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Okanagan Basin WATER BOARD

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Flood Risk Mapping for the Okanagan Valley Watershed

Prepared for Okanagan Basin Water Board
Prepared by IBI Group Professional Services (Canada) Inc. and Northwest Hydraulic Consultants Ltd.
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Submitted to Okanagan Basin Water Board
by IBI Group and Northwest Hydraulic Consultants

Report r2 March 2023

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1 Introduction

Okanagan Basin Water Board (OBWB) retained IBI Group and Northwest Hydraulic Consultants (NHC) to perform a flood risk assessment (FRA) and mapping of the major flood hazards considered by the Okanagan Mainstem Floodplain Mapping project (NHC 2020). FRAs are a primary tool for first understanding risk and supporting decisions to manage and adapt to reduce risk.

This report supplements the suite of digital deliverables including data sets for risk modelling and mapping. A summary presentation document containing results highlights and guidance on the deliverables is also provided.

This introduction contains a brief primer on risk and FRA fundamentals. The remainder of the report provides more details on the overall process and methods (Section 2), the hazard analysis (Section 3), data processing and derivation (Section 4), the engagement process (Section 4), the risk models (Section 6), and the risk analysis tools (Section 7).

1.1 Objectives

The stated overall objectives for this project were to:

- Broaden and deepen the understanding of flood risk in the Okanagan watershed; and
- Support risk-based decision-making for broader Okanagan Basin flood management strategies by identifying higher risk areas of regional priority for flood risk mitigation.

FRAs often quantify and report a total event impact or risk value. This is useful because reporting potential damages can effectively raise awareness prior to a devastating event and facilitate emergency planning, political or administrative attention to mitigation planning, and even some reduction of impacts alone with increased public preparedness.

However, reporting of total existing risk alone provides little insight into how to reduce risk and may contribute to a preventive focus rather than adaptive and prioritized planning processes. As discussed further below, risk is a product of hazard, exposure, and vulnerability. Therefore, risk reduction planning should consider opportunities within each variable. A risk model provides the framework to further identify and prioritize risks as well as the assessment of planning options within and across risk variables.

A baseline FRA produced with a repeatable risk model foundation can be built upon for mitigation planning. With prioritized improvements in local data, risk values can be compared with and without various alternatives or options to determine the benefits. Additionally, it can be maintained and updated as changes occur to the primary inputs including updated hazard scenarios or redevelopment plans.

This study does not include prescriptive recommendations regarding flood risk management or prioritization of mitigation efforts. Instead, the work focused on the provision of a baseline risk profile and the modelling framework. The modelling framework can be used in the future with improved data resolution for regional and local planning decisions to reduce risk. To this end, the following supporting objectives were also primary drivers of the effort:

- Provide a standardized, reproduceable, and adaptable risk modelling framework and datasets to support further regional or local analysis and planning at higher resolution.
- Provide a dynamic risk profiling platform to facilitate the understanding and potential for reduction of risk from multiple perspectives and variables.

OBWB and partners had recently invested in detailed flood hazard studies, including new LiDAR data and hydraulic modelling and mapping (NHC 2020). Therefore, another implicit objective of this study is to leverage this investment in hazard modelling for risk understanding, including the addition of flood events (probabilities) and scenarios such as current and future lake management operations, wave effects, and a potential breach of flood control structures.

1.2 Deliverables

Accomplishing the above objectives yielded the following key deliverables:

- A set of mainstem lake hazard layers for the risk modelling, and additional wave effects analysis, Penticton beach breach analysis, a dike vulnerability assessment, and a simplified floodplain velocity analysis.
- Reproducible risk modelling data packages, including spatial asset inventories (e.g., buildings), including event consequences and integrated annual risk values for set of 15 metrics.
- A dataset of inputs and results packaged with a web-based portal implemented with multicriteria analysis tools.
- Stakeholder engagement data including a survey of regional non-residential property flood vulnerability.
- Static risk maps and digital risk layers for use on the OBWB website.
- A spatial dataset of exposed assets collected from open and closed sources with attribute data for flood risk modelling.
- This report and appendices.

1.3 Study Area

This project focuses on the Okanagan River basin and major lakes down to the U.S. Border shown in Figure 1. A polygon of the study area is provided in the digital deliverables (see [aoi04_0901][1]).

[1] These [bracketed codes] are used to reference specific data in the digital deliverables, a catalogue of which is provided in Appendix G and Appendix H.

