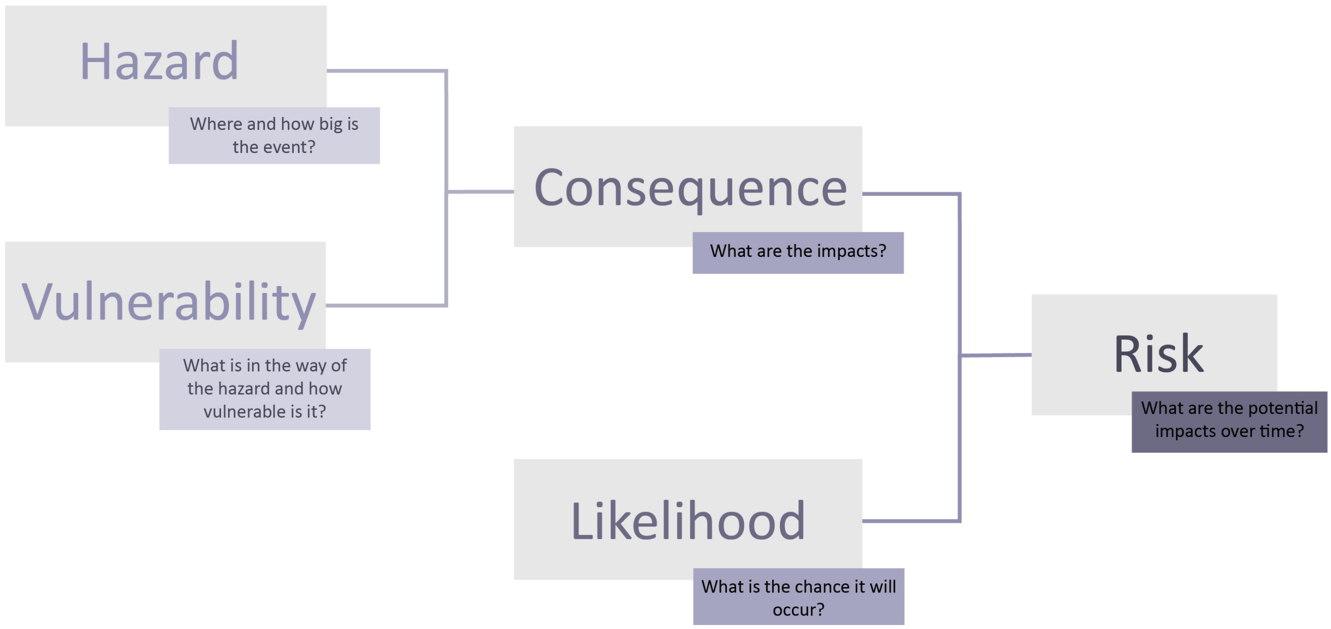


Figure 2: Risk as a function of hazard, likelihood, and vulnerability

Figure 3 shows how risk is a function of both likelihood and consequence, and that risk increases radially across the diagram. A virtually certain but insignificant event can have the same risk as a catastrophic but rare event. This becomes particularly important as we look across long time-horizons. For example, a nuisance flood that occurs annually over several decades may in fact be more impactful than a catastrophic flood that occurs just once (Figure 4). A risk assessment can be used to compare both the impacts and the potential benefits of mitigation options for the whole spectrum of nuisance to catastrophic events. This provides the best possible tool to make informed investment and planning decisions.

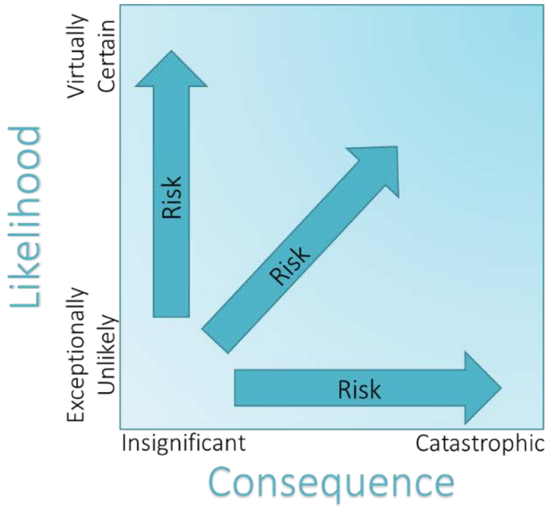


Figure 3: Risk as a function of likelihood and consequence

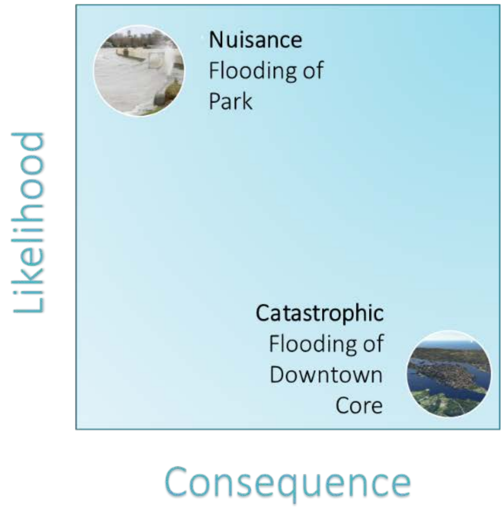


Figure 4: Nuisance and catastrophic flooding

2.2 What is a Quantitative Risk Assessment?

Given that risk is the combination of the likelihood of an event and its negative consequences, a risk assessment is essentially a methodology to determine the nature and extent of risk. This is done by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods, and the environment on which they depend. A risk assessment can be qualitative or quantitative. For example, the national all hazards risk assessment (AHRA) is a qualitative tool that will help identify, analyze, and prioritize a full range of potential threats[3]. This type of tool can be relatively quickly and cheaply developed at a national scale and is invaluable for prioritization exercises. However, to meet the needs of **Sendai Priority 2: investing in disaster risk reduction resilience,** in particular through the use of land-use policy, requires a more robust methodology—ideally a fine-scale quantitative risk assessment. A quantitative risk assessment is one that uses measurable, objective hazard, vulnerability and likelihood to calculate risk and loss. The quantification of risk, although at times cumbersome, provides invaluable information for risk reduction through the provision of robust, transparent data for planning and decision making.

2.3 What is a Quantitative Risk Assessment Tool?

The recognition of risk assessment, and quantitative risk assessment in particular, as best practice for natural hazards risk mitigation means that, over the last couple of decades, effort has been made in the disaster management community to develop tools to aid in quantitative risk assessment. These tools vary greatly, as is to be expected given the range of hazards, needs, and users (Figure 5).

The choice of tool should be based on the overall objective of the study. For example, at a fine scale, an insurance company needs to know the likelihood of damage and loss to a single home that is seeking insurance. Whereas, at the other end of the spectrum lies higher-level governments who need information to help them prioritize the expenditure of resources and dollars. In the middle, lies regional government, with the authority and responsibility to make land-use decisions, as well as consider structural hazard management (e.g., dikes). Each of these players will require different information, which points to a different methodology for risk assessment.

Another output of risk assessment tools that are particularly useful for all levels of users is the capacity to compare risk mitigation options and policies. For example, the long-term implications of decreasing vulnerability by retreating (moving people and assets) from the hazard can be assessed with the help of some risk assessment tools.

The choice of methodology will depend not only on the desired outcomes of the research, but also by the amount of resources available to conduct the work, and by the available data. For example, there is no point conducting a fine-scale study if there isn't good information about individual building materials, size, age, elevation, etc., as well as the consequence of each type of building being damaged by the hazard.

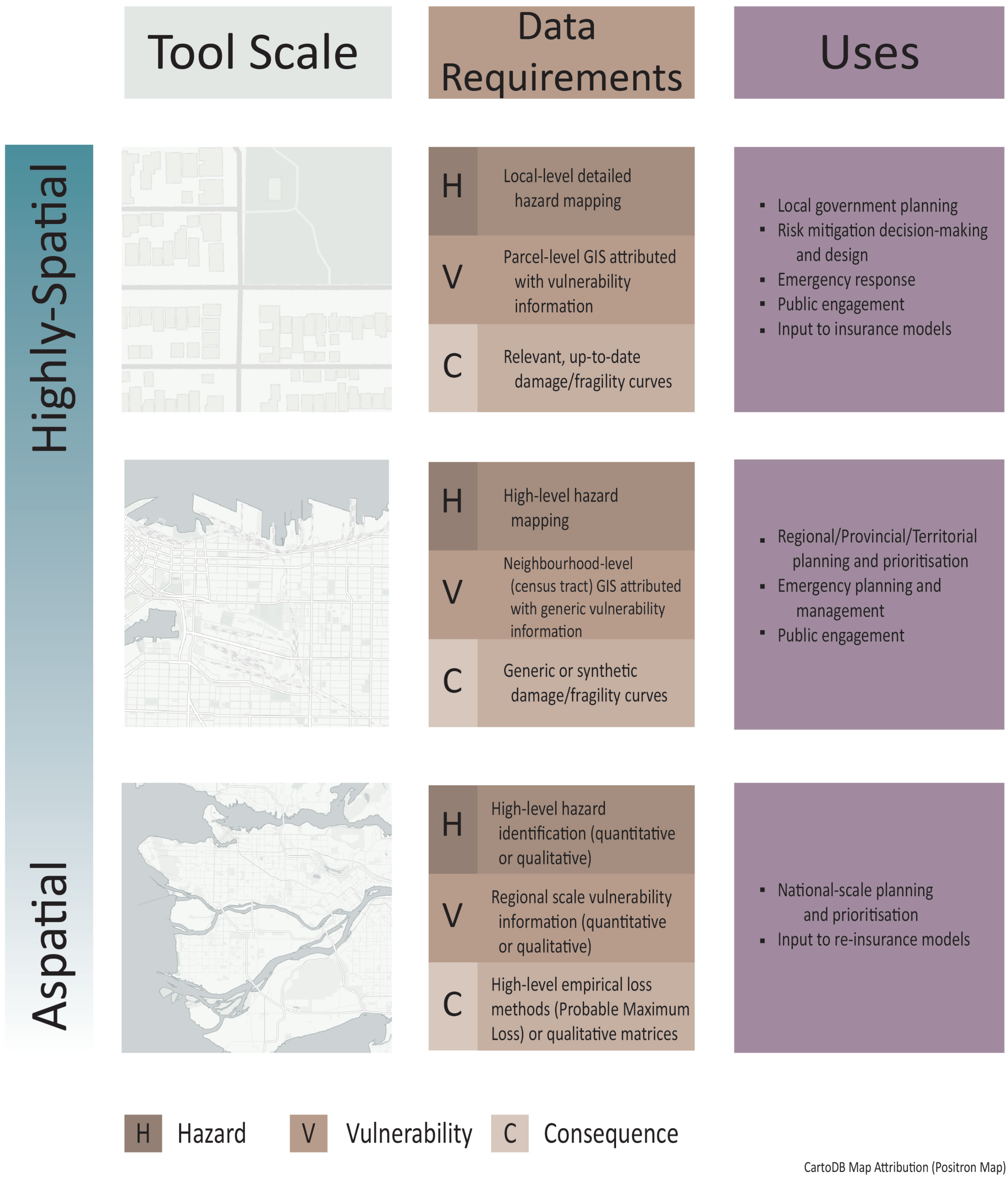


Figure 5: Scales of risk assessment

Essentially, a quantitative risk assessment (QRA) tool is a software or standardized methodology that can aid in the development of a risk assessment. It must be noted that although a tool can support risk assessment, it cannot alone provide enough information for risk mitigation. A QRA tool requires not only significant input data, but also knowledge and capacity to run the tool. Without the data or the capacity, a risk assessment tool has no value. Furthermore, it should be noted that risk assessments created with the aid of a tool are only valid for a short time; the input data on hazards and vulnerability in particular is dynamic and is changing every day, especially in the era of climate change. Risk assessments need to be updated regularly to be valid and useful. At a base, a five-year review of risk assessment results should be conducted[4].

2.4 Summary

In summary, a true risk assessment, one that looks at consequences over time, is an invaluable instrument for decision makers, policy makers, and planners. It can be used to understand and mitigate present and future damages, to create risk management strategies that are both cost effective and community supported, and to help plan for long-term financial investments in risk mitigation. A national scale risk assessment tool, such as the AHRA, or an aggregated quantitative risk assessment (based on standardized methods) will provide a national understanding of hazards and risks, and help prioritize mitigation strategies and funding. Further, the increased level of knowledge from a national-scale risk assessment will inform international understanding of disaster risk as per the Sendai Framework.

3 Hazus Canada

This section provides an overview of the Hazus Canada tool as well as an objective evaluation of the tool as a resource for Canadian professionals working in risk management and mitigation.

Hazus, a model initiated by FEMA in 1992, is a standardized methodology for the calculation of potential losses from natural hazards and is widely used across the United States. It was designed as a planning-level tool for local governments and agencies to develop emergency management and mitigation plans[5]. Natural Resources Canada began adapting Hazus for use in Canada in 2011[6]. Hazus Canada is currently available with earthquake and flood modules, and comes pre-packaged with a high-level asset inventory of building stock, basic demographics, and some business information.

Hazus, like most risk assessment tools, calculates only direct tangible and some indirect tangible damages and losses, providing a significant amount of information about damages and losses to buildings in particular (see Appendix A for more details on loss types). It also provides limited loss information pertaining to people, as well as indirect economic losses. Most of the calculations are done based on large-scale classifications of building stock and demographics, but there is also the opportunity to refine this information with User-Defined Facility (UDF) information on buildings and critical infrastructure.

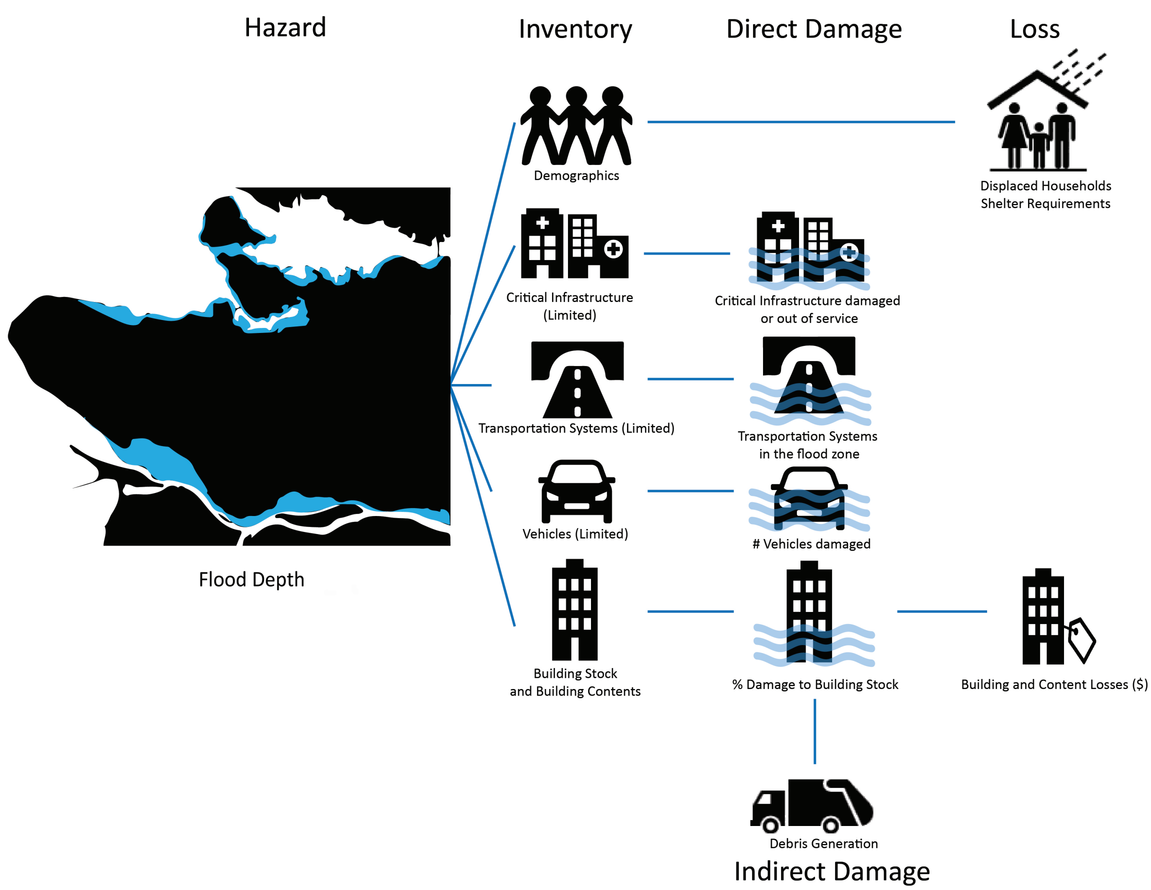


Figure 6: Hazus structure (adapted from [7]) for flood

For flood losses, damage and loss results are calculated based on an asset inventory (what's on the floodplain), and the hazard itself (where and how deep the water is). This information is then combined with damage and loss curves from the Hazus database to produce hazard and site-specific consequence information (Figure 6). Similarly, earthquake damages are calculated on the same asset inventory attributed with slightly different information—details on building structures, for example. These are then overlaid on shakemaps that define the local hazard conditions for a given earthquake event. These are combined using fragility curves to calculate expected levels of damage by building type and local shake conditions. Risk-to-life is also calculated as a function of building damages and time of day.

Since its development, Hazus Canada has been used by several groups, including private sector consultants, governments, and universities. However, over the course of the last 4 or 5 years, some obstacles to the use of Hazus Canada have come to light. The following outlines both the strengths and weaknesses of Hazus Canada as tool for geohazard risk assessment in Canada.

3.1 Methods

The strengths and weaknesses of Hazus Canada were explored by speaking with Hazus Canada users. An effort was made to find people who had actually used the software, either as an operator (mostly GIS professionals) or as engineers/hazard professionals who had overseen the work. As a base for this work, NRCan provided a list of people who had requested Hazus Canada, and user-needs interviewees were also asked if they had used Hazus Canada. Unfortunately, the user base of people who have successfully used Hazus Canada is quite small—somewhere between 10 and 15 people. Seven (7) people were interviewed for this project. Hazus Canada users were asked to discuss the strengths and weaknesses of the software under three categories: 1. Overall methodology, 2.Pre-populated datasets, and 3. Software platform. As for the user-needs assessment (see Section 4), the project researchers recorded the conversations in note form. The interview respondents came from private industry, local government, and academia. All the respondents had used the tool for only one project, and could only comment within this context.

Further to the user interviews, the project researchers discussed the strengths and weaknesses of Hazus Canada with the project leads at NRCan. Again, meeting notes were recorded, and the comments from these interviews are presented as part of the evaluation of Hazus Canada later in this report.

3.2 Hazus Canada Review

The Hazus Canada review was completed by interviewing a small group of users—unfortunately, most of interviewees had worked solely or mostly in developing flood risk assessments. No good information on the strengths and weaknesses of Hazus as an earthquake risk assessment tool were recorded. However, many of the strengths and weaknesses for flood risk assessment are equally applicable to other hazards.

3.2.1 Overall Methodology

Strengths

The interview respondents all felt that the overall methodology for risk assessment was reasonably robust, and conformed to basic academic standards. The spatial aspect of the program, and its interoperability with GIS software (i.e., the results are .shp files that can be analyzed in any GIS software) was cited as a great strength. Also of note is that the requirement that users input their own flood hazard maps was considered the correct path; using the hazard maps, especially for flood, generated internally by Hazus (US) was seen as a risk, as users might not recognize the level of uncertainty associated with the automated mapping. Note that for a base, earthquake hazard mapping is available in Hazus Canada [8].

Weaknesses

Interviewees cited several weaknesses with the overall methodology of Hazus Canada. Some of these are specific to Hazus Canada, but others apply equally to some, if not all, risk assessment tools. For example, interviewees noted that the calculated *consequences* (impacts) were limited to building damages and displaced populations. None of the interviewees had reported or used the indirect economic losses calculated within Hazus Canada, over concerns for the data quality. The Hazus users and the user-needs interviewees (see Section 4) noted the same discrepancy between consequences required to make good decisions to mitigate societal risk (vulnerable populations, small and medium business losses, etc.).

Other Hazus Canada weaknesses, specific to the software, included the relatively poor canned reporting produced by the program. Both the output datasets and the .pdf reports were described as limited; the data needs considerable manipulation to produce useful, understandable results.

In terms of data inputs, users noted that the development of UDF datasets (which are seen as best practice) was very time consuming and tricky, especially with this group of early adopters and beta-testers, who had limited support and documentation.

In terms of calculation methods, several interviewees cited concerns with the results from the GBS (Global Building Stock) calculations, especially for flooding. The same flood depth is averaged and applied across a census block, which can create large errors. The dasymetric approach being adopted by Hazus US goes some way to improve this, however fine-scale calculations are really required to remove this error. Fine-scale information is more readily available today than when Hazus was originally developed.

3.2.2 Pre-Populated Datasets

Strengths

The main strength noted by users was the underlying aggregated dataset for building stock and population. For regional scale studies, it was noted that this dataset was invaluable as it provided a consistent base, whereas working across multiple jurisdictions often requires significant resources to collect and aggregate datasets.

Weaknesses

The interviewees noted several weaknesses in the datasets. First, several found that finer-scale data (i.e., UDF data, as opposed to the pre-populated GBS data) is required to complete robust risk assessments. This is particularly problematic in rural or semi-rural areas where census tracts are larger and commonly cover an entire town. Further, others noted that they were suspicious of the results from the GBS-based assessments after they were compared to results from a UDF study. However, it was noted that some of these concerns could be addressed with a better understanding of how the underlying datasets were developed. The newly released documentation[9] should partially resolve this problem.

A further concern noted by Hazus users was the standard depth-damage curves that are included with Hazus Canada, although considered the best available information, are not representative of Canada. It was also noted that there is no guidance available within the program to help with curve selection. No similar comment was provided on the earthquake fragility curves; but this is likely because the interview subjects had primarily used the flood module or, in the one case where an earthquake scenario was run in addition to the flood module, the modeller was a GIS professional and not a technical expert. It is the researchers' understanding that the earthquake fragility curves are more robust than the flood damage curves.

3.2.3 Software and Platform

Strengths

Overall, no consistent strengths were identified related to software and/or platform. Contrary to most interviewees, one user noted that they did not see the requirement that Hazus Canada work within an ArcGIS environment as an obstacle. They noted that they, and all their clients, have access to ESRI licenses.

Weaknesses

The software itself and its reliance on ArcGIS were generally seen as big weaknesses and obstacles to use. With regards to the reliance on ArcGIS, respondents noted that this was an obstacle in itself because of the large cost associated with licensing. But even when users had access to ESRI licenses, they were required to keep separate machines (or partitioned hard drives) that had the requisite version of ArcGIS (10.0). This is not always a practical solution, especially when computer resources are limited.

In general, the software was found to be buggy; some of this relates to the newness of the software, and that some users were working with beta-versions. In addition, users noted that it was difficult, if not impossible, to resolve the bug issues as the program logs did not provide adequate information to help find and resolve the problems. Several interviewees noted that the software was clearly not developed by software engineers, who could have addressed many of the issues.

Furthermore, although NRCan provided valiant support efforts, it was not always possible to resolve problems. Several interviewees noted that it would have been helpful to have an intra-user forum, where bugs and other issues could be discussed and resolved online. The existing CanHUG website was seen as a resource, but required that questions related to software bugs be relayed through NRCan staff, as opposed to providing a venue for users to talk amongst themselves. Stack Exchange online communities are an example of an intra-user forum; they purport to help experts share knowledge in a simple format[10].

It was also noted that the existing documentation was not adequate, although this may be partially resolved by the recent release of the Hazus Canada Flood Module documentation[9].

One further issue identified by two separate users was that the software requires that all underlying datasets be stored on a single machine. This created two problems. In the first instance, one interviewee noted that some of the GIS datasets required for their project were very large, and it would have been less resource-intensive if datasets could have been stored on a server and accessed by the working machine, rather than having to acquire and use an expensive machine with adequate memory. A second user noted that the system of storing data on a single machine meant that datasets were not “live”. For example, any updates to the base data would not be applied to the Hazus modelling unless the newer “live” data was copied over to the working machine.

3.3 Summary

Overall, although many weaknesses were identified, Hazus Canada has provided some invaluable insights for the future of natural hazard risk assessments in Canada. Specifically:

4. The underlying inventory datasets (GBS and demographic) were seen as a starting point for future regional/national scale assessments because of the consistency of the data.
5. The risk assessments completed using Hazus Canada have provided an opportunity to better understand the gaps for natural hazard risk assessment in Canada. Specifically the underlying vulnerability datasets and the paucity of Canada-specific depth-damage curves for flood.
6. Finally, the consequence assessments completed with Hazus Canada also provided insights into the gaps in risk assessment and risk communication. Specifically, that dense standardized technical reporting cannot by itself be used to communicate risk and help decision makers.

The results of this review along with an assessment of user needs form the basis of recommendations on a way forward for risk assessment tools in Canada. These recommendations are provided in Section 6.

4 User Needs

At the outset of the project, it was recognized that user needs should define the way forward for risk assessment tools in Canada. Also, that risk assessment tools and methods should not be constrained by what is currently available, but rather by what the various professionals working in the field of risk management and mitigation need to make good decisions to reduce risk.

4.1 Methods

To this end, the project researchers conducted interviews with 47 professionals across Canada. This approach was selected to get rich information in a short period of time; the project had an 11-week schedule for all components, and interviews were mostly conducted in a 3-week window from January 25 to February 12, 2016.

Interviewees were solicited through multiple open calls on the CanHUG listserv, the NRCan Flood Mapping Technical Working Group listserv, the CRHNet LinkedIn Group, and on two separate e-mail blasts to the Canadian Water Resources Association membership. Further efforts were made to attract participants through a social media campaign on Twitter. A wide net was cast in order to attract a diverse group of interviewees. Natural hazard risk assessment can mean different things depending on the hazards faced and the roles and responsibilities of the risk assessment user, and it was important to capture a wide array of needs that would reflect diverse users. Furthermore, the project researchers did not want to limit the target group to those who already used risk assessment tools (either qualitative or quantitative), but rather hoped to learn from both existing users, and others who should be using risk assessment to guide future decisions.

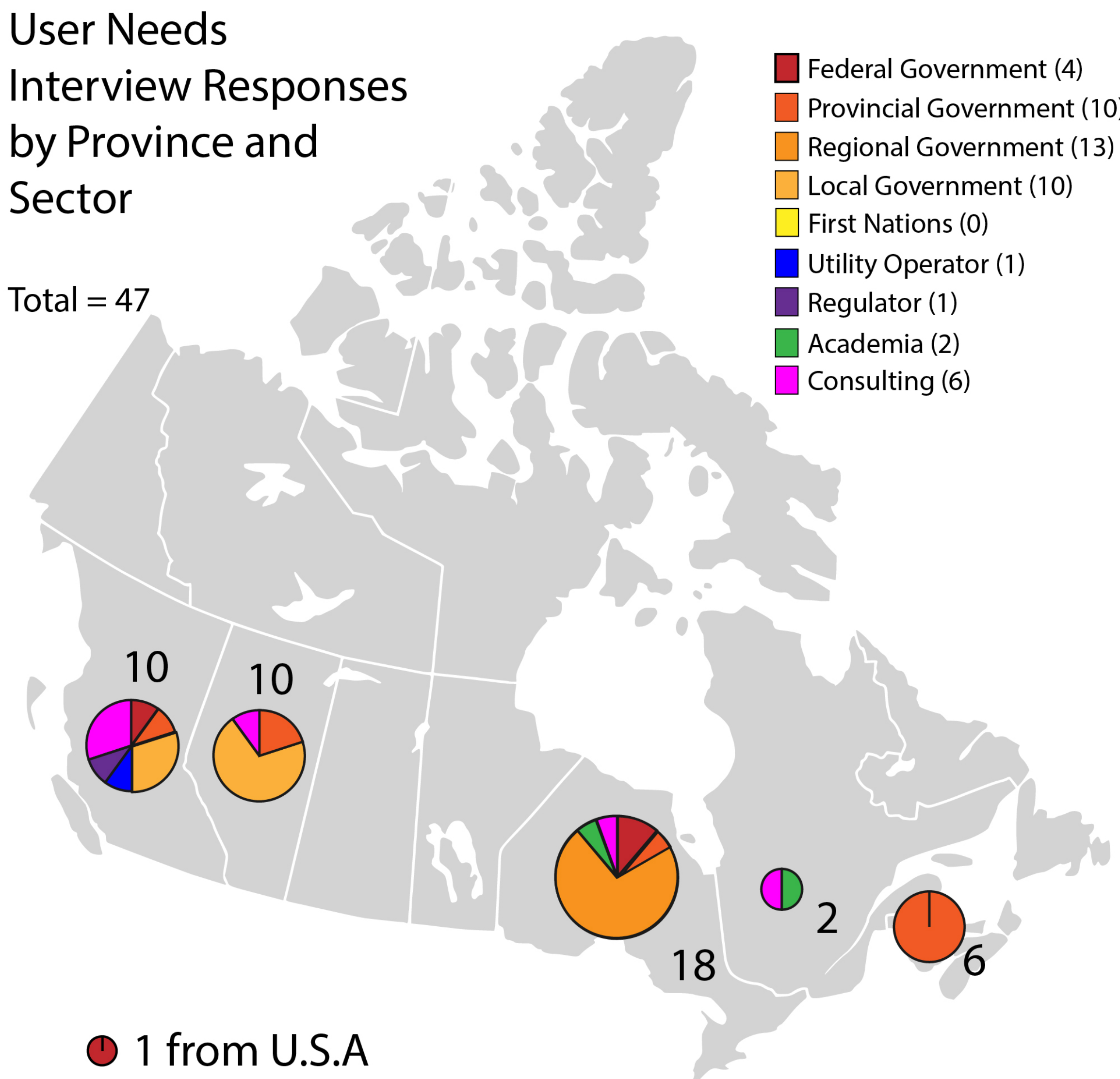


Figure 7: Summary of user needs interviewees

Interviewees were solicited to represent various geographic regions, and included public and private sector professionals with diverse roles and responsibilities (see Figure 7). Unfortunately, only two interviews were conducted with professionals from Québec—a higher number would have been preferred, given the relative population of the province. Furthermore, no First Nations responded to the call for interviews, which leaves a gap in understanding. A good diversity of people from other measures of employer and role were interviewed (see Figure 7).

The majority of interviews were conducted by phone and took approximately 30 minutes; a few interviews were conducted in person. A semi-structured interview process was used to allow for interviewees to express their diverse needs. It would have been difficult to capture some of the nuanced needs in a more rigorous survey format. A series of questions guided the conversation (see Appendix B) and these were broadly grouped into three categories. The first set of questions explored the interviewee's experience and role with regards to natural hazards management, the second set of questions probed their needs with regards to risk assessment outputs, and a third group of questions focused on software platform preferences. The interviewees remained anonymous and are only identified by province, public/private sector (and level of government for public sector), and professional role (engineer, planner, decision-maker, etc.). The conversations were captured in note form by the project researchers.

4.2 Results

Over the course of the user interviews, some distinct themes emerged and are outlined below.

4.2.1 Risk Assessment Methods

4.2.1.1 *Overall*

1. **Robustness** is important. A common thread amongst nearly all of the interviewee responses was that results from a risk assessment tool need to be robust and defensible.
2. **Spatial** outputs are necessary. Natural hazards are spatially variable for the most part and therefore any risk assessment tool needs to be spatial as well; it needs to be GIS-based.
3. **Fine-scale** information is strongly preferred. Many planning, mitigation, and emergency response decisions are made on a fine scale (at the property level), and therefore a tool that has this level of information is preferred. Additionally, fine-scale information can always be scaled up, whereas it is difficult to disaggregate down. It was noted by several interviewees that modern tools (GIS, big-data collection systems, etc.) mean that fine-scale information is readily available now; this wasn't necessarily the case five years ago.
4. A **consistent** tool or approach for the whole country (or at least at a provincial level) was seen as an important issue. This was seen as important to aid in the prioritization of mitigation projects.

4.2.1.2 ***Hazards***

1. **Overland flood** is seen as the dominant hazard across the country, although other hazards can be locally important. Specific natural hazards that were mentioned by interviewees include: hurricane, winter storms, wind storms, tornadoes, coastal surge, urban flooding, groundwater flooding, ice-related flooding, debris-flows, landslides, forest fires, droughts, and earthquakes. The hazards mentioned can be assumed to be related to the geographic location and expertise of the interviewees and should not be considered a comprehensive or prioritized list of natural hazards in Canada. However, it is clear that overland flooding is the dominant hazard of concern across the country (Figure 8).

Figure 8: Word cloud of responses to user-needs question on the greatest hazards faced by respondents

2. **Multi-hazard** risk assessment was for the most part seen as a benefit. Value was seen in looking both at the relative impacts of different hazards for mitigation prioritization, and at multi-hazard scenarios (for example, earthquake-induced flooding as a result of dike breaches).
3. **Human-induced hazards** (train derailments, chemical spills, etc.) were mentioned by many interviewees, although they are not part of the official scope of work. A multi-hazard tool that could be used to compare natural hazards against human-induced hazards would have value for emergency responders, planners, and decision makers.

4.2.1.3 ***Impacts and Consequences***

1. **Life safety** (or risk-to-life or public safety) and **critical infrastructure** were the dominant impacts mentioned by interviewees as being important to better understand or quantify (Figure 9).
2. Extremely diverse responses were found with regards to other impacts requiring further understanding or quantification, and included:

Figure 9: Word cloud of responses to question of greatest impacts or consequence of a natural hazard event

a. Impacts to people—especially vulnerable populations.
b. Impacts to the economy—both direct and indirect.
c. Impacts to property and infrastructure—from individual homes to civic institutions, as well as transportation routes, especially bridges and other lifelines. Communications infrastructure was also cited by several respondents.
d. Impacts to the environment were also mentioned by a few interviewees.

In summary, the project researchers found that **local needs drive the requirements for impact assessments**.

4.2.1.4 *Risk*

1. Many respondents, especially planners and decision makers, saw value in having a tool that was **cumulative** (i.e., a tool that could provide annual expected losses, or exposure) as opposed to simpler scenario-based tools. Although a few others, especially emergency managers and responders, thought that a scenario-based tool would be adequate for their work.

4.2.2 Data Requirements

1. **Accessibility** of high-quality data used for natural-hazard risk assessments was the primary concern of interviewees. **Comprehensive, standardized, and verifiable** datasets that define hazards, vulnerabilities, and fragility/damage curves were seen as paramount. Respondents were split on whether this data should be publically available or limited to those with appropriate expertise.
2. **Interoperability** of any data (both input and output) for a risk assessment tool was a key consistent response from nearly all interviewees. Respondents wanted the tool to work with their existing systems. These varied from existing GIS and CAD databases to emergency response systems, such as MASAS[i].

4.2.3 Interface/Accessibility

1. The **scalability** of any risk assessment tool was seen as important by nearly all interview respondents. There will be many potential end-users of the software, who will have differing levels of expertise and experience with risk assessment, and many respondents saw the need to have a tool that could be used by experts, generalists, and, in some cases, the public. Many hazard professionals (i.e., experts) noted that they would like to be able to **customize** the tool to best meet their needs and to correspond with their available input data.
2. **Ease-of-use** was cited as important by many respondents. Many of the interviewees noted that they have diverse roles and responsibilities, and that they might only get a few days a year to use a risk assessment tool. It therefore needs to be intuitive, relatively simple to use, and be backed by good documentation and/or support.

[i] Although not yet live and not currently geospatial, the new NEMS (National Emergency Management System) should also be considered as a tool that should have interoperability with any national risk assessment tool.

3. The actual platform for the software (i.e., downloadable stand-alone tool vs. web-based tool, or Windows vs. Mac vs. other operating system) did not appear to be a concern. Similarly, respondents were split on whether the risk assessment tool should be proprietary or open-source.

4.2.4 Sustainability/Viability

1. **Sustained federal government support** for any tool was seen as an important component of a risk assessment tool. This would aid in the development of a large user community, and would make any results more universally acceptable.
2. A **large and well-supported user community** was also seen as imperative to the success of natural hazard risk assessment in Canada. This is important to both individual risk assessment tools, as well as the overall process of risk assessment. Developing this community will obviously take time, but can be supported through good documentation, helplines, good examples, and user-forums (see also Hazus-user comments in section 3.2.3).

4.2.5 Cost

1. A **low- or no-fee** model was by far the most preferred option for interviewees. Many of the agencies that are currently mandated to manage natural hazards are poorly resourced; a large fee would be an obstacle. Some respondents did note that a scalable fee system (based on population, for example) would be acceptable if it was matched by appropriate quality software and support.

5 Quantitative Risk Assessment Tools Evaluation

In order to provide some guidance to the NSGR on future efforts to support quantitative risk assessment in Canada, a number of alternatives to Hazus were evaluated. Although no tool was found to meet all of the user needs defined above, many relevant ideas were found over the course of this research, and these are highlighted at the end of this section. This section also provides a description of the methods for the selection of alternative risk assessment tools, detailed descriptions of eight risk assessment tools including Hazus Canada, and an evaluation of the selected tools against measures defined by user needs (see Section 4).

5.1 Methods and Criteria for Selection

Part of the scope of this work was to provide an objective review of the risk assessment tools currently supported by NRCan and other federal government partners. As such, Hazus Canada, ER2-Flood, ER2-Earthquake, and LIRA were included in the list. Further to these tools, a comprehensive, but not exhaustive, research exercise was conducted to develop a database of applicable software from around the world. To this end, available literature [11–14] was reviewed. Furthermore, country-by-country internet searches (for instance, New Zealand, Indonesia, Europe) were conducted to assess new developments in risk assessment software. A complete list of tools considered is found in Appendix C.

Selection criteria were then developed to determine a smaller number of relevant software for a more detailed review. Selection criteria included:

- The focus on a risk/consequence assessment component was considered essential (some software only included hazard assessment, such as flood mapping, and were consequently disregarded for further assessment).
- In contrast, it was not considered essential that software include hazard modelling (considering that conditions across Canada may vary widely, making it more likely to use different, locally-relevant hazard software that allows hazard maps to be imported into a generally applicable risk assessment tool).
- The software had to provide a quantitative risk or consequence assessment (as opposed to a qualitative assessment).
- The software should be currently supported and regularly updated to new versions.

5.2 Alternatives Review

Considering the selection criteria developed above, the following software alternatives were reviewed in more detail:

1. Hazus Canada
2. Rapid Risk Evaluation – Flood (ER2-Flood)
3. Rapid Risk Evaluation – Earthquake (ER2-Earthquake)
4. RiskScape

5. InaSAFE
6. Vizonomy-ASTERRA
7. Global Earthquake Model (GEM)/OpenQuake
8. LIRA

Summary tables describing the tool and a second table evaluating the tool in each measure are provided below (Tables 1-16).

Available websites, manuals, tutorials, and other documentation were reviewed in detail. Where possible (in the case of open-source software, or where demo versions were available), the software was installed and tested, as far as time constraints allowed. Meetings and online demonstrations were conducted related to ER2-Flood (Heather McGrath), ER2-Earthquake (Miroslav Nastev), and Vizonomy-ASTERRA (Ricardo Saveedra).

All of the selected software tools include risk/consequence assessment components. While they may not all address all of the user needs, they each provide different, interesting components that can contribute to developing an overarching approach for natural hazard risk assessment in Canada. To allow a straightforward comparison of what one software can offer in relation to user needs, the software review was based on the user themes determined in the interviews.

Hazus Canada

DESCRIPTION

Hazus Canada is a standardized methodology for the calculation of potential losses from natural hazards. It has been adapted from the US version of the tool originally developed by FEMA. It was initially designed for local governments and agencies to develop emergency management and mitigation plans.

SOURCE

Developed by: Natural Resources Canada

Link: www.hazuscanada.ca

USERS AND APPLICATIONS

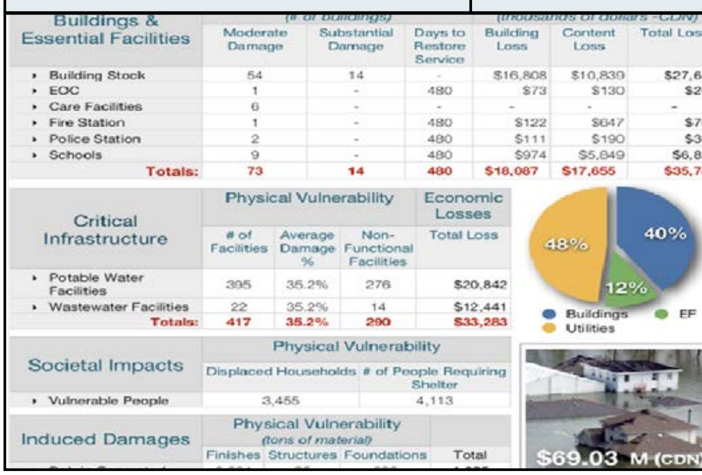
- Technically advanced scientific and engineering experts
- Mitigation planning and priorization tool

STRENGTHS

- Robust methods (for building losses) that have been developed and validated for decades.
- Strong spatial component
- Pre-populated building stock and demography allows for relatively quick regional assessments

WEAKNESSES

- Difficult to use
- Requires ArcGIS license
- Has not been fully adapted for Canada
- Pre-populated datasets are not fine-scale

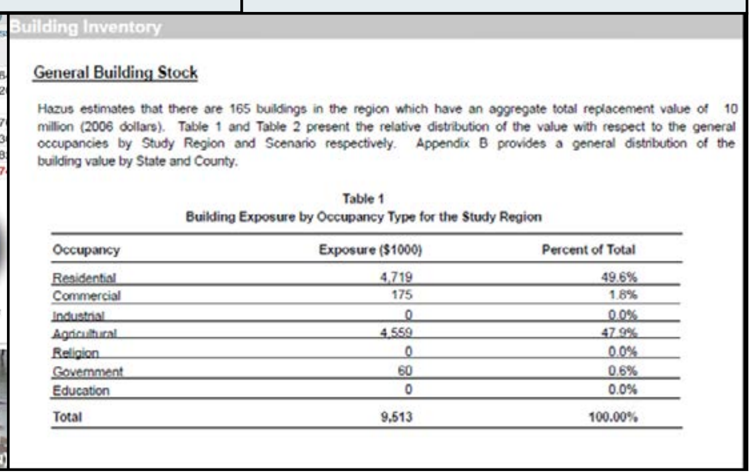


Buildings & Essential Facilities	Moderate Damage (# of buildings)	Substantial Damage (# of buildings)	Days to Restore Service	Building Loss (thousands of dollars - CDN)	Content Loss (thousands of dollars - CDN)	Total Loss (thousands of dollars - CDN)
Building Stock	54	14	-	$16,808	$10,839	$27,6
EOC	1	-	480	$73	$130	$2
Care Facilities	6	-	-	-	-	-
Fire Station	1	-	480	$122	$647	$7
Police Station	2	-	480	$111	$190	$3
Schools	9	-	480	$974	$5,849	$6,8
Totals:	73	14	480	$18,087	$17,655	$35,7

Critical Infrastructure	# of Facilities (Physical Vulnerability)	Average Damage % (Physical Vulnerability)	Non-Functional Facilities (Physical Vulnerability)	Total Loss (Economic Losses)
Potable Water Facilities	395	35.2%	276	$20,842
Wastewater Facilities	22	35.2%	14	$12,441
Totals:	417	35.2%	290	$33,283

Societal Impacts	Displaced Households (Physical Vulnerability)	# of People Requiring Shelter (Physical Vulnerability)
Vulnerable People	3,455	4,113

Induced Damages	Finishes (Physical Vulnerability, tons of material)	Structures (Physical Vulnerability, tons of material)	Foundations (Physical Vulnerability, tons of material)	Total



Building Inventory

General Building Stock

Hazus estimates that there are 165 buildings in the region which have an aggregate total replacement value of 10 million (2006 dollars). Table 1 and Table 2 present the relative distribution of the value with respect to the general occupancies by Study Region and Scenario respectively. Appendix B provides a general distribution of the building value by State and County.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	4,719	49.6%
Commercial	175	1.8%
Industrial	0	0.0%
Agricultural	4,559	47.9%
Religion	0	0.0%
Government	60	0.6%
Education	0	0.0%
Total	9,513	100.00%

Table 1: Hazus Canada summary

Hazus Canada

Risk Assessment Methods Evaluation

Overall	• Robustness/Simplicity: Robust in what it does • Scale: Medium with ability to go to a fine scale with appropriate input data • Spatial Representation: Yes, fully spatial
Hazard	• Earthquake and flood only
Impacts / Consequences	• Exposure: Buildings and occupancy classes, demography, limited business information • Fragility/Damage Curves: Base curves from original US version of Hazus are included as defaults
Risk	• Scenario-based

Data Requirements/Interoperability Evaluation

- Data formats: CDMS database - only used in Hazus. Outputs can be .shp files.
- Data input:
  - Assets: Pre-populated with census tract level GBS and demography
  - Own data: Can be added
  - Data output: Dollar amount damage for buildings, basic measures of life safety, limited indirect economic losses
- Internet and social media scraping: None

Interface/Accessibility Evaluation

- Interface: ArcGIS based, requires GIS expertise
- Scalability of user skills: Requires relatively high levels of both GIS and technical expertise
- Educational component/Documentation: Adequate but not exceptional documentation and other learning tools
- Communication tool: Canned outputs are poor for communication, but can be post-processed
- Platform: Any common platforms can be used, PC-based

Sustainability/Viability Evaluation

- Costs for use: Software is free, but requires the use of an expensive ArcGIS license ($5000 per license annually)
- Cost for development: Significant cost for FEMA over since 1995 when first developed, and the NRCan to adapt product
- Software development timeline: n/a
- Support: Documentation available, and NRCan offers support as possible
- User community: Small (10-15)
- Funding model: NRCan funding support
- Intellectual property rights: Proprietary, although underlying data and algorithms are freely available.