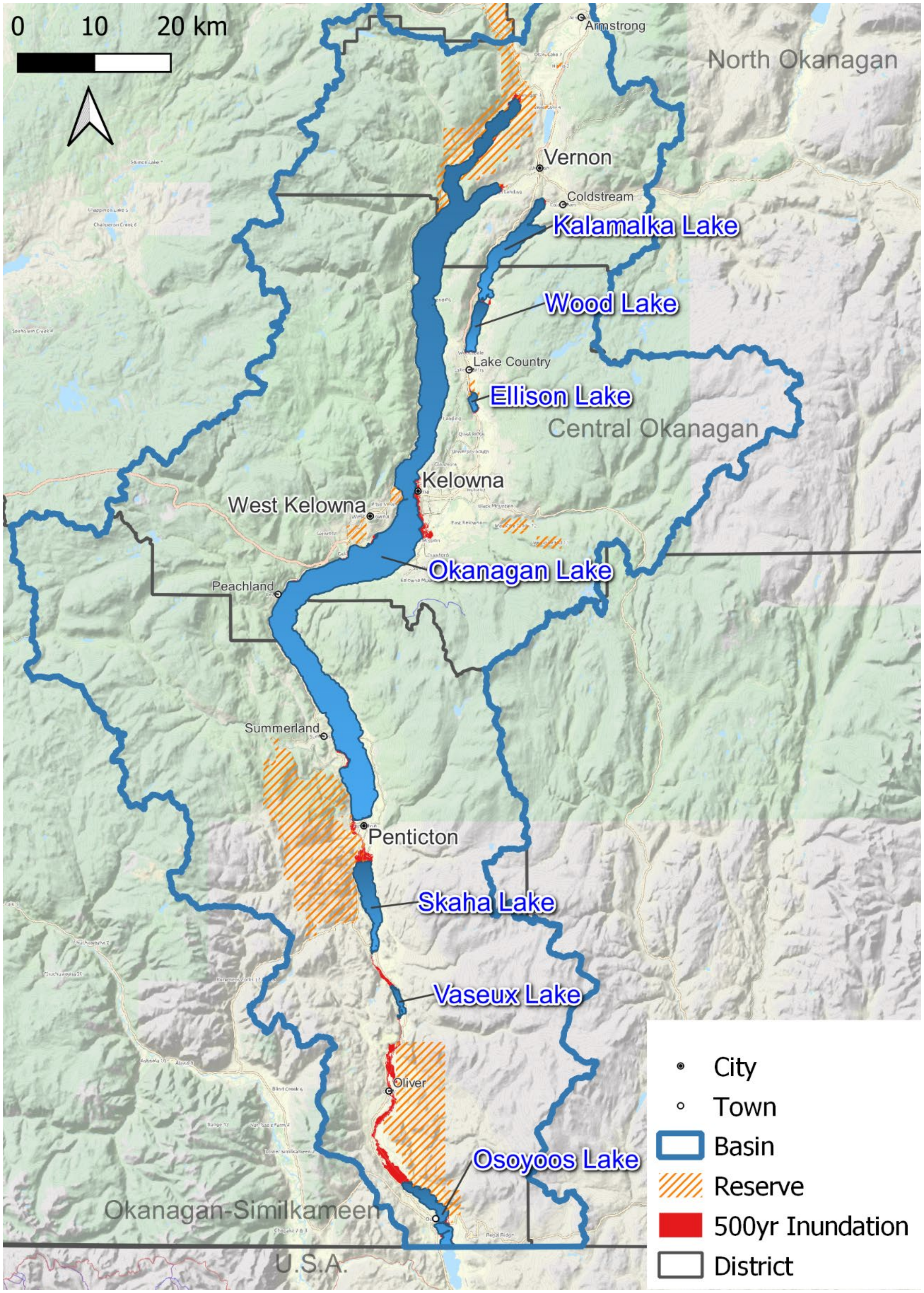

Figure 1: Study Area showing major lakes and boundaries.

1.4 Recent Flood Reporting in the Okanagan

OBWB and partners have provided an excellent and comprehensive web resource to increase awareness and understanding of flooding in the Okanagan. The URL and an image introducing the site is reproduced below:

https://okanagan-basin-flood-portal-rdco.hub.arcgis.com/

Flooding in the Okanagan - An Introduction

City Park in Kelowna. Photo: OBWB-OkWaterWise, 2017.

There have always been floods in the Okanagan – a valley born of water and ice. As times change, with different weather and different ways we live on the land, the story of flooding in the Okanagan changes with each generation. It is a story of resilience, regeneration, balance, and community.