Table 2: Hazus Canada evaluation

5.2.2 Rapid Risk Evaluation – Flood (ER2-Flood)

ER2 - Flood

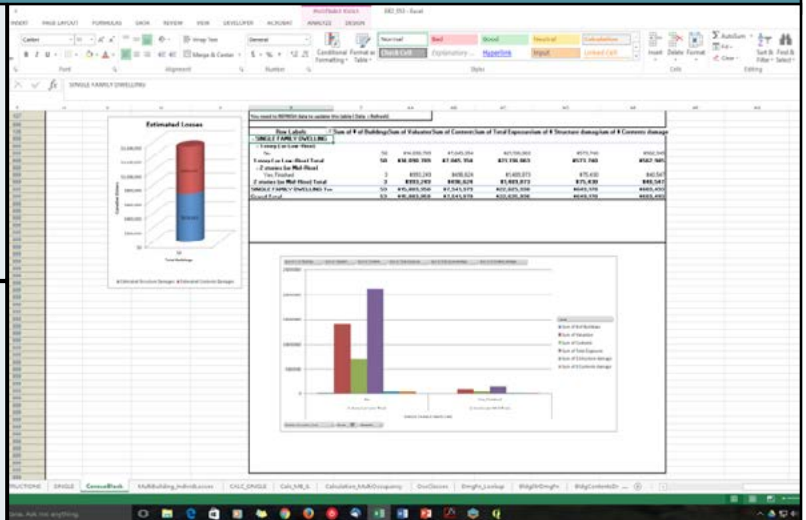
DESCRIPTION

This flood-focused and Excel-based tool takes Hazus damage curves and methodology and integrates them into accessible format. Focus is on flood damage to buildings.

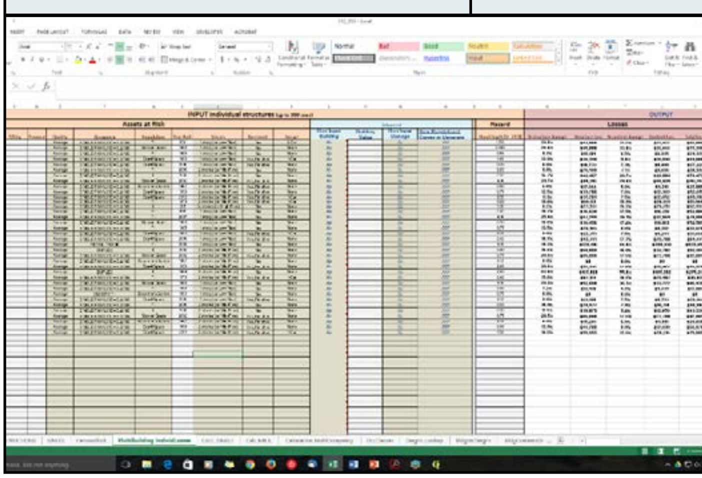
SOURCE

Developed by: University of New Bruns-wick (Heather McGrath), Natural Resources Canada

Link: http://www2.unb.ca/ hmcgrat1/



USERS AND APPLICATIONS	STRENGTHS	WEAKNESSES
• Community planners, non-expert users • High-level emergency planning (scenario-based)	• Very accessible and easy to use • Includes Hazus damage curves, but also provides opportunity to easily import customized curves	• Focus on flood hazard only • Focus on building (infrastructure) damage only • Aspatial • Small user group as soft-ware still in development (113 downloads recorded)



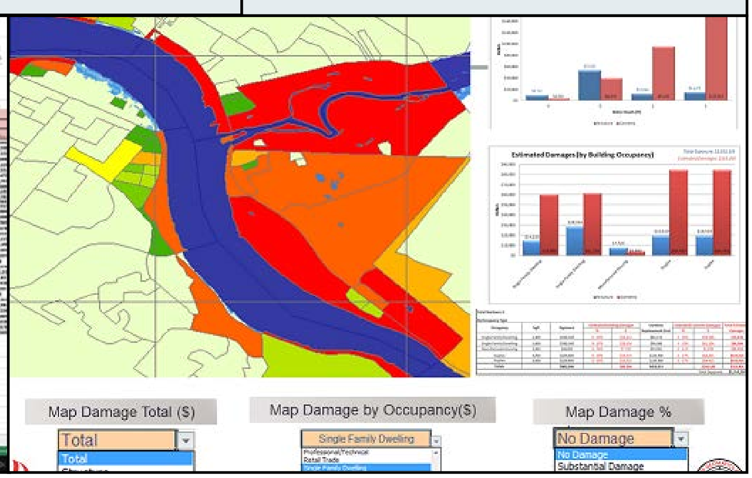


Table 3: ER2 - Flood summary [24–28]

ER2 - Flood

Risk Assessment Methods Evaluation

Overall	• Robustness/Simplicity: Simple approach, robust in what it does • Scale: Fine (property-level) can be aggregated to census blocks • Spatial Representation: No spatial representation for calculations. However, results (for instance, damages per building) can be represented with freely available ESRI map plugin for Microsoft Excel
Hazard	• Flood (user input). FIR2E - Flood Inundation and Risk Evaluation Estimator is under development
Impacts / Consequences	• Exposure: Buildings • Economic and Social Consequences: Impacts on economy is considered in terms of damage to buildings • Damage curves: Hazus damage curves are used. It is straightforward to choose between applicable curves. User-curves can also easily be input
Risk	• Scenario-based tool

Data Requirements/Interoperability Evaluation

- Data formats: Excel data format
- Data input:
  - Assets: Building attributes, flood water depth per building (or building block)
  - Own data: can be added. For instance, property values can be added if available to adjust varying property value throughout Canada (standard property values are already integrated)
- Data output: Dollar amount damage for buildings; graphs and map with buildings (and degree of damage)
- Internet and social media scraping: None

Interface/Accessibility Evaluation

- Interface: Excel, accessible
- Scalability of user skills: Simple to use, based on Excel, accessible for stakeholders
- Customization: Very customizable, all code freely available
- Educational component/documentation: Documentation and instructional videos available
- Communication tool: Graphs and maps can be exported for communication
- Platform: Any common platforms can be used

Sustainability/Viability Evaluation

- Costs for use: Software freely available, but based on proprietary Microsoft Excel.
- Cost for development: n/k
- Software development timeline: Development started in 2014 and is continuing. Excel component operational. Feature for flood inundation map tool in development. Time of completion: n/k
- Support: Developer
- User community: n/k
- Funding model: NRCan funding support for academic developer
- Intellectual property rights: Open-source tool, not proprietary

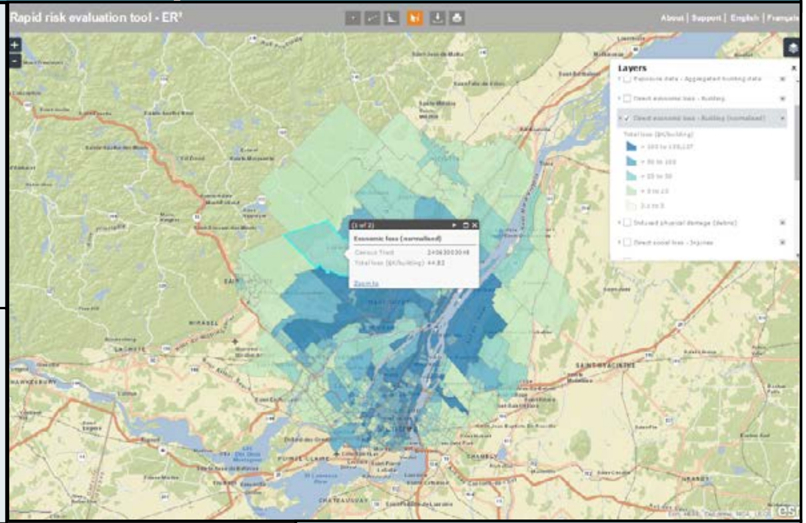
Table 4: ER2-Flood Evaluation

5.2.3 Rapid Risk Evaluation – Earthquake (ER2-Earthquake)

ER2-Earthquake

DESCRIPTION

ER2 Earthquake is currently in development. It consists of two software components. The first component addresses fast near real-time risk analysis in case of a major earthquake, while the other component allows hazard and risk planning, using an interactive web-based platform. A tool for rapid building inventory (Desktop App) has also been developed (UrbanRAT).



SOURCE

Developed by: Natural Resources Canada (Miro Nastev)

Link: n/a

USERS AND APPLICATIONS	STRENGTHS	WEAKNESSES
• Technically advanced scientific and engineering experts • Robust, detailed mitigation planning tool (probabilistic) • Web-based interface also accessible to non-expert users	• Visual and interactive web-based platform • Desktop-based fast near-time risk analysis • Probabilistic tool • UrbanRAT component valuable for rapid development of building inventory.	• Focus on earthquake hazard only • Not fully operational (and therefore full assessment difficult) • UrbanRAT app connects to ArcGIS (and therefore not accessible to everyone)

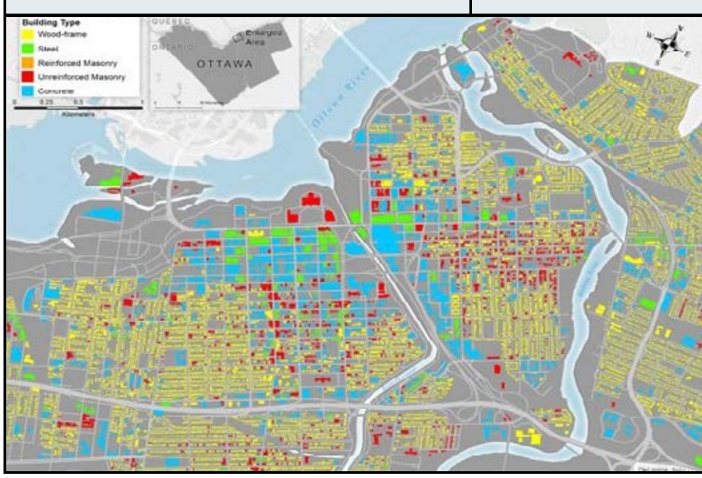


Table 5: ER2-Earthquake summary [6,8,28,29]

ER2-Earthquake

Risk Assessment Methods Evaluation

Overall	• Robustness/Simplicity: Rapid evaluation, robust in what it does • Scale: Fine • Spatial Representation: Yes, fully spatial
Hazard	• Earthquake only. Algorithm under development to generate shakemaps.
Impacts / Consequences	• Exposure: Buildings and occupancy classes, human casualties • Fragility Curves: Vulnerability calculations in ER2 - Earthquake are advanced from the standard Hazus methods; they consider spectral acceleration
Risk	• Scenario-based and probabilistic

Data Requirements/Interoperability Evaluation

- Data formats: n/k
- Data input:
  - Assets: n/k
  - Own data: Can be added.
  - Data output: Dollar amount damage for buildings; graphs and map with buildings (and degree of damage)
- Internet and social media scraping: Near-time component of ER2-Earthquake will be continuously connected to national and local seismograph networks to generate shakemaps. Economic and social losses will be estimated later using the shakemaps. The web-based planning component will have national coverage and comprehensive databases.

Interface/Accessibility Evaluation

- Interface: Interactive, web-based platform for seismic hazard and risk analysis is planned. This will make the tool useable to the non-expert community.
- Scalability of user skills: Low (web-based platform) to advanced (seismic hazard and near-time ER2 component)
- Customization: n/k
- Educational component/Documentation: n/k
- Communication tool: Interactive web-based real-time assessment with ability to show results of different scenarios is planned
- Platform: Any common platforms can be used

Sustainability/Viability Evaluation

- Costs for use: n/k
- Cost for development: n/k
- Software development timeline: Currently in development. ER2-Earthquake software not fully operational. UrbanRAT App is already operational. Time of completion: n/k

- Support: n/k
- User community: n/a
- Funding model: NRCan funding support for developer
- Intellectual property rights: n/k

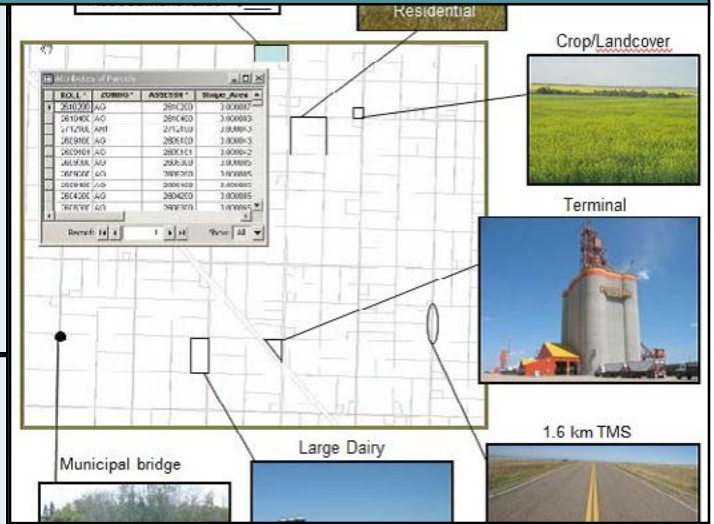
Table 6: ER2-Earthquake evaluation

5.2.4 Land and Infrastructure Resiliency Assessment (LIRA)

LIRA

DESCRIPTION

The LIRA project draws on a number of different tools. First of all, it describes a five step methodology for decision makers for flood risk assessment. It includes a flood hazard component (flood mapping using the WDPM, Digital elevation mapping Ponding Model), a probabilistic economic assessment tool (EMD, Economic Module Development, Cost-Benefit Analysis), as well as an agricultural land use mapping app (AgCapture). Focus on planning-level adaptation assessment (not engineering based). It was developed in Saskatchewan and primarily focuses on flood impacts on agriculture in a prairie environment.



SOURCE

Developed by: VEMA Management Inc. (now ATANA Management Inc.) with funding from Government of Canada

Link: None

USERS AND APPLICATIONS

- Technically advanced scientific and engineering experts
- Agricultural planners

STRENGTHS

- AgCapture tool
- Cost-benefit analysis (probabilistic)
- Focus on economic damages to agriculture, which is a good complementary tool to others that have agriculture as a gap
- Only tool that directly addresses environmental consequences of flooding
- 5-step framework for decision-making (mapping the landscape, hazard assessment, vulnerability impact assessment, and adaptation options)

WEAKNESSES

- Flood hazard only
- Mostly focused on prairie agriculture
- Small-user group to date

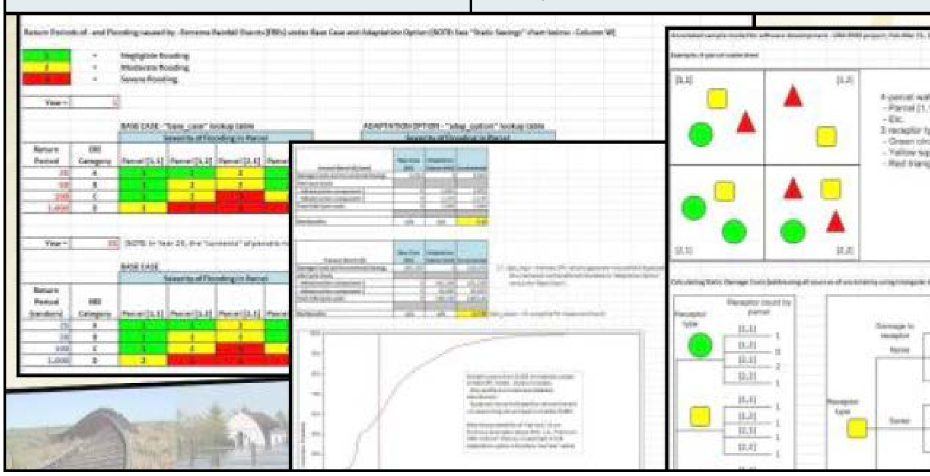


Table 7: LIRA summary[15–19]

LIRA

Risk Assessment Methods Evaluation

Overall	• Robustness/Simplicity: Medium • Scale: Grid-based, parcel level land use (appropriate agricultural scale) • Spatial Representation: Yes, fully spatial GIS based
Hazard	• Flood only with a focus on "fill-and-spill" prairie landscape. Includes Wetlands DEM Ponding Model (WDPM), which was developed at Centre for Hydrology at the University of Saskatchewan
Impacts / Consequences	• Exposure: Agricultural and residential buildings • Consequences: High, nominal and low ranges of damage costs are assigned to each receptor class (by parcel) including single residences, multiple residences, total forage area, total crop area. Dynamic costs are also provide for traffic interruption for railways and highways.
Risk	• Probabilistic: (EMD, Economic Module Development). The software is based on statistical sampling across a wide number of variables employed in deterministic model calculations. Deterministic model calculations include the cost-benefit framework, life cycle costing and (flood) damage costing components.

Data Requirements/Interoperability Evaluation

- Data formats: Common data formats
- Data input:
  - Assets: agCapture tool allows parcel-by-pacrcel inventory of land uses in the agricultural sector to be captured with mobile GIS application.
  - Own data: Can be added
- Data output: Common data format. Different adaptation strategies and cost-benefits analysis of strategies

Interface/Accessibility Evaluation

- Interface: LIRA software, and any GIS platform (QGIS currently used)
- Scalability of user skills: Three-levels of analysis
- Educational component/ Documentation: How-to guide available along with methods documentation
- Communication tool: Developed specifically for decision-making with map, hazard, vulnerability, adaptation options as outputs
- Platform: Windows

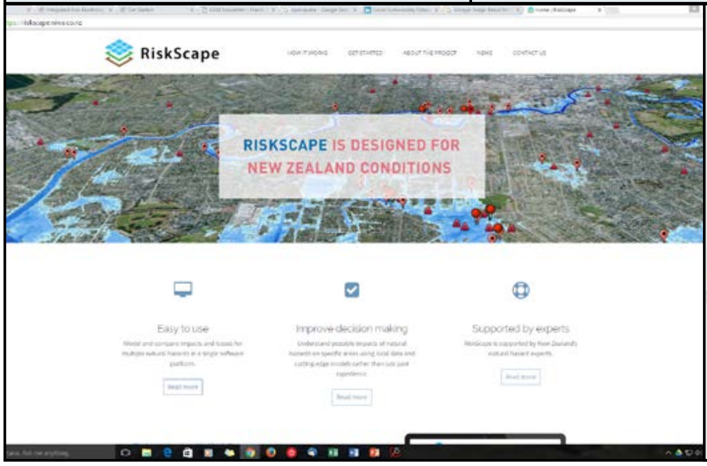
Sustainability/Viability Evaluation

- Costs for use: n/k
- Cost for development: n/k
- Software development timeline: The LIRA project is completed in the eyes of of Agriculture and Agri-Foods Canada (AAFC). Software manuals were completed in 2013. No further software development has occurred since then. The Climate Adaptation Unit is no longer functional.
- Support: Currently no support at AAFC for LIRA software. The Wetlands DEM Ponding Model still supported by the University of Saskatchewan.
- User community: n/k
- Funding Model: NRCan funding support

Table 8: LIRA evaluation

5.2.5 RiskScape

RiskScape		
DESCRIPTION	Modular natural hazard and risk assessment framework developed for New Zealand to estimate impacts and losses for assets exposed to different natural hazards. It combines hazard, asset and vulnerability modules to quantify a range of economic and social consequences. It is used across New Zealand, and is technically sophisticated.	RiskScape
SOURCE	Developed by: GNS Science, National Institute of Water Research, New Zealand Link: https://riskscape.niwa.co.nz/	
USERS AND APPLICATIONS	**STRENGTHS**	**WEAKNESSES**
• Technically advanced scientific and engineering experts • Robust, detailed mitigation and planning tool • Scalable usability	• Fully-operational national multi-hazard tool • Scalable and customizable • Software prototype for generation user damage/ fragility functions. • Probabilistic • Strong educational component	• Proprietary • Generally for more advanced users



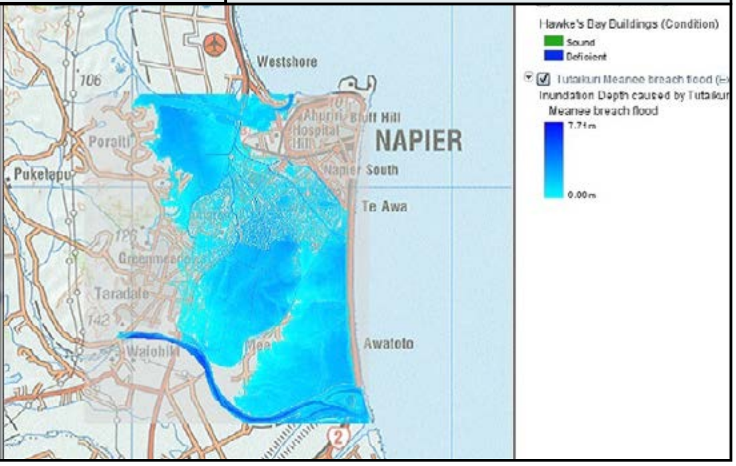


Table 9: RiskScape summary [30,30–34]

RiskScape

Risk Assessment Methods Evaluation

Overall	• Robustness/Simplicity: Technically advanced, includes multiple modules • Scale: Fine-scale (property level), different aggregation mechanisms • Spatial Representation: Yes, fully spatial with map visualization tool
Hazard	• Earthquake, flood, storm-tide inundation, tsunami, volcanic ash fall, windstorm, generic hazard
Impacts / Consequences	• Exposure: Agriculture, buildings, people, lifelines (roads, waterways, telecommunications cables) • Consequences: Building and vehicle damages, people (displacement, casualties), business downtime • Fragility /Damage Curves: Flexible implementation of curves, with prototype tool to aid in the development of new curves. Includes earthquake fragility curves, flood, wind and tsunami curves developed for New Zealand
Risk	• Scenario-based and probabilistic

Data Requirements/Interoperability Evaluation

- Data formats: Common data formats including .csv, .shp and .kml
- Data input:
  - Assets: Default asset database. Asset types and specifications, including option to define the reliability of asset attribute quality
  - Own data: Can be added
  - Data output: .csv, .shp, .kml, .pdf maps
- Internet and social media scraping: None

Interface/Accessibility Evaluation

- Interface: Clear and straightforward
- Scalability of user skills: Medium to expert users
- Educational component/ Documentation: Thorough description of hazard and risk concepts, tutorials, manuals and friendly open concept
- Customization: Users can build their own hazard and asset modules. A planned vulnerability module builder will enable users to be completely self-sufficient
- Communication tool: Maps can easily be exported and used for communication
- Platform: Any common platforms can be used, desktop based

Sustainability/Viability Evaluation

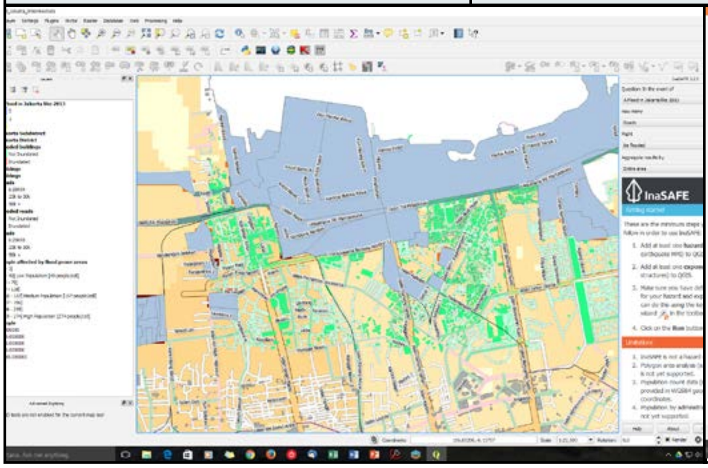
- Costs for use: Proprietary software, free for government and academic use in New Zealand
- Cost for development: n/k
- Development stage: Fully operational. Active since 2004
- Support: Good documentation, and wiki-style support
- User community: Widespread use within New Zealand
- Funding model: Funding provided by New Zeland Government Foundation for Research, Science and Technology.
- Intellectual property rights: Proprietary.

Table 10: RiskScape evaluation

5.2.6 InaSAFE

InaSAFE	
DESCRIPTION	This freely available software acts as a plugin for the open-source QGIS software and has been used across the world, with a focus in Indonesia. It serves a multi-hazard risk assessment tool to which hazard maps are imported. It allows combination of exposure data sets (e.g. building map) with hazard scenarios (e.g., flood maps) and provides maps and statistics on the overlap. At the current stage of development, no straightforward application of damage curves is integrated.
SOURCE	Developed by: Australia-Indonesia Facility for Disaster Reduction (AIFDR), World Bank, the Global Facility for Disaster Reduction and Recovery (GFDRR), and the Indonesian Disaster Management Authority (BNPB) Link: http://inasafe.org

USERS AND APPLICATIONS	STRENGTHS	WEAKNESSES
• High-level emergency planning • Communication tool • Educational	• Accessible, customizable open-source tool • Cost-free • Multi-hazard • Large user-community with active development of the tool. Contributions from a range of developers. Includes innovative methods to engage developers (FloodHack Fest for example)	• Exposure only, no damages or losses calculated currently • Exposure limited to building damages and displacement of people (more under development)



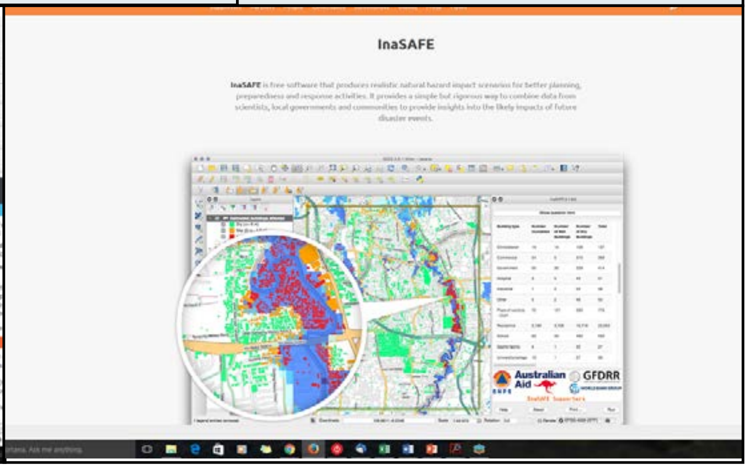


Table 11: InaSAFE summary[12,13,35,36]

InaSAFE

Risk Assessment Methods Evaluation

Overall	• Robustness/Simplicity: Simple, but robust in what it odes. • Scale: Fine-scale (property level), different aggregation mechanisms • Spatial Representation: Yes, fully spatial QGIS plugin
Hazard	• Multi-hazard, generic hazard
Impacts / Consequences	• Exposure: Buildings (by type), people, critical infrastructure and environment • Consequences: Very limited, essentially and exposure tool at present. Some loss functions available for Indonesia • Fragility /Damage Curves: None currently, but could be easily incorporated into Python Code
Risk	• Scenario-based

Data Requirements/Interoperability Evaluation

- Data formats: Standard GIS formats
- Data input:
  - Assets: Connects to OpenStreetMap (OSM) for building footprints, roads, critical infrastructure
  - Own data: Can be added
- Internet and social media scraping: Uses OSM mapping
- Data Output Export results as maps and .csv files. Includes simple generic reporting that summarizes results and provides mitigation options

Interface/Accessibility Evaluation

- Interface: Clear and straightforward
- Scalability of user skills: Medium to expert users. Straightforward use of QGIS plugin. Advanced users can add their own Python Code
- Educational component/ documentation: Tutorials, manuals and clear explanation of concepts are available as text and videos
- Customization: Highly customizable. Additional features can be added using Python.
- Communication tool: Simple and visual outputs
- Platform: Any common platforms can be used, desktop based

Sustainability/Viability Evaluation

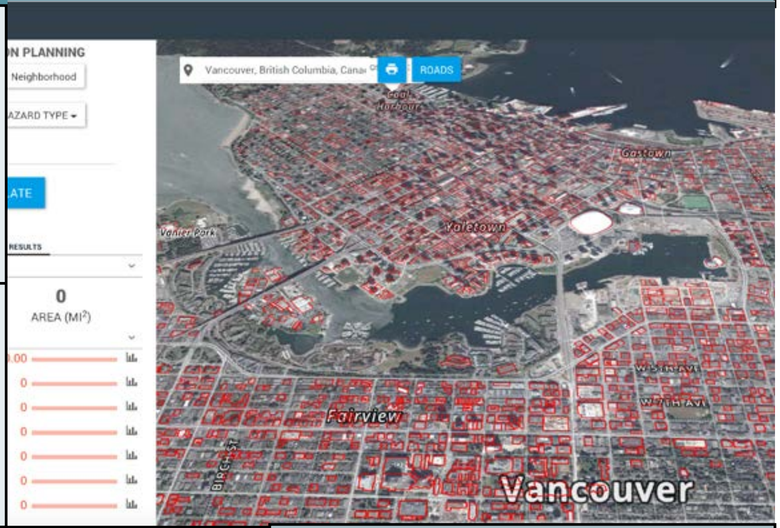
- Costs for use: Free. Open-source
- Cost for development: n/k
- Development stage: Fully operational. Is actively being used in southeast Asia. Development continues.
- Support: Includes User forums, Googlegroups, Facebook groups, Blog, Live chat. Developers continue to contribute to open-source code
- User community: Large and active developer and user community.
- Funding model: Funded and supported by Australian Aid, the Global Facility for Disaster Reduction and Recovery and the Indonesian Disaster Management Authority
- Intellectual property rights: Open-source

Table 12: InaSAFE Evaluation

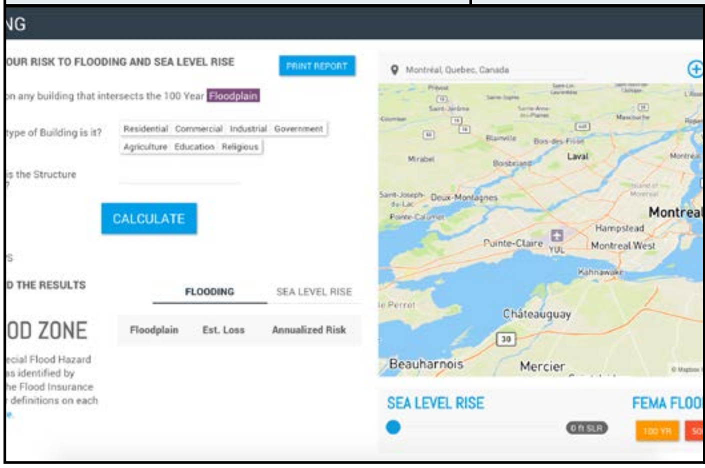
5.2.7 Vizonomy-ASTERRA

Vizonomy - ASTERRA

DESCRIPTION	The Vizonomy ASTERRA tool provides a visual and easily accessible web-based version of FEMA Hazus. It operates with an internal GIS (no dependencies on ArcGIS) and applies Hazus damage curves and methodologies. It also uses internet-scraping of openly available data, such as Open Street Map, to pre-populate maps.
SOURCE	Developed by: Vizonomy LLC, Washington, DC Link: http://vizonomy.com



USERS AND APPLICATIONS	STRENGTHS	WEAKNESSES
• Community planners, general public, non-expert users • High-level emergency planning and communications • Prioritization	• Easily accessible high-level tool: Visual and accessible web-based version of Hazus. Could be used to build awareness, to allow first high level risk assessment to determine where it is necessary to conduct a more detailed risk as-sessment. Easy to access for a range of stakeholders, communities • Good communication tool: clean, visual interface designed for interactive sharing of results. • Internet scraping of data (to pre-populate asset and hazard inventories) of openly available data such as Open Street Map (for critical infrastructure), Zillow (for property value), government sources, as well as social media and real-time satellite imagery	• Flood-focus only • Developed for U.S. where base data sets are different and more plentiful • Primarily based on weak Hazus damage curves • Proprietary • Early in development of tool



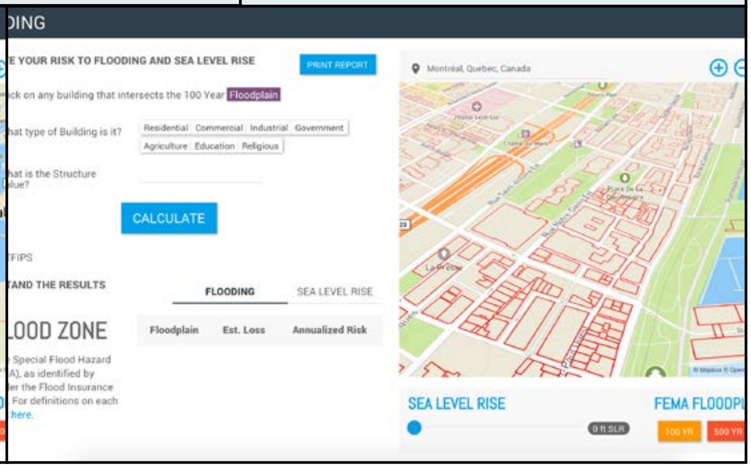


Table 13: Vizonomy-ASTERRA summary [37–39]

Vizonomy - ASTERRA

Risk Assessment Methods Evaluation

Overall	• Robustness/Simplicity: Relatively simple approach. Using Hazus methodologies in a web-based concept. Robustness reliant on data input quality (additional data bases through accessing open data, which are not used in traditional approaches, which may increase performance) • Scale: Fine scale (property-level) to neighbourhood, city and county level, as well as sector level (infrastructure assets across different sectors) • Spatial Representation: Yes, fully spatial
Hazard	• Flood only.
Impacts / Consequences	• Exposure: Buildings, poeple, infrastructure and critical infrastructure (roads, transportation, energy, communications, public health, schools) • Consequences: Uses Hazus methods and curves • Fragility /Damage Curves: Economic building damage curves from FEMA and USACE (using Hazus curves) with some addition of curves from UK databases (OASIS)
Risk	• Scenario-based, some probabilistic components

Data Requirements/Interoperability Evaluation

- Data formats: Uses common GIS formats, but has no user-input option.
- Data input:
  - Assets: Internet-scraping for building footprints and assets from OpenStreet Map (https://www.openstreetmap.org/) and other open data sources (based on publicly available datasets from agencies); residential building values from Zillow (http://www.zillow.com/).
  - Own data: Can be added
- Data output: Maps as pdfs, web-based tool can be shared in workshops for demonstration or via links Exposure summaries (on e.g. critical sectors, demographics and buildings).
  - Internet and social media scraping: Yes

Interface/Accessibility Evaluation

- Interface: Very visual and nice design, straightforward, easy to use
- Scalability of user skills: Accessible for anyone, no technical expertise necessary. User-friendly. Plug-and-play of scenarios and potential impacts through web-based platform
- Educational component/ documentation: Help and FAQ, as well as some shorter commentary available through website. Additional and more extensive education on e.g. "Hazard" or "Risk" concepts not included.
- Communication tool: Well-designed communication tool that allows interactive web-based displays of different scenarios. Allows sharing of (interactive) results online via link or as pdf maps.
- Platform: Web-based, cloud-based.

Sustainability/Viability Evaluation

- Costs for use: Proprietary software. Costs range between US$15,000 - $40,000/year (individuals or agencies)
- Cost for development: n/k
- Software development timeline: New but operational software: Vizonomy company founded in 2014, ASTERRA launched in April 2015. Further upgrading and development continuing and new features are being implemented
- Support: Vizonomy LLC help desk
- User community: Currently only US based. User community not apparent (proprietary software), no exchange or discussions between different users apparent
- Funding model: Proprietary
- Intellectual property rights: Proprietary

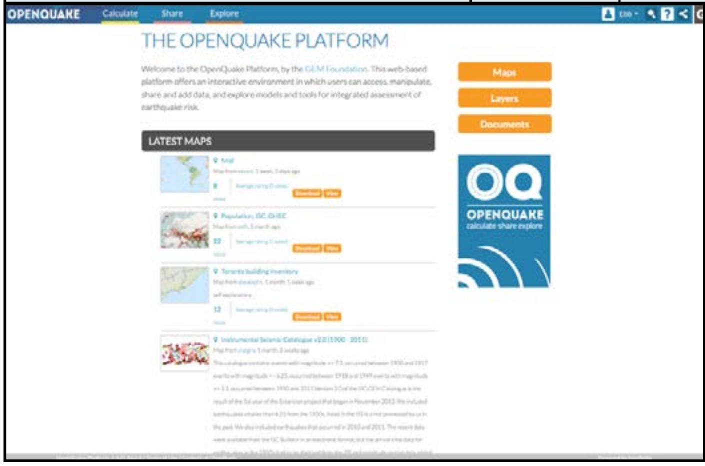
Table 14: Vizonomy-ASTERRA evaluation

5.2.8 Global Earthquake Model (GEM)/OpenQuake

GEM/OpenQuake

DESCRIPTION	
DESCRIPTION	OpenQuake is a suite of open-source software for earthquake hazard and risk modelling. It is composed of a variety of mod-ules, such as the Platform (for visualizing, exploring and sharing datasets, tools and models), and the Engine (software for calculation of seismic hazard and risk assessment, used on the desktop or in the cloud). Furthermore, a range of desktop tools exist to support the risk assessment, for instance Inventory Capture Tools and the Integrated Risk Assessment Tool. The OpenQuake Engine consists of a range of different calculators (Python pro-gramming language based, no graphical user interface) for computing human or economic losses for a collection of assets.
SOURCE	Developed by: International, scientists, experts, modelers from across the world- Link: http://www.globalquakemodel.org/

USERS AND APPLICATIONS	STRENGTHS	WEAKNESSES
• Technically advanced scientific and engineering expert users • Robust detailed mitigation planning tool (probabilistic)	• Large user community interesting in particular for their vibrant, world-wide user community. • Interactive environment and exchange between users through user chat room and blog, international forum for collaboration with the goal to pool regional and technical knowledge to create a global resource. • Mobile Inventory Data Capture Tool that supports crowdsourcing is an interesting model for improving vulnerability and damage models • Extensive documentation and guidelines • Robust validated research and tools at the leading edge of risk assessment for earthquakes	• Earthquake-focus only • Very advanced tool only suitable for expert users • Pricing model is unclear, but could be considered expensive to join network



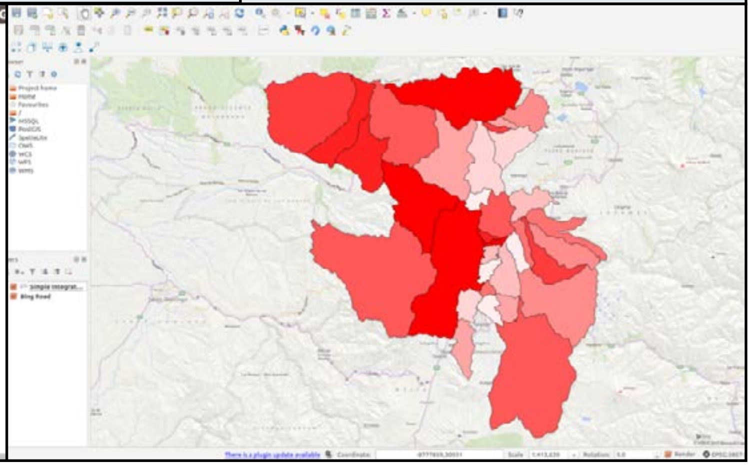


Table 15: GEM/OpenQuake summary [12,40–45]

GEM/OpenQuake

Risk Assessment Methods Evaluation

Overall	• Robustness/Simplicity: Technically advanced and robust. Many verification tests of the software have been conducted. • Scale: Fine scale (property-level) as well as global scale • Spatial Representation: Calculations conducted spatially but no GIS software or graphical user interface integrated in OpenQuake Engine. Additional toolboxes exist, for instance, as QGIS-Plugins.
Hazard	• Earthquake only.
Impacts / Consequences	• Exposure: Buildings, people, infrastructure • Consequences: Social Vulnerability and Integrated Risk – Plugin for QGIS (open-source GIS). For creating/editing social indicators and combining these with earthquake risk (i.e. estimates of human or infrastructure loss). Plugin interacts with the Open-Quake Platform (download/upload socioeconomic data or existing projects) • Fragility Curves: Variety of functions that can be edited and shared. Database also exists
Risk	• Scenario-based, probabiblistic calculations as well as cost-benefit options

Data Requirements/Interoperability Evaluation

- Data formats: Wide range of formats
- Data input:
  - Assets: Tools available to help populate asset databases
  - Own data: Can be added
- Data output: Multiple formats
- Internet and social media scraping: No

Interface/Accessibility Evaluation

- Interface: The OpenQuake Engine (desktop) is currently only available in Python programming language, but the development of a graphical user interface (GUI) is underway. A cloud-based version of the OpenQuake Engine (OATS) also exists (but also operates through Python programming).
- Scalability of user skills: Technically very advanced, python programming necessary to access the OpenQuake Engine calculator. However, other components of the OpenQuake toolbox, such as QGIS-Plugins, and the OpenQuake Platform data sharing features are more straightforward and operate with an interface or via a web-site.
- Customization: High, all open-source code is available.
- Educational component/Documentation: Very extensive and detailed documentation. Both on the level for stakeholders and on an advanced level for experts and developers. Detailed description of source code.
- Platform: OpenQuake Engine (for calculations): Desktop (Ubuntu) and cloud-based (OpenQuake Alpha Testing Service, OATS). OpenQuake Platform for data sharing: website

Sustainability/Viability Evaluation

- Costs for Use: OpenQuake and other Global Earth Model component are open-source and freely available. Additional software support and model development require payment under a membership structure tied to the GDP of the country.
- Cost for Development: Reported costs suggest that the program and tool cost in the order of $40 M to establish.
- Software development timeline: Global Earthquake Model project initiated in 2006. Global Earthquake Model built from 2009-2013 (5MEuro budget). OpenQuake software toolbox was released in January 2015 (OpenQuake engine was released in 2013 after 4 years of development). Ongoing development for further tools.
- Support: High level of intra-user support
- User community: large international user base, continuing development through input from users: Interactive environment and exchange between users: user chat room and blog, international forum for collaboration with the goal to pool regional and technical knowledge to create one reliable global resource. Online data sharing tools: users can contribute to existing datasets, vulnerability functions (Physical vulnerability suite), and models. Collaborative efforts: many developers contribute to it: combined effort from scientists/engineers, governments and private sector
- Funding Model: Open-source, contribution license

Table 16: GEM/OpenQuake evaluation

5.3 Tool Evaluation

The user-needs assessment provided some excellent insights into the base components of what is needed to grow natural hazard risk assessment in Canada. Through the user-needs assessment and the Hazus Canada review it also became apparent that many of the fundamental inputs required for any and all risk assessment tools are lacking in Canada, and they should be the focus of research and resources in the short term. Regardless, the eight alternative risk assessment tools have been evaluated qualitatively to look at their strengths and weaknesses under 11 different measures that are based on the user-needs assessment. These are grouped and ordered in the same manner as in Section 4.

5.3.1 Risk Assessment Methods

5.3.1.1 *Robustness*

The quality of output or robustness of a risk assessment tool was cited as a key component during the user interviews. A qualitative measure of the robustness was assigned to each tool. A robust tool was defined as one with a strong methodology based on current best practice that has been highly vetted, validated, and reviewed. At the other end of the spectrum are weak tools, which are defined as having an over-simplified methodology, and limited or no validation or review (Figure 10).