After highwater events in 2017 and 2018, the Okanagan Basin Water Board (OBWB) led a valley-wide partnership of local governments and Indigenous communities to update the region's floodplain mapping. This included mapping Okanagan valley-bottom lakes (Ellison [also known as Duck], Wood, Kalamalka, Okanagan, Skaha, Vaseux and Osoyoos) and the Okanagan River from Penticton to Osoyoos Lake. The project report is linked here: https://www.obwb.ca/flood/

t̓ik̓t (flood)

" t̓ik̓t is the Syilx (Okanagan) word for flood. There are also words for flood land... but t̓ik̓t talks about the water... it almost sounds like t'ik'wt, which is the word for lake. t̓ik̓t is shallower and not still like the lake..."

Richard Armstrong Syilx Okanagan Elder, Traditional Ecological Knowledge Keeper and Syilx language instructor

Figure 2: OBWB Flood Story website introduction

The site provides the following resources:

- Flood Mapping – Information about flood hazard events and interactive maps allowing users to navigate a variety of hazard and exposure layers;
- History – Information on historic floods and flood management activity in the Okanagan Basin;
- Our Changing Climate – Information on climate change in the context of water management and flooding in the Okanagan Basin;
- Mitigation – Information on shared responsibilities and risk reduction strategies;
- How to Prepare – Resources and information for residents and property owners to prepare for flooding;
- Response – Where to get information before and during a flood; and
- Recovery – Resources for flood recovery.

The flood hazard mapping project, *Okanagan Mainstem Floodplain Mapping*. (NHC. 2020) is the basis of the mapping for the Flood Story site as well as this risk mapping project. The report from the mapping project is available at https://www.obwb.ca/flood/.

Concurrently produced and incorporated into this study's assessment was a *Supplemental Changes to 2020 Okanagan and Wood-Kalamalka Lakes Floodplain Maps Based on Current Okanagan Lake Regulation System Operating Plan and Guidelines* (NHC 2022). Other risk assessments completed in the Okanagan River basin that complement this study include ones by the City of Vernon (NHC, 2020, 2021). The results of NHC (2020, 2021) do not overlap with the current study other than along the Okanagan Lake shoreline. In these areas along the Okanagan Lake shoreline, it is recommended that the new hazard mapping supersede the previous.

Another important and relevant study is the Syilx Okanagan Flood and Debris Flow Risk Assessment (Ebbwater 2019). This study can be found on the Okanagan Nation Alliance website at: https://www.syilx.org/projects/t%cc%93ik%cc%93t-flood-adaptation-project/.

1.5 Assessing Flood Risk

An FRA is a structured approach to understand flooding and its resulting consequences used to support risk-based decision making.

Assessing any risk requires an understanding of two key elements: the **likelihood** of an event occurring, and the **consequences** if that event does occur. This section introduces the specific terms used when performing an FRA; using the example of a typical family home located within a floodplain of a nearby body of water to illustrate key concepts.

First, imagine that the home in our example experiences a major flood event that causes floodwater to reach a depth of one metre on the main floor of the house. While an event of this magnitude might be considered rare (*low likelihood*), floodwater to this depth would be expected to cause significant property damage that would likely incur substantial repair costs (*high consequence*). Alternatively, a house in that location might experience less severe flooding events more frequently (*higher likelihood*) but if that floodwater only impacts the basement, the property damage and associated repair costs would be less (*lower consequence*).

The consequence of a flood on an asset such as a house is a product of two variables: **exposure** to the hazard (e.g., floodwater in a building) and the **vulnerability** to that exposure (e.g., property damage). To understand vulnerability, consider a neighbouring house, identical to the first except for the fact that the basement is unfinished. If both houses experience the same flood, we expect the house with the empty, undeveloped basement to be cheaper and quicker to repair. The lower value of the unfinished basement means it is less vulnerable to being flooded than a fully furnished one (*lower consequences).*

Put another way, a fully furnished basement is *more vulnerable* to the same flood event as an unfurnished basement, as the same depth of flood would result in higher consequences, all other things being equal. Note that a homeowner can take steps to change the vulnerability at the property level – for example by installing floodproofing measures[2].

[2] One may frame this as reducing exposure of vulnerable contents, but we are referring to vulnerability at the scale of a property.

Figure 3 illustrates how the **risk** associated with a **hazard** such as flooding can be expressed as a combination of the **exposure** of the asset to the hazard, and the **vulnerability** of the asset to that hazard.

Flooding only presents a risk if we have assets of value that are (or may be) exposed to the flooding hazard and are vulnerable to it. *Without exposure or vulnerability, there is no risk.*

Probabilities allow us to quantify the risk, which can help us understand if minor basement flooding every year or the potential for a rare but severe flood is of most concern. If we are only measuring property repair costs, we may find that small but frequent flooding represents greater financial risk than a devastating but rare event. However, if we are only concerned about life safety, we may find the opposite.

Figure 3: Relationship between risk, hazard, exposure, and vulnerability

1.6 Guidance and Best Practice

This section summarises the federal guidance and international best practices associated with FRAs and risk management, which have informed the approach.

1.6.1 Federal Guidance

In consultation with provincial and territorial partners and key stakeholders, the federal government (NRCan) has developed new documents in the Federal Flood Mapping Guidelines Series.

This series is a collection of evergreen guidelines that will help advance flood mapping activities across Canada. The series includes a (draft) Flood Risk Assessment Procedures with the objective of supporting risk-based planning with a standardized framework and common terminology. While this guidance document has not yet been published, this FRA and report has been conducted in alignment with the draft procedures. The key elements of the FRA process are summarized in Figure 4, and further described in the context of this study in Section 2.

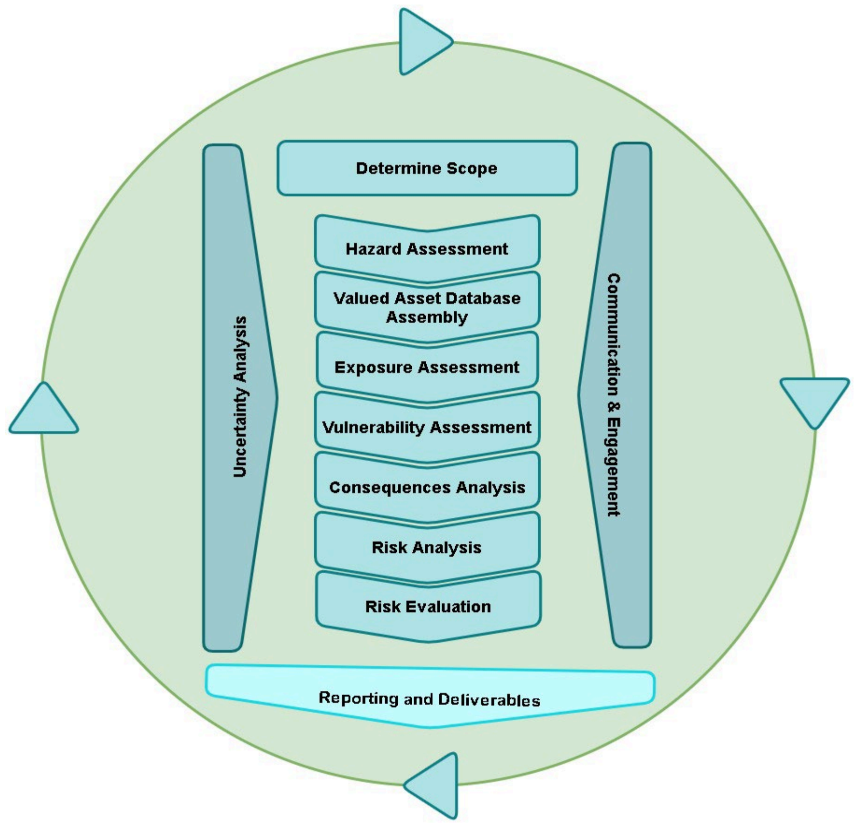

Figure 4: Flood Risk Assessment Procedures process summary diagram (NRCan 2021)

1.6.2 Principles

From an international standards perspective, ISO 31000 (2018): *Risk management – Guidelines*, provides principles, a framework, and a process for managing risk that can help organizations improve the identification of opportunities and threats, and effectively allocate and use resources for risk treatment; and states that

"*Risk assessment should be conducted systematically, iteratively, and collaboratively, drawing on the knowledge and views of stakeholders.*"

The following four principles in ISO 31000 served to guide the activities of this FRA:

Table 1: Guiding principles

GUIDING PRINCIPLE	OBSERVATIONS
Evidence Based	Evidence and research should guide the components and assumptions of FRAs to reduce bias and error, especially when there is limited knowledge of many aspects of flood risk which can result in high uncertainty
Transparent and Reproduceable	All procedures should be clearly documented, with all underlying data available, so that studies are transparent and reproduceable. This enables models to be easily updated with new data; ensures all assumptions are explicit; and increases the significance of the underlying data in driving results, relative to the practitioner's experience and bias.
Tailored to the Community	FRAs examine how a community's values and priorities intersect with their flood exposure. While every community is entitled to define their own values and priorities, and these can change over time, outside expertise is often needed to support such assessments, but care should be taken to ensure values are not imposed or assumed for a community.
Proportionate	The effort spent on collecting data and assessing risks should be proportionate to the significance of the decision or management issue.