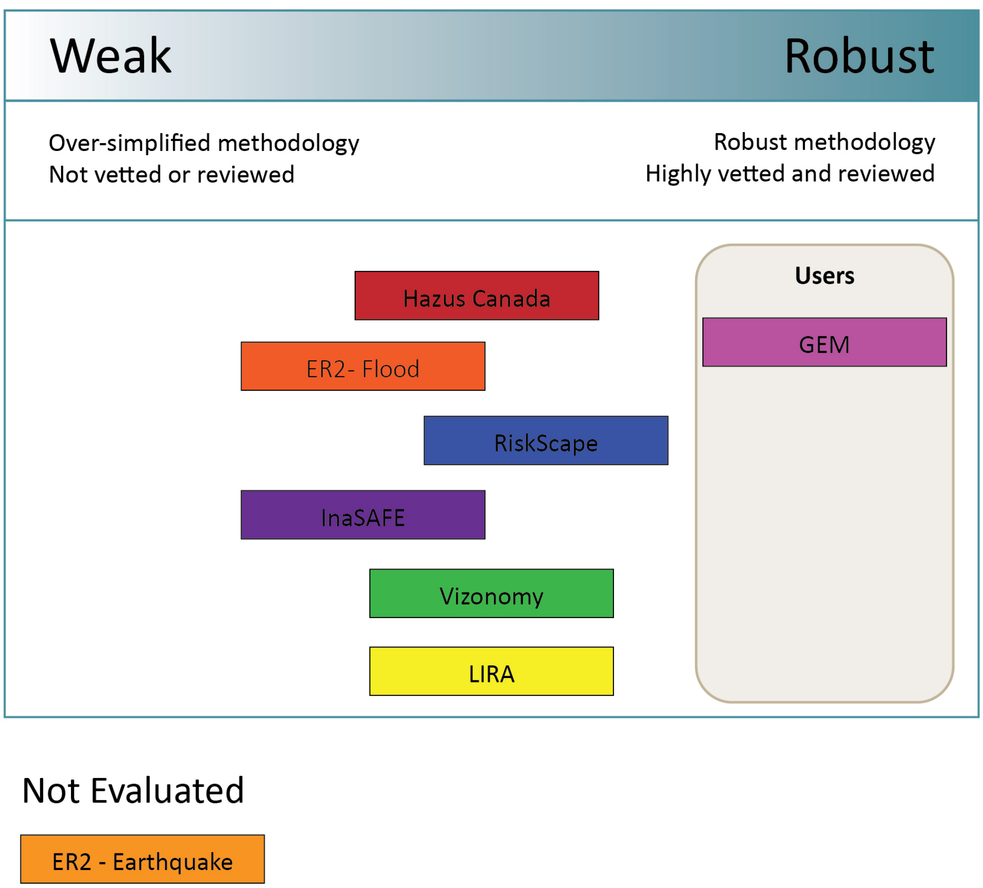


Figure 10: Evaluation of robustness

Most tools fall in the middle of the range, and are neither fully robust nor weak. The GEM model, however, was found to be very robust. The model community used for the development of this tool means that it is based on the best available methods and data, and is continuously validated, reviewed, vetted, and improved.

5.3.1.2 *Spatial Representation of Results*

The ability to map and review risk at a fine scale was considered a top priority for users. A measure of the capacity to produce fine-scale spatial results was therefore included in this assessment. Tools that can, with the right input data, produce risk or consequence assessments at a property level or parcel level were considered to be highly spatial. Whereas, at the other end, tools that have limited or no spatial component were ascribed to the aspatial category (Figure 11). More information on this can also be found in Section 2.

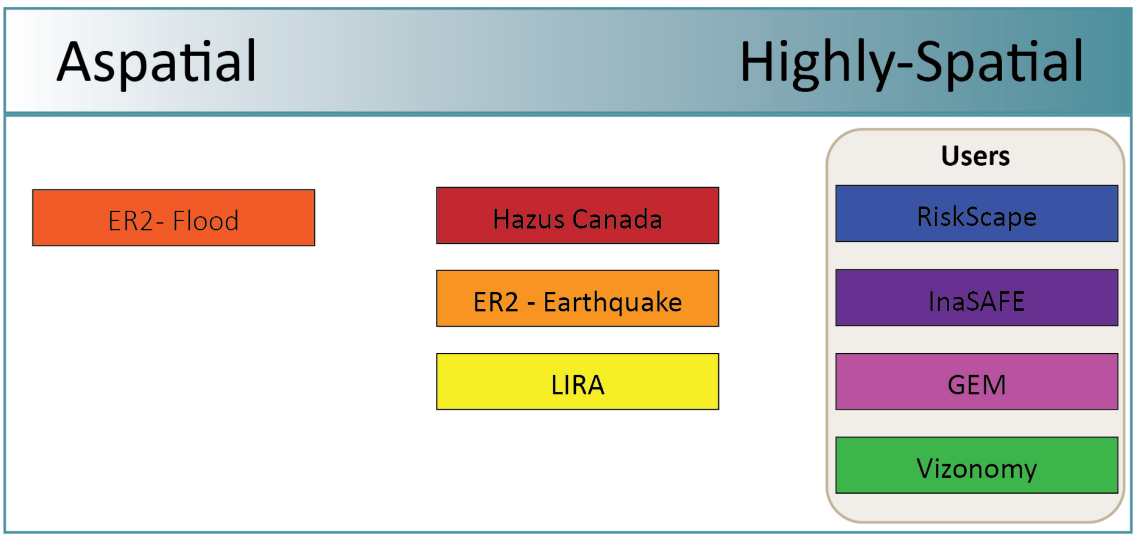


Figure 11: Evaluation of spatial representation

Most of the tools fall under the highly-spatial category, which is to be expected as this is generally considered best practice for quantitative risk assessment. The exceptions to this are the out-of-the box versions of Hazus Canada and ER2-Earthquake, which provide information at a census-tract level. That said, it should be noted that with additional input data they can also become highly spatial. Similarly, the LIRA tool provides information at an agricultural-lot scale, which is arguably an appropriate scale for a tool that focuses on agricultural losses. The existing version of ER2-Flood is effectively aspatial, as it was designed to work in Excel, therefore providing a wide audience access to a loss tool. However, it does provide the ability to view results in a map using a Google Maps plugin.

5.3.1.3 *Hazards Included*

Overall, the users interviewed noted a preference for a multi-hazard tool. However, top-of-mind for most at this time was flood. Table 17 shows which evaluated tools support each hazard.

Table 17: Summary of hazards included in risk assessment tools

	Flood	Hurricane	Winter Storms	Wind Storms	Tornadoes	Coastal Surge/Flooding	Urban Flooding	Groundwater Flooding	Ice-Related Flooding	Debris Flows	Landslides	Forest Fires	Droughts	Earthquakes	Generic Hazard	Multi-Hazard Capabilities
Hazus Canada	x													x		x
ER2-Flood	x															
ER2-Earthquake														x		
LIRA	x															
RiskScape	x			x		x								x	x	
InaSAFE	x			x		x								x	x	x
Vizonomy	x															
GEM														x		

The majority of tools support only one or two *hazards*, mostly flood. However, InaSAFE and RiskScape offer other geohazards as well as the ability to support a generic *hazard.*

5.3.1.4 *Consequences Calculated*

The user-needs interviews showed that the primary concern is for people and critical infrastructure. Other key impacts and consequences that were mentioned were direct damages to buildings and infrastructure as well as indirect economic infrastructure. Table 18 summarizes what type of consequences are calculated within each of the risk assessment tools.

Table 18: Summary of consequences calculated in risk assessment tools

	People: Risk-to-Life	Critical Infrastructure	People: Vulnerable Populations	Economic Impacts: Direct Damages	Economic Impacts: Indirect Damages	Lifelines (including transportation routes)	Communications Infrastructure	Environment
Hazus Canada	*			x	*			
ER2-Flood				x				
ER2-Earthquake	x			x				
LIRA				x		*		x
RiskScape				x	x			
InaSAFE	*	*		*				
Vizonomy	x	x		x		*	*	
GEM/OpenQuake	x	x	x	x	x	x	x	

x = robust methods, * = partial calculation

The GEM/OpenQuake tool comes the closest to meeting the user needs as it makes an effort to look at consequences across a broad spectrum of impacts to people, infrastructure and the economy. LIRA is the only tool that explicitly looks at environmental consequences.

5.3.1.5 *Scenario vs. Cumulative Risk*

The majority of users saw high value in having a tool that could provide cumulative risk information, especially annualized dollar costs; this is very helpful with financial planning. The tools were evaluated based on the direct outputs from the tool, and not on the ability of a professional to manipulate the data to create additional results (i.e., through the post-processing of multiple scenarios).

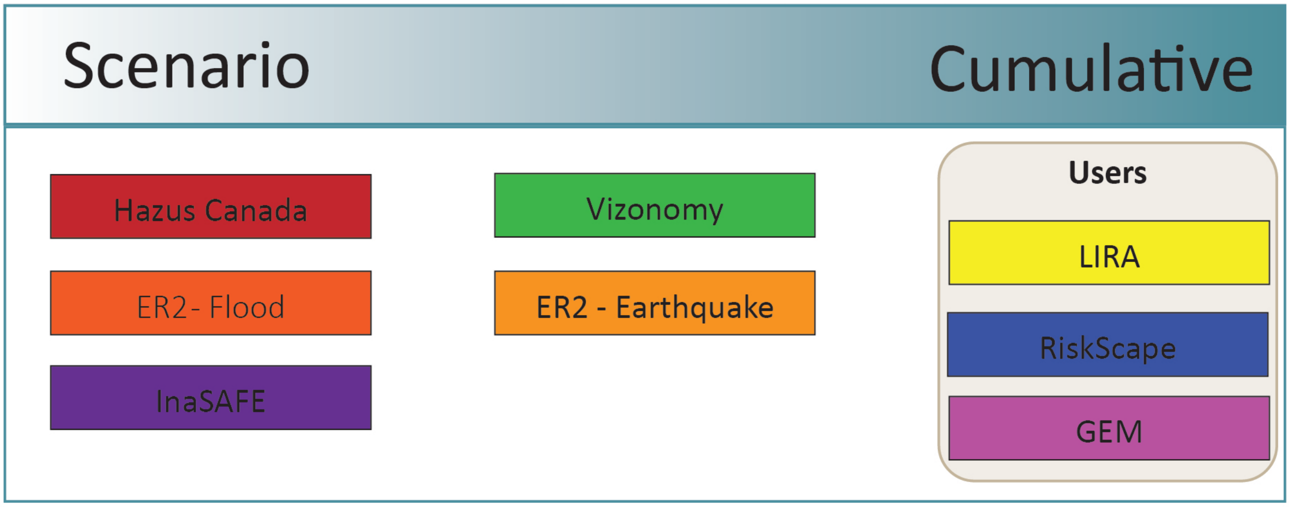


Figure 12: Evaluation of scenario versus cumulative risk calculations

At this time, many tools still fall in the scenario-based (or consequence-based) camp, although some tools provide cumulative risk information, including LIRA, RiskScape, and GEM/OpenQuake. Vizonomy provides annualized dollar losses, but because it is new and has limited documentation on the methods to do this, it has been placed mid-stream. Similarly, ER2-Earthquake also aims to provide some cumulative information, but until it is fully operational it is not clear where it will fall on the spectrum (Figure 12).

5.3.2 Data Requirements

5.3.2.1 *Interoperability*

A key concern highlighted by the user-needs assessment was a desire to have a tool that could seamlessly integrate with existing systems, especially GIS-based operational systems. Table 19 summarizes the input and output formats accepted by each of the programs. Most of the tools accept common GIS and database formats. The exceptions are the 'out-of-the-box' cloud-based tools that do not currently allow for user inputs – these are Vizonomy and ER2-Earthquake. Although, in both cases the developers noted that it would be possible to change the code to allow for user-inputs.

Table 19: Interoperability of data inputs and outputs

	GIS Files (.shp, etc.)	Google Earth files (.kml)	Excel/Spreadsheets (.csv, xls, etc.)
Hazus Canada	x		x
ER2-Flood			x
ER2-Earthquake			
LIRA	x		
RiskScape	x	x	x
InaSAFE	x	x	x
Vizonomy			
GEM/OpenQuake	x	x	x

5.3.2.2 *Ability to Customize*

Many users, especially those who defined themselves as hazard professionals, noted that the ability to customize the tool to their unique community needs was an important component of any future risk assessment tool. This was also highlighted by some of the existing Hazus Canada users; they didn't use the pre-packaged results, and instead used heavily post-processed Hazus outputs as a part of their assessments and reporting.

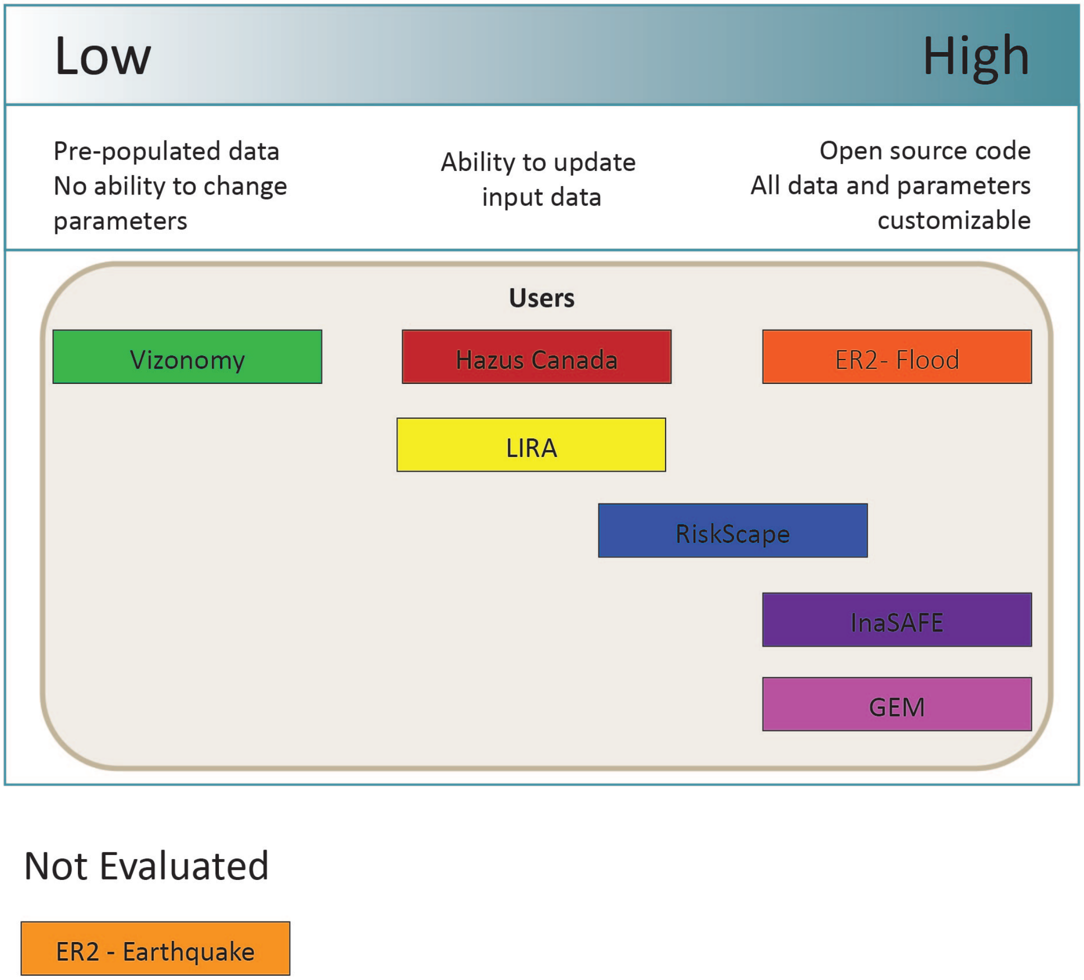


Figure 13: Evaluation of customization

Figure Notes:

1. The current version of Vizonomy requires that the software developer update inventory and hazard data. However, the developer noted that this model is flexible, and that in future it would be possible to allow more user customization.
2. RiskScape has been placed slightly to the left of other highly customizable tools. This is because we were unable to download the tool and did not speak to the developers, and therefore cannot confirm how customizable the tool is. Available documentation suggests that it is relatively customizable.

Most of the evaluated tools are customizable by the end user at least in some capacity. ER2-Flood, InaSAFE, and GEM/OpenQuake are fully open-source and, therefore, are completely customizable from the input data through the modelling algorithms. At the other end, Vizonomy currently requires that the software developers change input data or algorithms (Figure 13).

5.3.2.3 *Ease-of-Use*

As described in the User Needs section (Section 4), most interviewees commented that they needed a tool that is user-friendly. Furthermore, many noted that it was important to have a scalable tool that could be used by lay people as well as subject-matter experts. To this end, the alternative risk assessment tools have been evaluated on their ease-of-use on two measures: the simplicity of the interface and general user-friendliness, and the ability of the tool to function straight out of the box, without any effort to populate datasets or set up the tool for a given area or hazard.

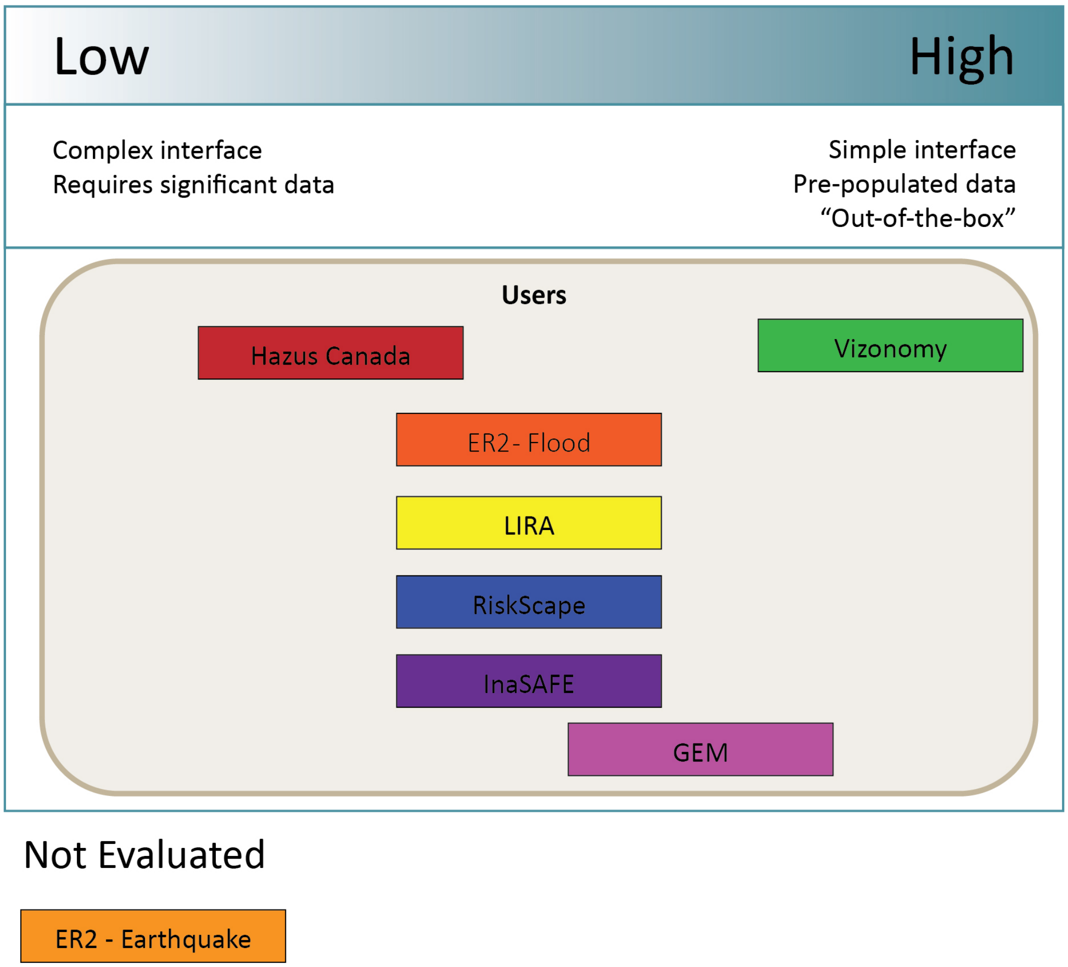


Figure 14: Evaluation of ease-of-use

Most of the tools evaluated fall somewhere in the middle of the constructed scale. Hazus Canada was seen as one of the least user-friendly tools; it has a steep learning curve and requires base knowledge of ArcGIS. At the other end of the spectrum is Vizonomy, an internet browser-based tool that has a well-designed simple interface that is readily useable. ER2-Earthquake was not evaluated in this instance, because the interface portion of the work is not complete. However, should the interface be completed, it will undoubtedly fall at the High end of the scale (Figure 14).

5.3.3 Sustainability/Viability

5.3.3.1 *User Community and Support*

The interviewees and the existing Hazus Canada users both noted the need to have a well-supported tool, either through excellent documentation, good helplines, or alternatively, through an active user community supported with appropriate tools to facilitate intra-user communication. To this end, each of the tools has been evaluated qualitatively on the researchers' understanding of the size of user community, the availability of good documentation (technical and software-related), and the ability to get support from either the software developer or the user community.

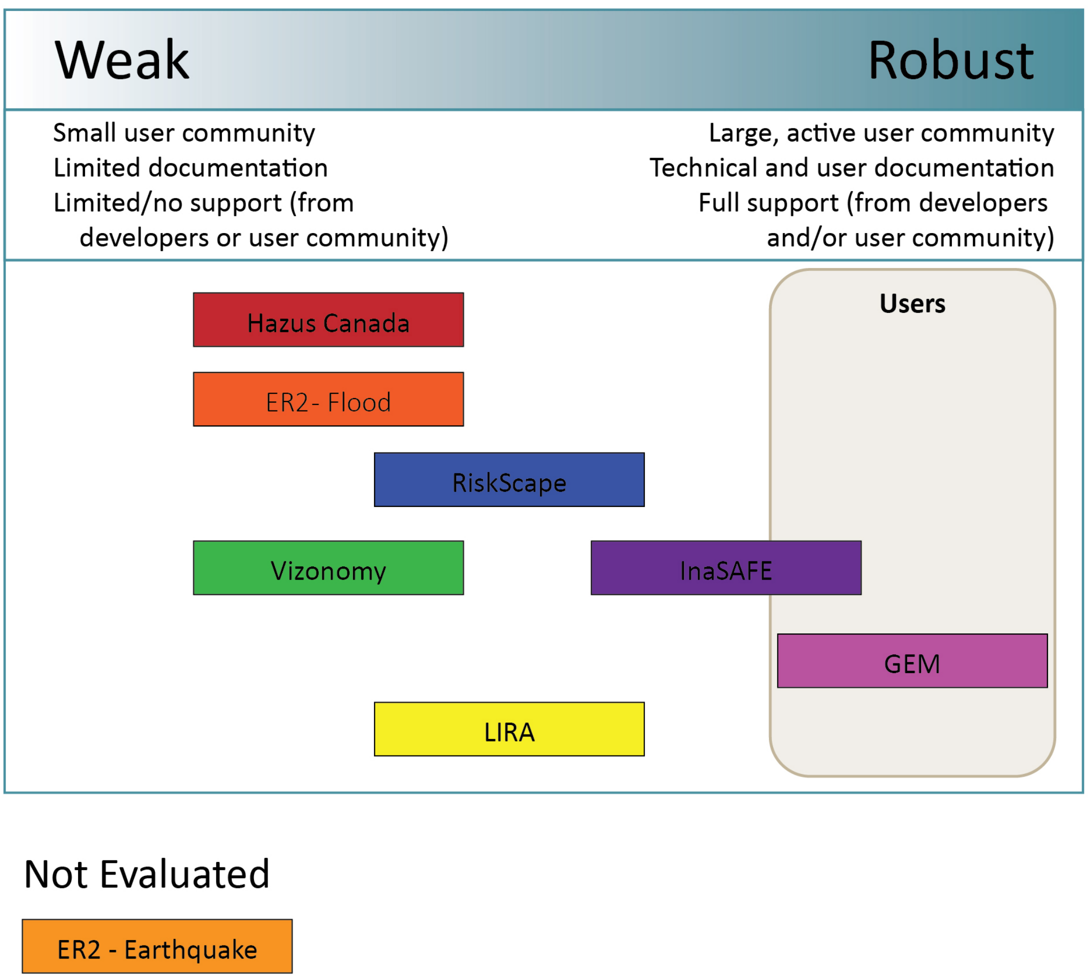


Figure 15: Evaluation of viability

The evaluated tools mostly fall in two camps at either end of the spectrum. Hazus Canada and ER2 are scored poorly, as both are relatively new tools with limited documentation, extremely small user groups, and no online forums for support. It should be noted that over the course of the research, first-step documentation was released for both of these tools, and videos were developed for the ER2-Earthquake tool. Similarly, Vizonomy is a very new tool and does not yet have documentation or a large user community. However, the software developer is readily available to provide support. At the other end of the spectrum are InaSAFE and GEM/OpenQuake, both of which have large user groups and excellent intra-user forums for support.