2 Methodology

This section outlines the general methodological context for this study, generally organized in order of the above process summary diagram from the draft FRA Procedures document (Figure 4), which is summarized in Table 2. Project-specific details on hazard assessment and data collection and processing are provided in subsequent sections.

Table 2: Elements of the risk assessment process *(NRCan 2021*) and activities conducted

ELEMENT	DESCRIPTION OF ACTIVITIES
2.1 Determine scope	Engaged with key stakeholders to review and confirm the proposed methodology.
2.2 Hazard assessment	Leveraged the models developed during the Okanagan Mainstem Floodplain Mapping (NHC 2020) project to produce the additional hazard layers required for risk modelling.
2.3 Valued asset database assembly	Surveyed, mined, and processed available datasets and generated derived datasets.
2.4 Exposure assessment	Determined asset heights and derived depths.
2.5 Vulnerability assessment	Transferred depth-damage functions, determined exposure scales, and develop functions from survey data.
2.6 Consequence analysis	Assembled the above elements into appropriate risk models, and executed the model suite to determine the consequences, and the resulting risk.
2.7 Risk analysis	
2.8 Risk evaluation	Compiled the results of the risk model to assemble regional risk profiles that facilitate multi-criteria analysis using stakeholder's priorities.

In parallel and integrated with the above, communication and engagement was conducted to solicit feedback and guidance from OBWB's advisory committee and broader stakeholder groups via online workshops and surveys and follow-up communication (see Section 4 for a summary of engagement activities).

2.1 Determine Scope

Upon commencement of this study, OBWB convened a small Technical Advisory Committee (TAC), and the study team prepared a presentation of proposed scope, methodology, and data sources. To clearly document and communicate the proposed work, the first deliverable was a draft methodology memo. After review and discussion with OBWB and the TAC, the methods memo was finalized and presented to the wider stakeholder group via the project site and materials for the first two workshops.

The methods memo included a scope summary, objectives, principles, data sources, limitations, and the preliminary methodology for the items discussed in the sections below. A copy of the methods memo is available in Appendix K2.

2.1.1 Modelling Framework

FRAs attempt to quantify the exposure and consequences of flooding in various ways. As the influencing conditions and purpose or perspective (e.g., insurance, emergency response, government relief, land-use planning) of assessments is diverse and complex, so too are the suite of modeling frameworks used. While numerous frameworks have been applied by academic studies, the following frameworks are the most common in practical FRAs:

- *Object-based*: Where asset interactions and spatial dynamics play a minor role in impacts. Object-based vulnerability models assume a consequence can reasonably be estimated with a single function assigned to each relevant asset (e.g., depth-damage functions).
- *System-based models*: Where interactions and connections between assets significantly influence vulnerability, within or beyond the inundation spatially or temporally. This catch-all applies to a broad group of sophisticated models.

As a foundational regional study, this FRA implements an object-based framework, reporting the aggregated results from a collection of individual exposed assets (direct consequences, see Section 2.6).

These two frameworks, however, should be considered more incremental than exclusive because many elements of a system-based approach are often best informed by range of object-based results. For example, determining the economic impact of recovery on labour, materials, and supply chains requires information on the aggregate of building (object) damages, among other variables.

2.2 Hazard Assessment

Typically, information about potential flood events is derived from technical hazard identification and mapping studies. These can include hydrologic assessments to estimate the likelihood of various discharge volumes from rain and snow melt; and hydraulic inundation modelling to estimate how and where the water flows on the ground. The three main outputs of hazard studies that are used to conduct this FRA are generalized below.

- ***Inundation Extents***. These are maps that illustrate the extent of overland flooding for each event modelled. As the most familiar product of hazard studies, they are an important communication tool capable of also showing combined information relating to the underlying characteristics of the modelled flood, such as high hazard due to velocity or waves, highlighting areas that determine or even comply with policy and planning conditions, or showing zones influenced (‘protected’) by flood control structures, such as dikes.

  For this study, the inundation extents were used to determine the study area and the assets that may be exposed to flooding (Section 2.3.1).

- ***Water Surface Elevation (WSE) data.*** An output of the hydraulic modelling used as the main source of the flood maps is the water surface elevation. The depth of flooding is derived as the difference between the water surface elevation and the ground elevations. Inundation extents are typically delineated where the WSE and the ground elevation are equal, indicating zero depth. The WSE data is provided as a spatial raster file with elevation values, much like a ground or terrain file (Digital Elevation Model, DEM) used for the hydraulic model.