5.3.3.2 *Software Source*

The interviewees did not indicate any overall preference for whether a risk assessment tool should be open source or proprietary. However, the NRCan project managers did express interest in a tool that is currently open-source and therefore easy to adapt to the Canadian context. Table 20 outlines the software types for each of the evaluated tools.

Table 20: Summary of ownership models

	Software availability
Hazus Canada	Linked to commercial ESRI
ER2-Flood	Free + open-source
ER2-Earthquake	n/k
LIRA	Proprietary
RiskScape	Proprietary, free for academic and government users in New Zealand
InaSAFE	Free + open-source
Vizonomy	Proprietary
GEM/OpenQuake	Open-source, contribution license

5.3.3.3 *Cost*

Cost for the development for each of the evaluated tools was hard to define in the available time for this project; in many cases the researchers were not able to get hard costs from the developers in time. In many instances, the evaluated tools have been in development for many years or even decades and there is no audited data available on the full cost of the programs. Some inferences can however be made. At the cheaper end of the scale, as it benefitted from earlier work, is Vizonomy – it was developed by a small group of coders in less than year. Also at this end of the scale are the two ER2 models as well as LIRA. Hazus Canada (and its parent Hazus) along with RiskScape, GEM/OpenQuake are much larger multi-year (multi-million dollar) programs.

5.4 Summary

Risk assessment is seen as best practice for natural hazard risk mitigation, and as a result there are numerous tools available to help develop risk assessments. Each tool has been developed with a specific audience and user in mind, and so they have wide-ranging capabilities, strengths, and weaknesses. No evaluated tool comes close to meeting all the user needs defined as part of this project. However, most of the tools have a component that is relevant to the Canadian context and could be used as a model for the development of risk assessment tools in Canada. These are explored in the recommendations in Section 6.0.

6 A Way Forward for Risk Assessment in Canada

Quantitative natural hazard risk assessment in Canada is still more of an anomaly than the norm. It is, however, recognized as an incredibly important tool in risk mitigation; a comprehensive risk assessment tool can provide a better understanding of the impacts and consequences of impacts and consequences over time. This type of information is invaluable in understanding the trade-offs between mitigation actions (including no action), and allows for more transparent and robust decision making for risk reduction.

This research project has clearly shown that there is a need for a federally supported program to help lower-level governments prepare and use quantitative risk assessment. However, there is not necessarily a need to support a single risk assessment tool or software, as needs vary widely; hazards, vulnerabilities, and values are ultimately local. Rather, there is a need to create and support the building blocks of natural hazard risk assessment. More specifically:

1. A standardized, complete, and accessible set of hazard maps, starting with flood hazard.
2. A standardized, complete, and accessible set of vulnerability information, collected at a fine (property-level) scale.
3. Locally relevant and up-to-date fragility/damage curves. At first, focused on empirical-based flood damage curves.

There is also a need for a simple, high-level risk assessment tool, which could be used for public education or to prioritize where more fine-scale risk assessments should occur.

Finally and most importantly, there is a need to support the growth of natural hazard risk assessment expertise and capacity across the country.

Specific recommendations for each of these categories are provided below.

6.1 High-Level Risk Assessment Tool

For many, a high-level risk assessment tool is an imperative first step. It can provide sufficient information to help prioritize funding for more detailed risk assessment (or, indeed, the collection of underlying data: flood-mapping, for example). In addition, high-level risk assessment tools can be educational in their own right, especially when used or viewed by the public or non-technical decision makers. There is a lot of value in having an easily accessible, simple, pre-populated risk assessment tool. Specific recommendations to move forward with the idea of a simple high-level risk assessment tool for Canada are outlined in Table 21.

Table 21: Recommendations for high-level risk assessment tool

	Description	Effort/Cost	Priority	Comments
A-1	Development of web-based pre-populated risk assessment for flood.	M	H	Initially, the GC should discuss licensing the Vizonomy software tool for Canada.
A-2	Continued support for ER2-Earthquake tool, specifically the interface.	L	M	Although not currently fully functional, the ER2-Earthquake tool interface appears to be well designed and user-friendly and is a good base for a high-level tool for earthquake risk.
A-3	Explore the use of the insurance industry flood maps as a base for flood hazard in this tool (see A-1).	L	H	The researchers of this report discussed this option with the IBC, who hold one set of flood hazard maps and exposure data. They suggested that this would be possible, but that licensing arrangements would ultimately be required with the data/model owners. Other insurers and re-insurers, such as AIR, hold their own models (http://www.air-worldwide.com/Models/flood/). They should be contacted separately.
A-4	Initially, use GBS and [illegible]	L	M	
A-5	Explore the use of insurance industry exposure databases.	L	H	The researchers of this report discussed this option with the IBC. They suggested that this would be possible, but that licensing arrangements would ultimately be required with the data/model owners.
A-6	Explore the use of internet scraping and citizen science to populate exposure and vulnerability databases.	L	H	See below for examples and resources (Section 6.1.1).

L-Low, M-Medium, H-High

6.1.1 Inspiration for the Future

Although none of the alternative risk assessment tools reviewed fully met the defined user needs, some of the tools contained innovative and useful components that could be used as a base for future work in Canada. In relation to a high-level risk assessment tool the following examples and resources were identified (Table 22).

Table 22: Examples and resources for high-level risk assessment tool

Referenced Recommendation	Concept	Tool(s)	Details
A-6	Connect to Open Street Map or other open datasets.	InaSAFE, Vizonomy	Both InaSAFE and Vizonomy use open-source datasets to populate exposure/ vulnerability databases (building footprints, critical infrastructure, etc.). The InaSAFE tool is open-source (i.e., coding is available).
A-6	Internet scraping for additional vulnerability datasets.	Vizonomy	Vizonomy uses publicly available datasets from government agencies, and residential building values from Zillow (http://www.zillow.com/). Zillow is US-based, but internet scraping of real estate postings/property values could similarly be developed for Canada.
A-1	Simple communication.	Vizonomy	The web application Vizonomy is a well-designed communication tool that allows interactive web-based displays of different scenarios. It allows sharing of (interactive) results online via link or as .pdf maps.

6.2 Standardized, Complete, and Accessible Hazard Mapping

The development of a base of information on the location and severity of natural hazards is a key recommendation of this project. At present, this information is sporadic and inconsistent. For example, it is well known that flood hazard mapping is lacking[20]. Other hazards, like debris flows, are rarely considered at all. It is, therefore, imperative that the knowledge-base around natural hazards is increased. Through the NDMP, the federal government has made some recent progress in this area. Specific recommendations related to the development of standardized, complete, and accessible hazard mapping are outlined in Table 23.

Table 23: Recommendations for standardized, complete, and accessible hazard mapping

	Description	Effort/Cost	Priority	Comments
B-1	Continued support for the development of national flood mapping guidelines.	L	H	
B-2	Support (both financial and capacity-building) for the development of flood hazard maps by P/Ts and local governments.	H	H	
B-3	Continued support for the development of consistent hazard maps for other natural hazards of high concern (earthquakes, forest fires, avalanche).	M	L	
B-4	Research and development support for the scientific understanding of less well-studied hazards (debris flows, pluvial flooding, ice-induced flooding, etc.).	M	L	
B-5	Development of a funding program to allow for event mapping, so that actual events can be properly recorded.	L	H	During a natural hazard event it is common to focus on emergency response. However, the collection of data during the event is invaluable, and should be seen as a priority.
B-6	Development and support for an information management system where maps and metadata can be stored and accessed.	M	H	This recommendation is in alignment with the current draft flood-mapping guidelines, and also aligns with the researchers' understanding of the NEMS project.
B-7	For all hazard mapping, climate change (and, therefore, hazard change) should be considered to at least the year 2100.	L	H	

6.2.1 Inspiration for the Future

Although none of the alternative risk assessment tools reviewed fully met the defined user needs, some of the tools contained innovative and useful components that could be used as a base for future work in Canada. In relation to standardized, complete, and accessible hazard mapping, the following examples and resources were identified (Table 24).

Table 24: Examples and resources for standardized, complete, and accessible hazard mapping

Referenced Recommendation	Concept	Tool(s)	Details
B-5	Mining of social media during/after disaster.	Vizonomy	Automated text and email alerts on upcoming hazard events. Internet-scraping for real-time data (e.g., daily updated satellite imagery), and overlay of probabilistic storm surge scenarios 12 to 24 hours in advance. Feature currently under development.

6.3 Standardized, Complete, and Accessible Exposure and Vulnerability Mapping

The development of a base of information on exposures and vulnerabilities (assets at risk) is a key recommendation of this project. At present, this information is sporadic and inconsistent. The original Hazus Canada program successfully started to develop a comprehensive and consistent database of some key assets at risk (population, global building stock, and base business at a census-tract level). This has successfully been used for regional studies (for multiple local governments), but was critiqued for its lack of usability at a municipal scale, especially in rural areas, and also for the quality of the results it can produce. Other very relevant information, such as the location of critical infrastructure, is often not collated or, alternately, not reported. Furthermore, much of the information that has been used for risk assessment in Canada was not originally designed for this purpose. Instead, data collected for other purposes (tax assessments, business licenses, etc.) are jerry-rigged, and are, therefore, prone to error.

To improve exposure and vulnerability databases that are a key input to risk assessment, the following recommendations are made (Table 25).

Table 25: Recommendations for standardized, complete, and accessible exposure and vulnerability mapping

	Description	Effort/ Cost	Priority	Comments
C-1	Develop guidelines for local and provincial governments on what exposure and vulnerability data they should be collecting for use in risk assessments. This should be focused on fine-scale (property-level) data collection.	L	H	
C-2	Provide examples of how exposure and vulnerability information can be collected at a marginal cost, using existing systems. This should be completed in parallel to C-1.	L	L	The recently completed City of Vancouver Coastal Flood Risk Assessment work included a recommendation that first-floor elevations should be collected as part of any new development permit process. City staff stated that this would not have any associated cost (incurred to the City).
C-3	Support for research and development into tools to aid in the collection of exposure and vulnerability information.	L	H	For example, the Urban RAT and agCapture tools, supported by NRCan, are a starting point for this. Other research priorities should include the development of tools to automatically scrape existing web databases for information for example, building footprints and attributes, or the development of an app to enable citizen science collection of exposure and vulnerability information. See below for additional information (Table 26).
C-4	Develop online information management system to support exposure and vulnerability databases. This should support fine-scale information (to a property level).	M	H	This should be in alignment with other related information management systems such as the National Emergency Management System (NEMS), the proposed flood mapping repository being recommended as part of the National Flood Mapping Guidelines, and the fragility/ damage and risk assessment databases that are also proposed in this document.
C-5	For all exposure and vulnerability databases, future development (to	L	M	This, along with hazard information to the year 2100, will provide a basis for long-range planning.

	Description	Effort/ Cost	Priority	Comments
	the year 2100) should be considered.			
C-6	Continued support for the long-form census.	L	H	The lack of detail in the 2011 census was noted as an issue in the development of robust risk assessments.

6.3.1 Inspiration for the Future

Although none of the alternative risk assessment tools reviewed fully met the defined user needs, some of the tools contained innovative and useful components that could be used as a base for future work in Canada. In relation to standardized, complete, and accessible exposure and vulnerability mapping, the following examples and resources were identified (Table 26).

Table 26: Examples and resources for standardized, complete, and accessible exposure and vulnerability mapping

Referenced Recommendation	Concept	Tool(s)	Details
C-3	Earthquake exposure/ vulnerability data collection tool.	Urban RAT (ER2 project component)	ArcGIS-Google-Android tool developed for rapid building-by-building inventory. Consists of 1) Urban RAT Desktop with ArcGIS with connection to Google Street View to view and enter building characteristics, and 2) Urban Rat Mobile, a digital survey tool (Android App) which supplements the Desktop version to allow rapid entry (i.e., photos) during street surveys. Both components add to common database accessed in ArcGIS (a proprietary software).
C-3	Earthquake exposure/ vulnerability data collection tool.	GEM/ OpenQuake	Open-source suite of tools to generate information and models on inventory , from a) remote sensing, and b) field observations: 1. GEM's Mobile Inventory Data Capture Tool (**IDCT**): Android App, tool for collecting building-inventory data for seismic or multi-hazard risk assessment. Consistent GEM Building Taxonomy exists and is used in most GEM databases.

Referenced Recommendation	Concept	Tool(s)	Details
			2. Building Data Capture application for Android phone or tablet - Windows tool for field data collection and management - Tool to develop homogeneous exposure datasets. The mobile apps directly support crowdsourcing. They facilitate various types of users to combine and share their knowledge on buildings, which is particularly important immediately after an earthquake to understand the damage and to define a plan for rescue, and later for reconstruction.
C-3	Citizen-science asset inventory app.	n/a	A crowdsourcing app for asset/exposure/ vulnerability. Citizens could document their neighbourhood assets (infrastructure, people, and environment) and upload into a national database. In addition to a growing dynamic database, citizen engagement in disaster preparedness would be improved. Especially if the app was tied to schools or other social programs.
C-3	Remote sensing and Internet scraping for building assets.	QGIS/InaSAFE	QGIS has an open-source plugin to extract building footprints from satellite imagery
C-1	Guidelines and protocols for extracting data from remote sensing.	GEM/OpenQuake	GEM/OpenQuake includes protocols and guidelines that help in using tools for extracting data from remote sensing (satellite and other) images. The tools can be used for development of exposure datasets and models at the sub-national level, for exposure dataset development per building, and to capture earthquake consequences per building.

6.4 Locally Relevant and Up-to-Date Fragility/Damage Curves

A key methodological piece in the calculation of impacts and consequences from a natural hazard event are curves or algorithms that can be applied to vulnerabilities for a given event to calculate expected losses. For flood impacts and consequences, these are generally described as damage curves, and for earthquakes, these are called fragility curves. For flood in particular, there is a paucity of information relevant to present-day Canada[21] (also see Appendix A). Lacking any local up-to-date information, flood risk assessments in Canada have relied on curves from FEMA (as used in Hazus Canada), other more generic curves from the Multi-Coloured Manual (UK), or Australian National curves (see Appendix A for more details on the curves and concerns with their use).

To improve the quality and availability of damage and fragility curves, the following recommendations are made (Table 27).

Table 27: Recommendations for the development of locally relevant and up-to-date fragility/damage curves

	Description	Effort/Cost	Priority	Comments
D-1	Allow for the collection of metadata (including spatial attributes) from the Disaster Financial Assistance Arrangements (DFAA) payments to provide information to develop empirical loss curves.	L	H	It is the researchers' understanding that spatial payout information is not collected in some provinces and that, in all provinces, the data is considered to be protected by privacy laws. Information from this dataset could easily be used without impacting personal privacy rights.
D-2	Development of standardized methodology for the Canadian Disaster Database (CDD), which currently lacks consistency.	L	M	The CDD could provide a simple base for empirical event-loss information, while other programs are developed.
D-3	Long-term research funding support for the development of Canada-specific damage and fragility curves for all asset types (first, risk-to-life and critical infrastructure, followed by other social, economic, and environmental impacts).	H	H	Likely through the support of university-led research. Dependent on the development of prioritization program (see next recommendation).
D-4	Development of a long-term program to help prioritize research focus (supported by the federal government).	L	H	Would likely include an in-depth study into priority impacts (could use the outcomes of the user needs in this study as a stepping-stone).

6.4.1 Inspiration for the Future

Although none of the alternative risk assessment tools reviewed fully met the defined user needs, some of the tools contained innovative and useful components that could be used as a base for future work in Canada. In relation to the development of locally relevant and up-to-date fragility/damage curves, the following examples and resources were identified (Table 28).

Table 28: Examples and resources for the development of locally relevant and up-to-date fragility/damage curves

Referenced Recommendation	Concept	Tool (s)	Details
D-3	Social vulnerability and integrated risk plugin.	QGIS/OpenQuake	For creating/editing social indicators and combining these with earthquake risk (i.e., estimates of human or infrastructure loss). QGIS plugin interacts with the OpenQuake platform to download/upload socioeconomic data or existing projects. These tools are of major importance to update and improve the Global Exposure Database and the Global Earthquake Consequences Database, so they continue to increase in value. The tools can combine remote sensing imagery with GEM data and data from users, to develop exposure models as input to advanced risk (loss and damage) modelling with GEM's OpenQuake tools.
D-3 (also C-3)	Citizen-science asset inventory app.	n/a	The development of an app or website, where individuals could enter damages and associated costs for their property, would increase the DFAA database. This might also contribute information on damages for small events, when DFAA information is not collected. Implementation of standards and some measure of quality control would be an important component of this.

6.5 Support for growth of natural hazard risk assessment capacity

Quantitative risk assessment is a relatively new field. This, combined with the fact that that hazard management has been relatively under-resourced in Canada in the last couple of decades, means that there is a capacity deficit in the country. There is a great need to improve this in the near term. The uptake of risk assessment for decision making will not increase unless the knowledge capacity for risk assessment is improved. This could be supported through several mechanisms as outlined in Table 29.

Table 29: Recommendations to increase natural hazard risk assessment capacity in Canada

	Description	Effort/Cost	Priority	Comments
E-1	Support of in-person networking opportunities for risk assessment professionals.	L	H	Financial and in-kind support for networking events. CRHNet annual conference, for example.
E-2	Support for development of online and in-person courses on risk assessment (both the value and the methods).	L	M	This could be done with the support of academia and marketed through regulatory agencies (Engineers Canada for example, which is the overarching body for the P/T associations)
E-3	Develop a web-portal where risk assessment professionals can share and learn.	M	M	The Australian government has recently developed this type of portal[22] although it is not yet widely used. APEGBC*'s School Seismic-Upgrade program[23] is another potential model, where a regulatory body is also involved.
E-4	Promotion of quantitative risk assessment as best practice in natural hazard risk mitigation through the showcasing of best practice.	L	L	For example, the showcasing of best practice cases in NRCan-supported webinars.
E-5	Support for engagement of decision-makers in natural hazard risk assessment	L	H	As per Sendai Priority 3, risk assessment should be the basis for land use and other planning decisions. This will require that decision-makers and their staff understand the value of risk assessment. Using existing networks like the Federation of Canadian Municipalities to showcase examples of best practice in risk assessment

*Association of Professional Engineers and Geoscientists of BBC (APEGBC)

	Description	Effort/Cost	Priority	Comments
				might be one means of achieving this. Examples should showcase how quantitative risk assessment can be used to look at both infrastructure and policy implications to risk mitigation.
E-6	Support for engagement of public in natural hazard risk assessment.	L	H	Public engagement is key to the success of risk mitigation projects that should be based on quantitative risk assessment. Furthermore, the public, through citizen science and crowd sourcing, could add significant value and resources to the underlying datasets used for risk assessment.
E-7	Active financial support for local level governments and P/Ts that embark on risk assessment projects.	H	H	If quantitative risk assessment is to be the norm across Canada, it will take significant financial investment from the federal government. Funding should allow initial studies, and for 5-year reviews and updates as necessary.
E-8	Explore changes to the National Building Code of Canada with the National Research Council of Canada that would require consideration of all-hazards (as opposed to just seismic hazards).	L	L	The seismic requirements of the National Building Code of Canada not only protect public safety, but have also driven research into underlying hazards and vulnerabilities. By extension, updating the code to require an all-hazards approach would likely improve capacity in Canada for risk assessment.

6.5.1 Inspiration for the Future

Although none of the alternative risk assessment tools reviewed fully met the defined user needs, some of the tools contained innovative and useful components that could be used as a base for future work in Canada. In relation to supporting a growth in capacity for natural hazard risk assessment in Canada, the following examples and resources were identified (Table 30).

Table 30: Examples and resources for standardized, complete, and accessible exposure and vulnerability mapping

Referenced Recommendation	Concept	Tool(s)	Details
E-3	Online resources and community support	InaSAFE, GEM	Both InaSAFE and GEM have large active user communities that contribute to the field of natural hazard risk assessment. This is supported through online user-forums, google groups, Facebook groups, blogs, and livechats that enable intra-user support.

6.6 Alignment of NRCan Programs with Related Work Within and Outside the Department

In addition to the recommendations outlined above that aim to improve the adoption and use of quantitative risk assessment in Canada for natural hazards management, the authors would like to note that additional policy work must be completed to ensure alignment of the quantitative risk assessment program with other related programs. For example, it is important to explore the implications of hazard and risk maps prepared for planning and management purposes with those prepared by the insurance industry. Inconsistencies in mapping could lead to problems—where, for example, homeowners are unable to get insurance or mortgages because insurance maps show a property as being high risk, but governments show the property as low risk (and therefore do not protect it).

It is an exciting time with regards to natural hazards and risk, especially for flood, in Canada. There is a great resurgence in capacity and resources at the federal government level. However, given that over the last couple of decades lower-level governments have had the main responsibility for natural hazard risk assessment, it is important to ensure that new programs work within the existing frameworks and that their policy implications are fully thought through.

6.7 Summary

The Government of Canada has recognized that understanding and assessing the hazards and risk posed by natural disasters is the first step in any mitigation plan; these are clear cornerstones of the NDMP and the Sendai Framework. Quantitative risk assessment is seen as best practice in the understanding of natural hazard risk – especially with regards to long-range planning, land use decisions, and infrastructure investments.

There is at present a deficit in capacity for quantitative risk assessment in Canada. This is partly due the lack of underlying datasets that inform quantitative risk assessment, and secondly due to the lack of professional capacity in this area, which stems from not having resourced or regulated risk assessment in Canada for the last couple of decades.

There is also a renewed interest in increasing capacity for risk assessment in Canada as evidenced by the 2015 NDMP. To Canada's advantage, many other nations have made great strides in this area in the last decade. There is now an opportunity for Canada to learn from others and to borrow research and knowledge from these groups.

The recommendations provided in this report are designed to help close the gap in risk assessment capacity in Canada by leaning on tools and research from the other nations. It is hoped that in future, once Canada has rejuvenated its risk assessment sector, that the country can contribute back to the global understanding of disaster risk.

7 Glossary

Term	Definition	Source (if any)
All-Hazards	Referring to the entire spectrum of hazards, whether they are natural or human-induced. **Note:** For example, hazards can stem from geological events, industrial accidents, national security events, or cyber events.	PSC
All-Hazards Approach	An emergency management approach that recognizes that the actions required to mitigate the effects of emergencies are essentially the same, irrespective of the nature of the incident, thereby permitting an optimization of planning, response and support resources.	PSC
Asset-At-Risk	Refers to those things that may be harmed by hazard (e.g., people, houses, buildings, or the environment).	RIBA
Asset Inventory or Database	An inventory of assets-at-risk including the location, and sometimes vulnerability or resiliency measures.	
Critical Infrastructure (CI)	Processes, systems, facilities, technologies, networks, assets, and services essential to the health, safety, security, or economic well-being of Canadians and the effective functioning of government. The ten CI sectors in Canada are: Health; Food; Finance; Water; Information and Communication Technology; Safety; Energy and Utilities; Manufacturing; Government; Transportation.	PSC
Exposure	A measure of the amount of a structure, life, or other asset-at-risk that could be impacted by a potential hazard. Example: parts or all of houses, schools, and livestock on a floodplain are exposed to a potential flood.	
Flooding	Overflowing of water onto land that is normally dry. It may be caused by overtopping or breach of banks or defenses, inadequate or slow drainage of rainfall, underlying groundwater levels, or blocked drains and sewers. It presents a risk only when people and human assets are present in the area where it floods.	RIBA
Frequency	The number of occurrences of an event in a defined period of time.	PSC
Geohazard	A hazard of natural geological or meteorological origin (i.e., this does not include biological hazards).	
Hazard	A potentially damaging physical event, phenomenon, or human activity that may cause the loss of life, injury, property damage, social and economic disruption, or environmental degradation. Hazards can include latent conditions that may represent future threats, and can have different origins: natural (geological, hydrometerorological, and biological) or be induced by human	UN-ISDR

Term	Definition	Source
	processes. Hazards can be single, sequential, or combined in their origin and effects. Each hazard is characterized by its location, intensity, frequency, and probability.	
Hazard Assessment	Acquiring knowledge of the nature, extent, intensity, frequency, and probability of a hazard occurring.	
Hazard Inventory or Database	An inventory of the location, nature, and extent of influence of any potential hazards in an area of concern. Generally compiled as a GIS database.	
Natural Hazard	Natural process or phenomenon that may cause loss of life, injury, other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.	UN-ISDR
Likelihood	A general concept relating to the chance of an event occurring. Likelihood is generally expressed as a probability or a frequency of a hazard of a given magnitude or severity occurring or being exceeded in any given year. It is based on the average frequency estimated, measured, or extrapolated from records over a large number of years, and is usually expressed as the chance of a particular hazard magnitude being exceeded in any one year.	RIBA
Probability	In statistics, a measure of the chance of an event or an incident happening. This is directly related to likelihood.	PSC
Quantitative Risk Assessment	A risk assessment that is completed using quantified or calculated measures of risk.	
Resilience	The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.	UN-ISDR
Risk	The combination of the probability of an event and its negative consequences.	UN-ISDR
Risk Assessment	A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods, and the environment on which they depend. Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards, such as their location, intensity, frequency, and probability; the analysis of exposure and vulnerability, including the physical, social, health, economic, and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities, with respect to likely risk scenarios. This	UN-ISDR

Term	Definition	Source
	series of activities is sometimes known as a risk analysis process.	
Risk Management	The systematic approach and practice of managing uncertainty to minimize potential harm and loss.	UN-ISDR
Vulnerability	The characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard.	UN-ISDR

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Appendix A:

Backgrounder on Risk Assessment Methods for Flood

1. Introduction

Floods matter; they matter a lot. People whose homes are inundated will remember it for the rest of their lives; landscapes are changed forever; regional and national economies suffer. Floods are consistently Canada's most costly natural disaster [1], a recent example being the Southern Alberta floods of 2013 that resulted in approximately $6 billion of direct damages [2], in addition to enormous long-term impacts to the environment and to people. The Federal Government is on the hook for $1.3 billion of Disaster Financial Assistance for this same event [3]. Flooding continues to pose a risk to Canada's economic vitality, infrastructure, environment, and citizens.

It is well-documented that preparation and planning ahead for a disaster will greatly reduce cost and suffering during and after a disaster event [4]. This can be best managed through the development of flood risk assessments and, ultimately, comprehensive flood plans. Understanding and assessing the hazard and risk posed by natural disasters is the first step in any mitigation plan (Figure A-1); risk assessment tools are key components of this.

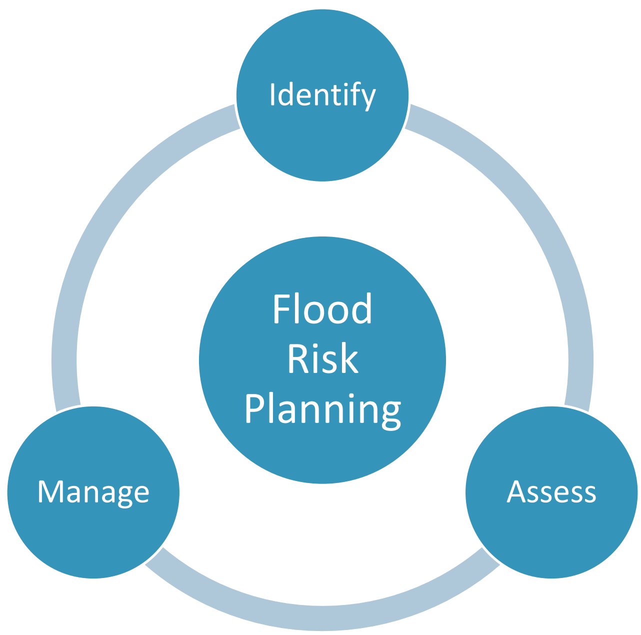

Figure A-1: Flood risk planning process

Flood risk is a function of both the likelihood of an event occurring and the consequences if that event occurs (Figure A-2). Flood consequence is defined as a function of flood hazard (where will the water go?), and vulnerability (what's in the way and how susceptible is it?).

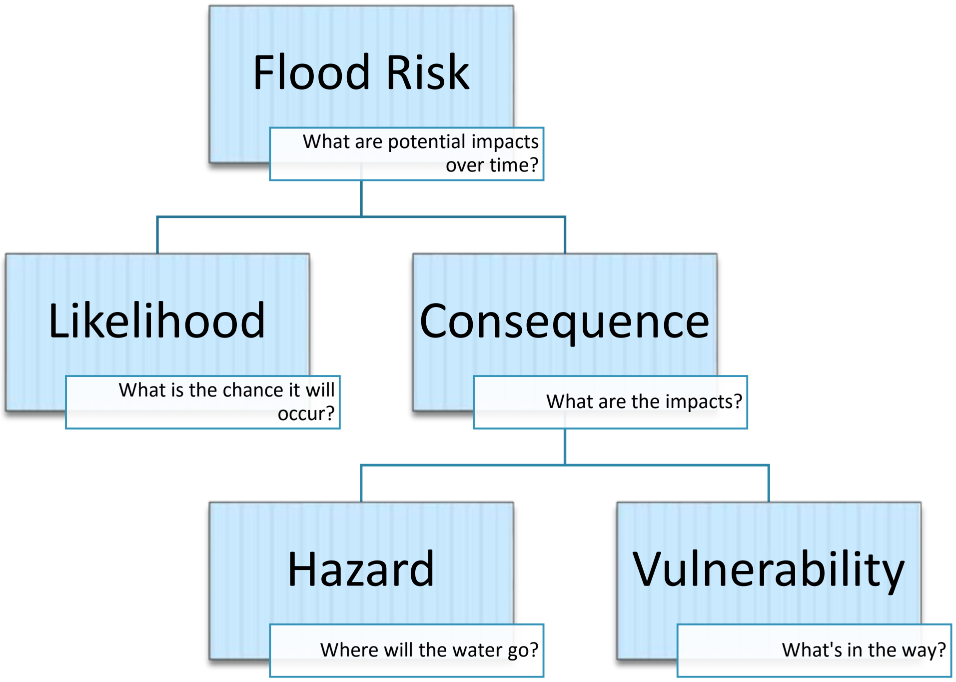

Figure A-2: Flood risk as a function of hazard, likelihood, and vulnerability (after [5])

Figure A-3 shows how risk is a function of both likelihood and consequence, and that risk increases radially across the diagram. A virtually certain but insignificant event can have the same risk as a catastrophic but rare event (Figure A-4). This becomes particularly important as we look across long time-horizons. A nuisance flood that occurs annually over several decades may in fact be more impactful than a catastrophic flood that occurs just once. A risk assessment can be used to compare both the impacts and the potential benefits of mitigation options for the whole spectrum of nuisance to catastrophic events. This provides the best possible tool to make informed investment decisions.

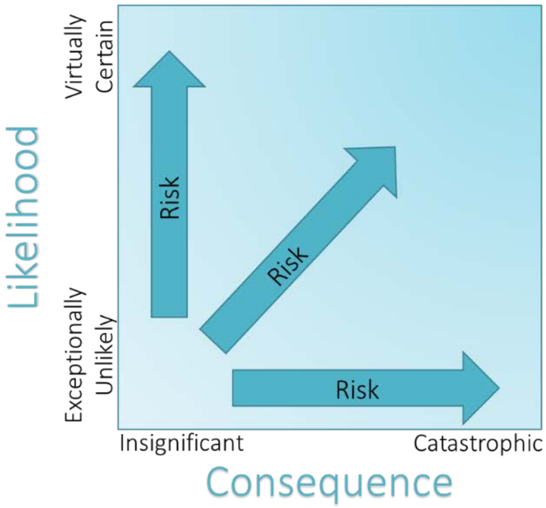

Figure A-3: Risk as a function of likelihood and consequence

Figure A-4: Nuisance and catastrophic flooding

In summary, a true flood risk assessment, one that looks at flood impacts over time, is an invaluable tool for decision makers. It can be used to understand and mitigate present and future flood damages, to create flood management strategies that are both cost-effective and community supported, and to help plan for long-term financial investments in flood mitigation. Furthermore high-level flood risk assessments also create a tool to prioritize projects, given limited funding.

2. Flood Consequences or Impacts Overview

Water on a floodplain itself is not a problem. The impacts of flooding occur when water interacts with natural and human environments in a negative sense, causing damage, disruption, and occasionally death. The impacts of a flood event are varied, and can be described in many ways. Some basic background into the topic of flood impacts is presented below. Detailed information on the calculation of direct damages and losses to building stock through the use of depth-damage curves is also presented below.

2.1 Flood Impact Typologies

The source-pathway-receptor model is a common method of looking a flood risk, where the impacts are defined by the "receptors" or elements at risk on a floodplain [6,7]. In the model used in the main report, this is also described as *Exposure*. These include people, buildings/infrastructure, natural environments, and the economies that link them (Figure A-5). These groupings are one means of considering and organising flood consequences for practical reporting, however it must be noted that there are many linkages and common elements between these groups.

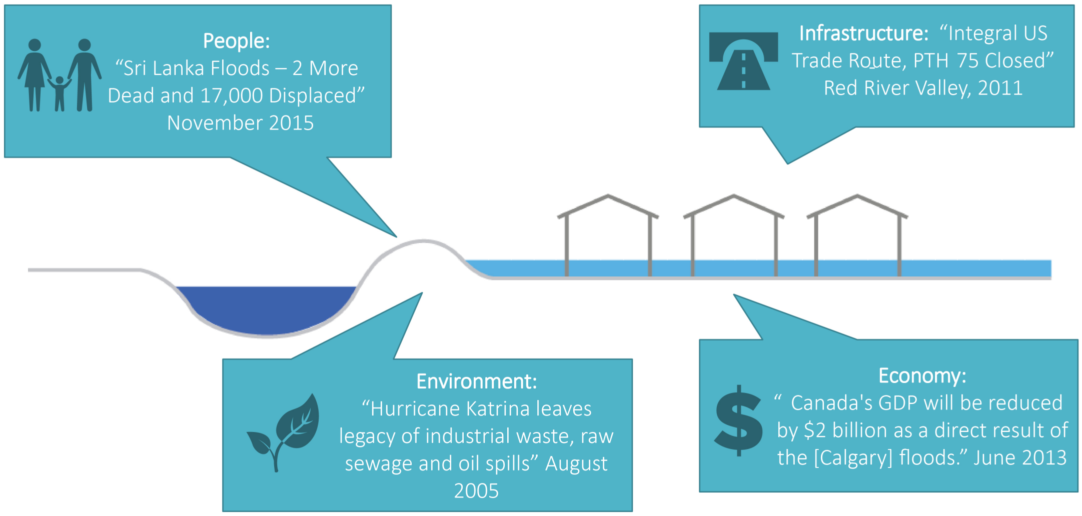

Figure A-5: Flood impacts by receptor

2.1.1 Direct and Indirect Flood Impacts (or Consequences)

Flood impacts can be further divided into direct and indirect impacts. **Direct** impacts describe all harm that relates to the immediate physical contact of water to people, infrastructure, and the environment. Examples include damage to buildings, impacts to building contents and other assets, damage to the environment, and loss of human life. Whereas, **indirect** impacts are those caused by the disruption of the physical and economic links in the region, as well as the costs associated with the emergency response to a flood. For example, business losses because of interruption of normal activities, or costs associated with traffic disruption when roads are impassable.

2.1.1 Flood Impacts (or Consequences) by Tangibility

The effect of a flood on the environment, human or community health, or the loss of life are difficult to quantify, and are therefore considered to be **intangible** impacts. On the other hand, the **tangible** dollar losses from a damaged building or ruined inventory in a warehouse are more easily calculated. This does not mean that tangible losses are more important than the intangibles, just that they are easier to quantify and assess. However, the inclusion of intangible impacts is desirable for the development of a robust flood risk assessment [6]. Table A-1 provides examples of direct/indirect and tangible/intangible impact typologies.

Table A-1: Examples of flood impact typologies

Form of Damage/Measurement	Tangible	Intangible
Direct	• Building damage • Infrastructure damage • Content/inventory damage	• Loss of life • Health effects • Loss of habitat and environment
Indirect	• Loss of industrial production • Traffic disruption • Emergency response costs	• Inconvenience of post-flood recovery • Increased vulnerability of survivors

Source: [6]

As we transition from a standards-based approach to flood planning and damage mitigation to a more holistic risk-based approach, there has been a significant increase in the knowledge base around flood consequences. The impacts of flooding are widespread and affect people, infrastructure, the economy, and the environment. Flood damage estimation, however, has traditionally been the domain of engineers and, as such, has focused on economic valuation of infrastructure and building losses, leaving a large gap in knowledge [8]. This gap has increasingly been acknowledged, but there is still very limited validated research available, and tools to look at intangible impacts are largely undeveloped. However, it is known that when damages are monetized, buildings become priorities for flood mitigation, whereas when damage is expressed as the number of people affected by a flood (through stress or inconvenience), road flooding and resultant damage/closures become a mitigation priority [9]. The metrics chosen for assessing flood damage can deeply affect subsequent planning decisions. In effect, the non-inclusion of intangible impacts can affect priorities. There is promising new research into methods that take intangible effects into consideration, including these methods [10]:

- revealed preferences
- stated preferences

- benefit/value transfer
- hedonic pricing
- replacement cost
- choice modelling of life satisfaction

3. Calculating Flood Impacts Overview

Estimates of potential flood impacts are an essential piece of a flood risk assessment (see Figure 2). A general approach to estimating flood impacts is to first assess potential flood damages to the various elements at risk: people, infrastructure, the environment, and the economy. This is done with knowledge of the hazard (where is the water, how deep is the water, and sometimes what is the velocity and/or salinity of the water) in combination with knowledge of the elements at risk on the floodplain (an asset or exposure inventory). A flood damage methodology is then applied to these two data sets to produce damages and, ultimately, losses.

For example, building damage is by far the easiest to quantify (it is a direct tangible impact), and is commonly calculated as a percent of damage to a structure based on information about the structure and the level of hazard at that structure. This, in turn, is translated into a cost or loss by considering the amount of money or other resources required to repair, rebuild, replace, or move the damaged structure (Figure A-6). Similar, although more subtle, calculations can be made to look at damages and losses to people, the environment, and the economy; these calculations tend to be more difficult as the impacts are either indirect or intangible. At present, the tools to calculate the indirect or intangible impacts are not well-developed in the field of flood risk management [8,9] (see also section 2.1.2).

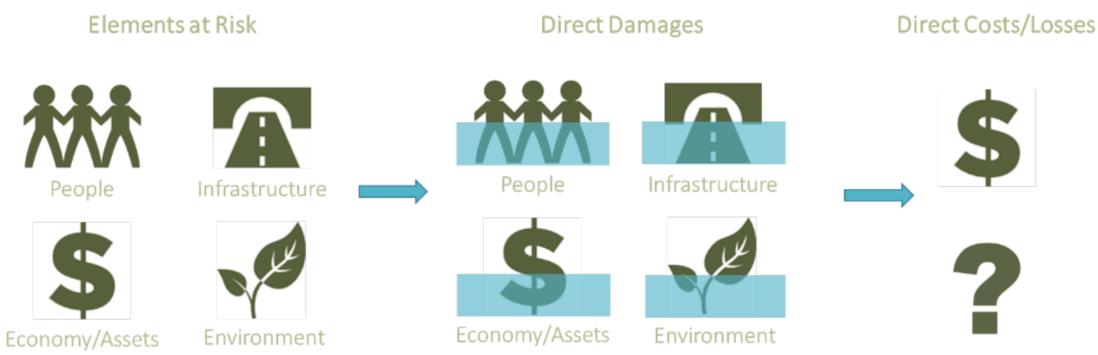

Figure A-6: Estimating flood impacts

There is a spectrum of methods available to calculate flood damages and losses. And, the choice of method should be based on the overall objective of the study. For example, at a fine scale, an insurance company needs to know the likelihood of damage and loss to a single home that is seeking insurance. At the other end of the spectrum, federal governments need information to help them prioritize the expenditure of resources and dollars. In the middle, provincial and territorial governments have the authority and responsibility to make land-use regulations, as well as consider structural flood management (e.g., dikes). Each of these players will require different information, which points to a different methodology for flood risk assessment.

Three general approaches are described in Table A-2, and further details are provided below. **Object-oriented approaches**, refer to the fine-scale, individual building approach to assessing flood damages. At a slightly larger scale, **aggregate-oriented approaches** refer to block-level assessments, where broad assumptions are made regarding the building stock within a given area (e.g., 30% of the buildings are single-storey and constructed of wood), which are used to calculate damages and, ultimately, losses. At the furthest extreme, **high-level (probable maximum loss) approaches** estimate losses from natural hazards at a provincial, or even a national, scale. See also Figure 5 in the main document.

Table A-2: Spectrum of methods to calculate flood losses

Approach	Object-Oriented	Aggregate-Oriented	High-Level (Probable Maximum Loss)
Scale	Fine (individual building level)	Medium (city block or neighbourhood level)	Large (city or regional level)
Users	City and regional officials (planners and engineers), insurers, resilient (flood-proof) home builders	P/T and federal officials (planners and engineers)	Re-insurers and federal government
Data Requirements	High (e.g., detailed spatial hazard and asset information, site-specific damage curves)	Medium (e.g., broad spatial hazard and asset information, synthetic damage curves)	Low (e.g., historical flood losses, inflation rates, and demographic trends)
Outputs	Building-scale information that can be aggregated to provide spatial damage and loss information	Broad–base spatial damage and loss information	Regional scale, effectively non-spatial, total losses (no damage)

The choice of methodology will depend on the desired outcomes of the research, the perceived vulnerability of the area to be assessed, the amount of resources available to conduct the work, and finally by the available data. For example, there is no point conducting a fine-scale study if there isn't good information about individual building materials, size, age, elevation, etc. Furthermore, developing site-specific damage curves for use in an object-oriented model is a resource-intensive exercise, requiring extensive data and diverse expertise. Modern databases of these curves (see Table A-3 below) are generally compiled over many years by national bodies with large budgets; these also often involve significant academic input.

4. Calculating Direct Damages Using Object-Oriented and Aggregate-Oriented Approaches

The estimation of flood damages to the various receptor groups (people, infrastructure, the environment, and the economy) is a complex process that involves a large number of hydraulic, engineering, and socio-economic factors. The estimation of economic flood damages is gaining importance in the world of flood management as flood risk assessment is adopted as the preferred method for flood planning around the world. Despite the efforts made to date on the calculation of flood damages, it is known that there are still many gaps [11]. This is in part because of limitations in available data and knowledge about flood damage mechanisms. As a further constraint, the models and information available are not considered robust, as, unfortunately, flood damage model validation is rarely performed [12].

The lack of progress in the estimation of flood damages is due in part to the many parameters that contribute to flood damages. These include water depth [13,14], velocity [15–17], wave action [18], flood duration [19], and contamination, sediment, or debris load [17,18]. Furthermore, building construction type and age can influence damage [20]. Further examples of less tangible factors, such as warning time and human behaviour, can be found in the literature. Despite the enormous number of factors that play a role in building damages, only flood depth has been widely studied and used in flood risk assessment [11,15,17]. In the last couple of years, alternatives to this approach have been explored such as the use of data-mined multi-variate damage models, which are derived from large datasets of damaged buildings [21]. For the moment, this approach is the domain of researchers and has not yet been widely applied as a tool for flood damage estimation.

4.1 Depth-Damage Curves

The most common and internationally accepted method of estimation for direct flood damage to building-scale infrastructure is the application of depth-damage curves (Figure A-7). Damage to a building is based on stage elevation (i.e., water depth) as a percentage of damage or as a loss to the structure or contents. Depth-damage curves can be developed from empirical data following a flood event; these curves are based on data from a specific location and flood event, and are therefore not easily transferable. Or, as an alternative, synthetic depth-damage curves from a broader base of information have also been developed; these tend to be more transferable and more accurate at an aggregate level, but less robust when considering single-building losses [13,17].