  For this study, the WSE and DEM files were used to derive depth of flooding as the exposure metric at each asset (Section 2.4).

- ***Probability,*** or event likelihood, is used to calculate risk using annualized values (Section 2.7). Each flood event is modelled to determine an estimated probability of occurring, based on the hydrology. This 'annual exceedance probability' (AEP) can be expressed as a percentage or as 'average recurrence interval' (ARI) expressed in years. A 100-year flood, or 1:100-year flood event, has an AEP of 0.01, meaning there is a 1% chance of occurrence in any given year.

  Hydrologic probabilities are generally derived from the historic record. However, climate change is affecting many of the variables and the projected effects of mid-century climate change were incorporated into the hazard data for this study (see NHC, 2020).

  For this study the event probabilities were used to derive annualized risk values (Section 2.7)

The flood hazard foundation for the FRA conducted in this study was the Okanagan Mainstem Floodplain Mapping project (NHC 2020), with additional events and operational scenario as detailed in Section 3 and associated appendices.

2.3 Valued Assets

Valued assets are people, buildings, facilities, infrastructure, environmental components, cultural sites, and other physical objects whose exposure to floods results in consequences. FRAs typically focus on negative consequences to a community's assets. To do so, the exposure is determined to apply respective vulnerabilities to flood hazards to estimate consequences, either directly where feasible or appropriate (e.g., $ damages to a building), or through simple quantitative exposure analysis to inform a qualitative or separate assessment of potential consequences (e.g., number of people or cultural sites exposed; see Section 2.5).

"*Valued* assets" of course implies values are considered, which is consistent with the recognition that hazard is not a risk alone, that risk is defined by community values and the consequences of concern.

Therefore, the convenience of separating the methodology for exposed assets, vulnerabilities, and consequences for reporting purposes dissipates when considering the inextricable relationship between these risk components, perhaps better suited to a "systems-based" approach to vulnerabilities, which is the direction of current research and future practices[3].

To illustrate this, consider segment of roadway. Does the community value the road segment intrinsically as a layer of asphalt? Not likely, but we may place high value the service it provides enabling escape to safety, delivery of goods and services, getting to work, or connecting with family. If that road segment is flooded to an extent that it is impassible, even if it is not physically damaged, it represents a range of potential consequences. However, if there is an alternative route, the individual segment may become less "valuable", or in other words, we become less vulnerable to it.

This study is limited to an assessment of available asset data and quantification of exposures and limited vulnerabilities with the hopes that this information may inform further estimation of a wider range of consequences and mitigation strategies. Nonetheless, the collection of valued asset data is inherently value-based and inseparable from the consequences of interest. This section describes the selection process. The final set of assets and data sources (risk models) is presented together with the consequences they may represent in Section 2.6.

[3] A good introduction to systems thinking is provided in the UK Government's "*Systems thinking for civil servants"*
https://www.gov.uk/government/publications/systems-thinking-for-civil-servants

2.3.1 Selection of Assets

The determination of assets and associated data collection was a central component and objective of engagement for this project. However, in consideration of the above, valued assets were presented along with consequences of interest as a means of providing metrics to represent the consequences. In other words, the valued assets are the tangible representation of consequences. Therefore, the development of the "risk models" is dependent on our ability to collect data to estimate the exposure of these assets.

An immediate challenge with an FRA scope such as this is the identification of valued assets for the region that have available data to assess their exposure and potential consequences. Some aspects of this challenge are as follows:

- The general lack of data, and available data is created for other purposes which may not be conducive to FRA use.
- The need for a consistent regional level of detail. If one community has a greater quantity or quality of data, it will bias the results and cannot be used (i.e., 'lowest common denominator' problem).
- The inability to overcome all above data limitations through engagement activities within the project scope and schedule (e.g., community developed and validated inventories of valued assets and flood vulnerabilities).

The development of the asset inventories for this project began at the proposal stage with a collection of known public, private, and potentially derived data sets that may be available, based on categories from guidance documents, past experiences, and preliminary searches or enquiries. The objective was to use this preliminary list for engagement throughout the project to identify additional assets and/or data sources for inclusion, removal, replacement, or enhancement.

Table 3 contains a condensed summary of the preliminary asset/consequence table. The table shared throughout the project also included proposed data sources and method summary. This initial set was presented for discussion and opportunities for improvement in the activities summarized below, as further discussed in Section 4, engagement. The engagement material is provided in Appendix K.

Table 3: Preliminary Asset and Consequence Set

<table>
<tr><th colspan="2">ASSETS & CONSEQUENCES</th></tr>
<tr><th>NAME</th><th>METRIC DESCRIPTION</th></tr>
<tr><td colspan="2">people</td></tr>
<tr><td>people - life safety</td><td>number of mortalities from flooding</td></tr>
<tr><td>people - affected</td><td>number of exposed persons</td></tr>
<tr><td colspan="2">economy</td></tr>
<tr><td>buildings - damage</td><td>estimated repair/replace costs</td></tr>
<tr><td>buildings - contents</td><td>estimated cost to replace building contents</td></tr>
<tr><td>crops - agriculture</td><td>financial loss from flooded crops</td></tr>
<tr><td>facilities - commercial, industrial</td><td>cost to repair or replace equipment, stock</td></tr>
<tr><td>docks, piers, marinas</td><td rowspan="2">repair costs</td></tr>
<tr><td>public parks</td></tr>
<tr><td colspan="2">infrastructure</td></tr>
<tr><td>roads & highways</td><td rowspan="10">exposure score (count and significance)</td></tr>
<tr><td>public parks</td></tr>
<tr><td>underground pipes</td></tr>
<tr><td>medical facilities</td></tr>
<tr><td>police and fire stations</td></tr>
<tr><td>transformers & sub-stations</td></tr>
<tr><td>railways</td></tr>
<tr><td>water supply facilities</td></tr>
<tr><td>wastewater facilities</td></tr>
<tr><td>power facilities</td></tr>
<tr><td colspan="2">environment</td></tr>
<tr><td>contaminants release</td><td>number of registered sites exposed</td></tr>
<tr><td colspan="2">culture</td></tr>
<tr><td>archaeological sites</td><td>number of registered sites exposed</td></tr>
<tr><td>cultural monuments</td><td>number of registered sites exposed</td></tr>
</table>

The following activities were included in the process to refine, improve, and confirm the selection of assets for the risk models and the collection of any missing data.

1. *Technical Advisory Committee (TAC)*. A proposed methodology memo (Appendix K2) was provided to the TAC, including the proposed modelling suite summary.
2. *Workshop 1*. The first workshop was attended by approximately 50 participants and the primary objective was a presentation of scope and methods, including the selection and data collection for the valued asset datasets. In relation to the valued asset selection and collection, the workshop included:
    - Live presentation with description of identified data and repeated requests for feedback on improvement of the asset lists and data sources.
    - Live discussion and breakout opportunities to discuss assets and data sources.

- Background information including the final TAC methods memo and a presentation of the preliminary "Project Risk Modelling Suite Summary" (see Appendix K2)
- A feedback form (see Appendix K1) that requested information on past flood impacts, requests for data on the preliminary consequence/asset list presented, and specific questions relating to the valued assets:

  > *"Are there unique values assets or vulnerabilities in your community that you feel may be missing in the described approach and standard data set? If yes, please provide a brief description and include your contact information below."*

3. *First Nations Assets*. In recognition that several of the main datasets may lack coverage for First Nations communities due to jurisdictional differences and service provision, additional effort was made to identify and include assets of value for these communities. After an initial outreach to establish the appropriate contacts, data requests were made by email and telephone follow up. The requests indicated two specific objectives:

   - *"Provide consistent and fair representation across the region by filling in any gaps in datasets we're already collecting (see table below), and,*
   - *Give you the opportunity to identify any additional valued assets, sites, or flood vulnerabilities we are not considering or aware of (see attached map)."*

   The attached table contained the current datasets and indicated if we had any data for that community or not. The attached map showed flood extents and all the spatial data we had collected for the area thus far to elicit any missing assets. A follow-up was made with additional mapping and questions regarding any infrastructure, buildings, or other assets of value in the study area.

   The established contact list is provided as Appendix K7 and a sample of the email requests and maps is provided as Appendix K8.

4. *Workshop 2.* While the primary objective of the second workshop (45 attendees) was the presentation of preliminary results and the discussion of risk evaluation (Section 2.8), there was also continued effort to improve and validate the asset data and even to include additional asset data at this stage. For example, after the description of the workshop's focus on weighting the consequences based on the metrics available, the workshop information boards (Appendix K10) included the following request:

   > *"…we are still open to suggestions for additional data to improve the study – either additional knowledge about vulnerabilities of included assets or missing assets to model exposure with. Please use the interactive map or contact form at the desk for any feedback. The table here provide a summary of the individual risk models currently constructed for reference..."*

   To this end, the workshop included the following in relationship to the valued asset database assembly:

   - Presentation of the data identification, acquisition and licensing, pre-processing, derivation and analysis, and assembly of the asset inventories. The presentation also included a detailed summary of each asset model for discussion (Appendix K12).