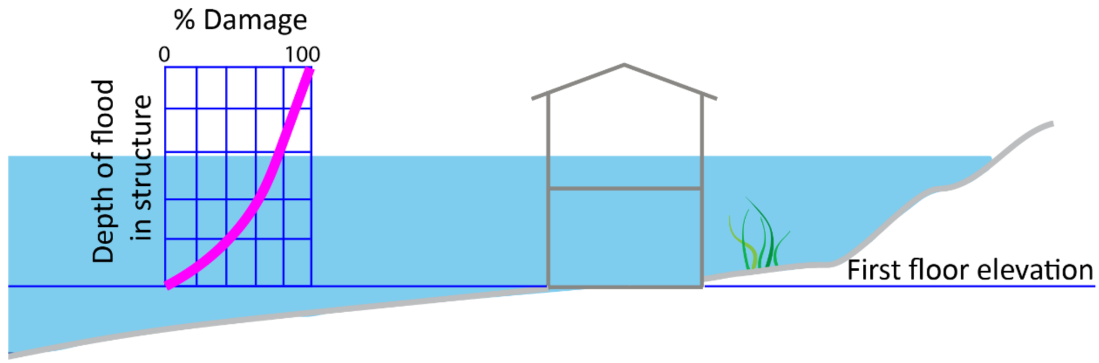

Figure A-7: Schematic representation of a depth-damage curve (after [22])

4.1.1 Uncertainty and Sensitivity in Stage-Damage Curves

Stage-damage curves are a key component of flood consequence modelling. Research has shown that along with information about the assets that depth-damage curves are the most important source of uncertainty in consequence modelling [23,24] , and can affect the end results by a factor of 2 [25]. It is therefore extremely important that care and attention is paid to the applicability and robustness of the stage-damage curves for a given flood consequence model. Specific issues include: the transferability of stage-damage curves, errors in stage-damage curves for shallow depths of flood, and the omission of velocity and waves from the default curves. More details are provided below.

4.1.1.1 Transferability of Stage-Damage Curves

It is well known that stage-damage curves are inherently uncertain, but continue to be used as they are the best available tool for fine-scale flood consequence assessments. One major issue is the paucity of available stage-damage curves; there are only half a dozen or so publically available datasets worldwide, and no recent generic curves for Canada at all. As such, these datasets tend to be broadly used without full consideration of the applicability and transferability of these functions to a new geographical region or time. Recent research has shown that stage-damage curves are not directly transferable, and that care should be taken to at least select curves from related regions with similar flood and building characteristics [26]. Across Canada, there is considerable variation in both the built environment (the assets) and flood hydraulics (the hazards), and a single set of curves is unlikely to be applicable across the whole country.

4.1.1.2 Information Gap for Stage-Damage Curves for Industry and Commercial Sector

A large number of the flood hazard areas in Canada are industrial zones, and therefore many industries are at risk. There is very limited information available on stage-damage functions for industry, this is mostly due to the variation in industry [27]. Inventory (content) losses in Hazus, a FEMA risk assessment tool, are generally assumed to be 100% the value of the building [28]. This may be true of some traditional manufacturing businesses, but is unlikely to reflect the potential losses from a high-tech industrial plant. Research has shown that the only reliable way to estimate losses from industrial areas is to establish, on a case-by-case basis, what is housed in industrial buildings on the floodplain, which would take a large amount of effort. Similarly, there is limited information on commercial losses—Hazus uses the same approach for both industry and commerce, and assumes the damage of inventory is directly correlated to the value of the building. Some research has recently been conducted on commercial losses [29], which again shows that considerable effort should be taken to look at local circumstances.

4.1.1.3 Uncertainty in Use of Stage-Damage Curves for Shallow Depths

Furthermore, it is known that available stage-damage curves are not applicable for shallow flood depths, and tend to underestimate damages and losses [30,31].

4.1.1.4 Omission of Velocity from Damage Curves

Velocity is known to be a key factor in the damage of buildings in a flood, however few empirical databases exist that describe expected damages under a combination of depths and velocities [15,17]. And, no velocity is used in the default Hazus curves at this time that are being widely used in Canada. The literature[32] has also suggested that this may not be an oversimplification for damage to buildings but that there is no argument that road damage is always known to be highly sensitive to velocity. Road damage is not currently considered in Hazus. Very new research into velocity-induced damages is being conducted in Europe [18] and may eventually be incorporated into Hazus. In the meantime, it is important to consider that Hazus likely underestimates damage.

4.1.1.5 Lack of Understanding of Surge Flood Damages vs. Slow-Rise Riverine Flood Damages

As mentioned above, the majority of research into flood damages has been conducted for instances of riverine flooding, where the mechanism of flooding tends to be slower and lower-energy than for coastal flooding. Recent studies have shown that the time-to-peak plays a significant role in flood damages [18]. For example, damage resulting from a coastal storm surge, tsunami, or dike breach could be 40% higher than for the same building with the same depth of water from a slowly increasing river flood.

Depth-damage curves, being the most common method of assessing direct damages to building stock, have been developed at various times by various groups (Table 3). The grounding for much of this work was conducted at the University of Waterloo in the 1980s. However, limited progress for Canadian-context curves has been made since this time, with the exception of directly-applied (not synthetic) curves that have been developed for the Red River Valley [33] and the St. Lawrence Valley[34], and most recently for downtown Calgary[35], which also include multipliers for other areas in Alberta. Fortunately, research has continued outside Canada over this period in the European Union, the United States, and Australia. Some of these curves are applicable to Canadian building stock, although many are not directly transferable.

Table A-3: Sample databases for depth-damage curves

Model/Database	Origin	References
HAZUS/FIA	US	22,28
FLEMO	Germany	11,21,23–25,29,30,36–38
HOWAS	Germany	6,10,24
ANUFlood	Australia	17
Multi-Coloured Manual	UK	http://www.mcm-online.co.uk/

"Standard Method"	Netherlands	[39,40]
FDRP Era (1970s and 1980s) Curves	Canada	[13]
Red River Curves from 1997 event	Canada (Manitoba)	[33]
Saint–Laurent Valley Curves	Canada (Québec)	[34]
GOA	Canada (Alberta)	[35]

4.2 Asset Inventory for Object-Oriented Damage Assessment

Depth-damage (or multi-variate-damage) curves are only one component of a damage assessment. Knowledge of the elements at risk (vulnerable assets) on the floodplain is also required (Figure 6). For an object-oriented approach, this needs to be information about individual buildings, and at a minimum requires location data, building structure information (size, dominant building material, presence/absence of basements, age, etc.), and value information. A basic approach to collecting this information, as used recently by the City of Vancouver [41,42] is presented in Figure A-8 and detailed below.

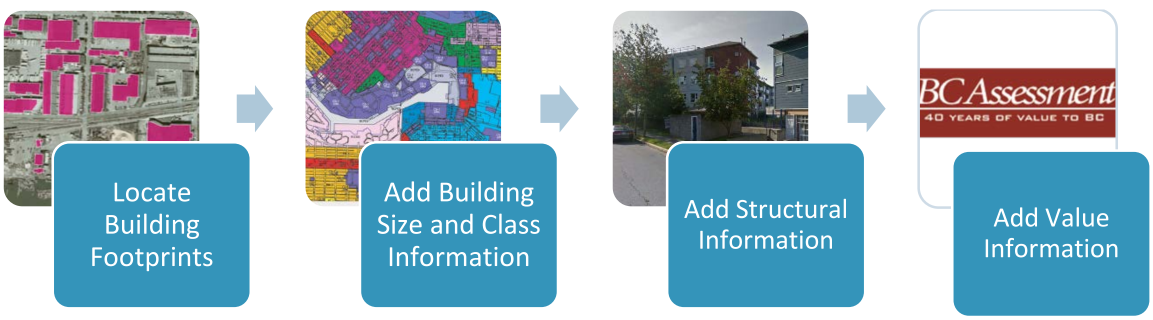

Figure A-8: Summary of object-oriented database development process

1. **Locate Building Footprints**: A LiDAR-based dataset of building footprints was used as a base. In order to update footprint information to reflect new development and demolitions since the LiDAR was flown, the City development permit database was used to identify changes, and new footprints were developed from orthophotos.
2. **Building Size and Class**: Building size was derived directly from the footprint information, and building class was determined from a combination of pictometry images, Google Streetview, zoning, and generalized land use.
3. **Structural Information**: Base elevation was determined from LiDAR for lands neighbouring the footprint. First storey height and presence/absence of a basement was then determined as function of the base elevation, pictometry, oblique images, Google Streetview, and familiarity with generalized land use. Building construction type was established in a similar manner.

4. **Value Information**: Building value (not land value) information was determined using BC Assessment data.

The development of an object-oriented asset inventory is a resource-intense exercise. For the City of Vancouver, this took several months of full-time work.

4.3 Asset Inventory for Aggregate-Oriented Damage Assessment

An aggregate building stock inventory requires less effort than an object-oriented database. In this instance, global building stock, which generalizes building features over a given area, is used. Through its Hazus Canada program, Natural Resources Canada has expended significant effort over the last few years to develop a nation-wide global building stock (GBS) database. This provides GBS information at the census-dissemination block level (the size of an average city block in urban areas, and up to many square kilometres in rural areas).

5. Calculating Direct Losses for Object-Oriented Approaches

Direct damage estimates are useful for planning and mitigation projects, but losses—often dollar losses—can be a more effective tool for communication. Therefore, losses are often calculated as a function of damage and asset values. Commonly in flood risk assessments direct losses are monetary representations of the cost to repair or rebuild. Direct losses may also be calculated for social indicators, specifically loss of life.

Most flood consequence models use flood damage information in conjunction with value information for floodplain assets to derive a loss. For example, a $150,000 residence that has 10% damage will be reported as a $15,000 loss, and other losses for the contents of the building may also be added to the total loss calculation. Loss calculations are therefore highly dependent on the damage curves and on the assessed values of the building stock.

6. Calculating Direct Damages and Losses with a High-Level (or Probable Maximum Loss) Approach

Probable maximum loss scenarios are generally used by the re-insurance industry to gain an understanding of the worst-case scenario for natural disasters. Probable maximum losses (PMLs) are generally generated based on global loss statistics, historic loss information, and general economic and demographic trends. SwissRe, a re-insurer, calculated a PML for Southern Alberta of $0.6–1.0 billion for insurable flood damages[1]. In the wake of the 2013 floods, this has been shown to be an underestimate. However, the 2013 floods are now a valuable data point that could be used to refine this work.

7. Closing

Flood risk assessments are an invaluable tool for flood risk mitigation and resource planning, and are considered best practice around the world. However, they do require significant resources to develop. There is generally a paucity of data in Canada to complete flood risk assessments, and there is also a poor understanding of the uncertainties associated with the methods. With increased investment in the building blocks of risk assessment, as well as a concerted effort to increase professional capacity, Canada can be a leader in this area again.

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Appendix B:

Semi-Structured Interview Questions for User Needs Assessment

Questions related to user:

1. Who are you? Who do you work for? (Level of government, private practitioner – who are your clients?) What is your role/title? (Decision-maker, planner, engineer, etc.)
2. Do you make direct decisions based on risk-assessment outputs?
3. Do you provide information to decision-makers on natural hazard risk?
4. What is your role if you don't fit the questions above?

Questions related to risk assessment needs:

5. What types of hazard do you need to mitigate in your jurisdiction? (Earthquake, Flood, Tsunami, Hurricane, Fire, etc.)
6. What types of impacts do you think are the most important to quantify/understand so that you can make decisions or help decision makers mitigate risk? (People, Environment, Infrastructure – including building damages, Economy – direct and indirect losses, Other)
7. Would your decision benefit from having probabilistic (cumulative) risk information, or is a scenario-based risk assessment be adequate?
8. What level of detail is required for you to do your job well? High-level non-spatial, High-level spatial information, detailed non-spatial (i.e. tabulated $/# amounts for various events), detailed spatial?
9. Would you like to see a tool that provides additional information on mitigation measures?

Questions related to software platform:

10. Where would you look to find a natural hazard risk assessment software? What would be required to assure you that a software is credible and authoritative?
11. Is it important to you that software for risk assessment is easily accessible? How would cost play into your decision to use a particular software? Does it need to run on a readily available open-source platform?
12. Recognising that simplicity in use can lead to simplicity in outputs, how simple/useable should a risk assessment tool be? How simple/useable would you like a software for risk assessment to be? What level of technical understanding would an average user in your organization have?
13. Do you have GIS support at your organization? What level or technical understanding in the use of geospatial software would an average user in your organization have?

Closing:

14. Are you a Hazus Canada user? If so, can we contact you again when we get to the next stage of this project (in 2-3 weeks)?
15. Do you know of anyone else inside or outside of your organization that we should speak to?
16. Is there anything else you'd like to tell us?

Appendix C:

Complete List of Risk Assessment Tools Reviewed

Software name, website & developers	Short description	Reason not evaluated
3Di Flood Deltares, TU Delft, Netherlands http://www.3di.nu/international/	Three-dimensional hydraulic modelling software	Hazard modelling, no risk component
AHRA (All-Hazards Risk Assessment) Public Safety Canada https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/mrgnc-prprdnss/ll-hzrds-rsk-ssssmnt-eng.aspx	Protocol for identifying, analyzing and prioritizing threats and mitigating risks in a standardized way. Includes natural hazards (earthquakes, floods), as well as chemical, biological, radiological, nuclear and explosive hazards, both non-malicious and malicious threats. Includes a scenario-based risk assessment approach (high-level perspective). AHRA tool prototype, to help users define and score potential hazards or threats across different categories of impacts (people, economy, environment, territorial security, Canada's Reputation and Influence, Society & Psycho-Social, and Critical Infrastructure), and determine the likelihood of the event occurring with a 5-year timeframe. Initially: Excel program with step-by-step prompts, second version: fully automated and online capable solution using Microsoft Sharepoint as enabling platform.[1,2]	Not a quantitative risk assessment software (qualitative), focus on emergency response management, not emergency planning
The Awareness and preparedness for emergencies at local level (APELL) United Nations Environment Programme, Division of Technology, Industry, and Economics	Focus mostly on addressing industrial accidents, not natural hazards. Handbook to assist decision-makers and technical personnel in improving awareness of facilities and chemical handling operations (such as factories, warehouses, ports and others, as well as transportation), with risk of chemical releases. Focus on planning process.[3]	Focus on industrial accidents
Austria: Flood risk maps Wasser Information System Austria (WISA) http://wisa.bmlfuw.gv.at/wasserkarten/hochwasser/risikokarte.html	Risk maps (including critical services, population at risk, etc.) available for all of Austria. But not possible to calculate/update/change assets themselves. Maps all ready and presented online for download.	Not a quantitative risk assessment tool
BfG ESRI Germany Bundesanstalt für Gewässerkunde (BfG) http://geoportal.bafg.de/mapapps/resources/apps/HWRMRL-DE/index.html?lang=de	Online freely available interactive flood map database for all of Germany.	Not a quantitative risk assessment tool

Software name, website & developers	Short description	Reason not evaluated
Catastrophe Models for Risk Appraisal (CAT) For instance, developed and used by: Risk Management Solutions, (RMS, 2016): http://www.rms.com/ AIR Worldwide [5]: AIR MODEL. http://www.air-worldwide.com/	A range of CAT models exist by different catastrophe risk modeling companies The focus of the software tools is on analyzing the probability of economic losses due to catastrophic events for insurance purposes. AIR MODEL: Probabilistic models for assessing financial impacts of catastrophes.	Focus on analyzing the probability of economic loss for insurance purposes. Proprietary software that is not available for independent use.
CAPRA (Central American Probabilistic Risk Assessment) Center for Coordination of Natural Disaster Prevention in Central America (CEPREDENAC), the United Nations International Strategy for Disaster Reduction (UN ISDR), the Inter-American Development Bank (IADB) and The World Bank. http://www.ecapra.org/	CAPRA is an open-source natural hazard and risk assessment software that allows probabilistic risk analysis (includes graphical user interface). It is mostly used and developed in Latin America. It consists of different software modules (hazard, vulnerability and exposure) that can be combined. It also includes an in-built GIS. Multiple hazards (earthquake, flood, hurricane, volcanic and secondary hazards such as landslides can be assessed.	Software development and support discontinued, no further updates anymore.
Digital Coast National Oceanic and Atmospheric Administration, U.S. Dept of Commerce https://coast.noaa.gov/digitalcoast/	Website for integrating resources on coastal management for communities. Refers to many different resources, for instances: CanVis (for visualizing impacts of future management decisions); Coastal Change Hazards Portal (interactive acces to coastal change science and data); Coastal Flood Exposure Mapper; Coastal Resilience 2.0 (framework for decision support); Data Access Viewer; and many more	Not a spatial quantitative risk assessment tool
Disaster Risk Index (DRI) Developed by: UNEP/GRID-Europe (United Nations Development Programme) http://www.nat-hazards-earth-syst-sci.net/9/1149/2009/nhess-9-1149-2009.pdf	Global scale, model for factors influencing levels of human losses from natural hazards (1980-2000). Assessing what countries are most at risk, four hazards (droughts, floods, cyclones & earthquakes) modeled with GIS & overlaid with population exposure -> human vulnerability. Analyze links between vulnerability to natural hazards and development. Index-based.[6]	Aspatial, global scale, different focus, formula only
EconoMe Federal Office for the Environment (FOEN), Switzerland http://www.slf.ch/ueber/organisation/warnung_praevention/projekte/EconoMe/index_EN	Natural hazards in mountains (avalanches, rockfalls). Obligatory tool in Switzerland (since 2008) for evaluating protection projects by comparing costs (economy) and benefits (i.e., reducing risks) of protective measures. It employs standardized scenarios and calculation factors (not editable). Also includes EconoMe-Railway & RoadRisk, for addressing rail and road safety. Access to EconoMe is restricted to authorized personnel and institutions.	Focus on evaluating protective measures in mountains (against avalanches, rockfalls, etc). Not a quantitative spatial risk assessment tool for all natural hazard.

Software name, website & developers	Short description	Reason not evaluated
EQRM (Earthquake Risk Model) Geoscience Australia http://www.ga.gov.au/scientific-topics/hazards/earthquake/capabilties/modelling/eqrm	The model is utilized in the form of a Python or Matlab-based program founded on the Hazus model. Addresses both hazard (earthquake shake) and risk.	No Graphical User Interface (GUI) available
FloodMap Atkins Global http://www.atkinsglobal.com/en-gb/north-america/sectors-and-services/services/applied-technologies/flood-map	Flood hazard mapping tool [7].	Proprietary, no specific risk assessment
IBC Floodmaps Insurance Bureau of Canada (IBC); Lead Vendor: http://www.lexisnexis.com/risk/insurance/ http://www.mapflow.com/ Flood maps produced by JBA Risk Management Consulting http://www.jbarisk.com/ partnered with DMTI Spatial Inc. http://www.dmtispatial.com/	Cat (catastrophe) modeling for insurance purposes. Mapflow / Map View (LexisNexis): Exposure Management for insurance industry. JBA Risk Management: Focus on providing natural hazard modelling for insurance and reinsurance industry. Model: JFlow (2D, hydrodynamic flood model, grid-based). Produced high-level flood maps for Canada. Partnered with DMTI Spatial Inc, Canada, to integrate JBA's Flood Map of Canada into DMTI's location economics platform (Location Hub).	Focus on flood hazard for insurance and reinsurance purposes
The Hazard, Impact, Risk and Vulnerability Model (HIRV) Laurence Pearce, University of British Columbia	Qualitative, aspatial http://search.proquest.com/openview/f0045804bd4ede99cd19c9edf7190eaf/1.pdf?pq-origsite=gscholar https://open.library.ubc.ca/cIRcle/collections/ubctheses/831/items/1.0099665 [9,10]	Qualitative, aspatial. Currently not in use
Hazard, Risk and Vulnerability Analysis toolkit (HRVA) Province of British Columbia http://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/local-emergency-programs/hazard-risk-and-vulnerability-analysis	Toolkit with a range of methods and tools, with participatory components, geared towards municipalities. Screening tool for assessing hazard, vulnerability and risk, and identifying priority areas for emergency programs. Also as Online tool.[11,12]	Qualitative
ICLEI – BARC (Building Adaptive and Responsive Communities) http://www.icleicanada.org/programs/adaptation/barc	Interactive web-based planning tool to take community representatives through a climate change adaptation plan. Can also be integrated with PIEVC Engineering.	Not a quantitative risk assessment tool

Software name, website & developers	Short description	Reason not evaluated
Municipal Risk Assessment Tool (MRAT) Insurance Bureau of Canada (IBC) http://www.ibc.ca/nb/disaster/water/municipal-risk-assessment-tool	Tool for identifying areas where sewer systems and stormwater infrastructure in cities need to be repaired or replaced, with the goal to reduce overflowing of the sewer system and reduce flooding of basements. City engineers can use maps to plan and prioritize infrastructure repairs.	Focus on sewer systems and storm water infrastructure. Not geared towards natural multi-hazard risk assessment
NOAA RVAT (Risk and Vulnerability Assessment Tool) National Oceanic and Atmospheric Administration, U.S. Dept of Commerce http://www.noaa.gov/ http://nsgl.gso.uri.edu/riu/riuc04001/pdffiles/papers/20884.pdf	Risk and Vulnerability Assessment methodology for community planners, GIS components. Includes 1) hazard identification through work with community; 2) Creating Hazard Analysis Map; 3-6) Critical Facilities, Social and Environmental Vulnerability Analysis: including scoring system for vulnerabilities; 7) Mitigation Opportunities Analysis. Planning tool, for aggregated exposure.	Planning tool and not a quantitative and spatial risk assessment / loss estimation software. No longer operational.
PDRA-VCA (Participatory Disaster Risk Assessment - Vulnerability Community Assessment) Red Cross & Red Crescent Societies **http://drm.cenn.org/Trainings/PGIS/Lectures_ENG/CBDRR%20CRA%20Methodologies%20Toolkits%20Part%201.pdf**	Qualitative vulnerability assessment method. Participatory methods such as workshops and focus-group sessions are used, with no formal analysis or evaluation.[11]	Qualitative
PIEVC – Public Engineering Vulnerability Committee http://www.pievc.ca/	Protocol to assess the engineering vulnerability of individual infrastructure. Focus on engineering aspects, not risk and vulnerability assessment.	Not a spatial risk assessment tool
Risk and Impact Analysis Program (Risk-GIS) Geoscience Australia, Australian Government https://researchdata.ands.org.au/gis-risk-gis-support-tools/571051	Risk-GIS was developed as a fusion between Risk management and GIS (based on ArcGIS). High-level, not spatial disaggregated to property level. [8]	No longer supported, based on ESRI proprietary software. No spatial disaggregation.
SELENA-RISe Open Risk Package International Centre for Geohazards ICG, NORSAR, Norway, the University of Alicante, INETER (Managua, Nicaragua) and the Technical University of Madrid (Spain). http://selena.sourceforge.net/	Open-source & free of charge, accessibility of source code and open documentation / Detailed technical user manuals. Focus on seismic risk analysis of urban areas.	Focus on seismic hazard analysis. No recent updates.

Software name, website & developers	Short description	Reason not evaluated
TELEMAC http://www.opentelemac.org	Open-source numerical hydraulic modelling	Hazard modelling, no risk component
Zürich Natural risk maps Kanton Zürich, Switzerland http://maps.zh.ch/?topic=AwelGKHWsynoptischZH	Online GIS database of flood maps and land slide	Not a risk assessment tool

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