- An interactive map of the region containing selectable inundation extents for the study's main four flood events and both scenarios. Viewers could pan and zoom to explore areas of interest. The map also had a feature to drop a pin and add comments to identify any additional or missing assets or local vulnerabilities (Appendix K10).
- A feedback form for attendees to provide input on the asset models presented and discussed.

5. The above activities were also supplemented with a range of individual requests and conversations. For example, targeting local data sets such as building footprints (see Section 4.2) and municipal infrastructure, such as water and wastewater facilities.

2.3.1.1 ***Selection Results: exclusions, additions, modifications***

This process found there was little additional pre-existing information gathered for flood risk purposes nor coordinated identification of flood vulnerabilities or consequences. The engagement succeeded in facilitating some of the data acquisition but did not substantially enhance the breadth or depth of the consequences considered. The assets or consequences that were excluded, added, or modified are discussed below. The final set of models is presented in Section 2.6.

Life Safety and Affected Population

In addition to the total affected population, it was originally proposed that an indication of safety risk could be included and used in conjunction with the velocity information provided by the supplementary hazard assessments. There are studies providing methods for estimation of mortalities and Priest et al. 2009 was proposed. However, the transferability of these methods involves great uncertainties. While the components of physical safety including hazard (e.g., depth, velocity, rate-of-rise, timing, debris) and vulnerability (e.g., stability of humans in depth/velocity combinations) are relatively well documented, the exposure component is problematic – where and why are people exposed. This is what makes transferability of methods difficult.

Public safety is of course one of the most significant concerns and decision-making metrics for flood risk management. Globally, flooding causes a significant number of deaths and injuries from direct physical trauma to lack of critical medicine, food, or clean water. The factors that contribute to physical harm from flooding are complex and involve many variables beyond just the nature of the flood hazard. Except for sudden catastrophic events or extreme localized flash flooding, exposure of individuals to flood hazards is highly dependent on individual behaviour and actions as well as prevailing socioeconomic, health, and institutional conditions of the community.

Without the ability to make assumptions on the influence of these conditions on local exposure, there is no defensible basis for reporting a quantification of safety risk because it would not provide more information than the identification of the high-hazard areas[4] and the population independently. Doing so would obfuscate the actual value of this information for planning and be potentially misleading.

[4] The dike fragility, "dikes down" velocity information and the Penticton Beach Breach information may be used to identify potentially high-hazard areas, see Section 3.2.

Given the uncertainties, lack of added value, potential distraction, and feedback from the engagement process regarding the sensitivity of reporting potential for deaths or injury, this consequence was removed from the study. Instead, the “affected” population component of this study focusses on an estimation of the population at risk of experiencing the many indirect impacts that can arise from the flooding of their residence.

Affected Vulnerable Population

During the discussions regarding population exposure and the removal of life safety metrics, it was decided to incorporate an additional relative measure of the affected population in terms of potential social vulnerabilities, which may exacerbate the indirect impacts relative to the general “affected” population. A spatial vulnerability score based on demographic indicators was adopted as a weighting or modifier, as described in Section 6.2.

Foreshore infrastructure: docks, piers, marinas.

Foreshore infrastructure including docks and piers, and potential flood damage repair or replacement costs was one of the initially proposed assets and consequences, but without an identified data source or vulnerability information. Discussions with OBWB and the TAC revealed a very promising source of foreshore information, the Draft Foreshore Inventory and Mapping data prepared for Living Lakes Canada. Upon receipt and analysis of the spatial data, it was unfortunately determined that, although rich in information for the study area’s shoreline, a damage estimation would not be feasible within the scope of this study. This decision was due to the balance of effort required vs the uncertainty of results. Individual structure vulnerability would vary greatly (many types) and the certain exposure due to location would provide dubious results disproportionate to the extent other consequences are not monetized.

Regarding the foreshore beyond infrastructure placed there, it is acknowledged that erosion due to high water and wave action could result in other consequences and its omission one of the limitations of this study. More specifically (because flooding is a natural and often creative process), the negative consequences would likely arise from actions taken to reclaim or reenforce the shoreline and the resultant impacts on the environment such as foreshore habitat.

Assets not exposed or vulnerable.

In addition to the above changes, preliminary analysis led to the removal of some asset categories that, according to the data available, did not appear to be exposed. Based on the available data (see Section 4) to identify facilities, no medical or emergency response (police, fire, hospital) were within the flood extents of this study.

While this is an important first finding of the study regarding resilience of these functions, it should be emphasized that this assessment was based on the primary use data and it is not uncommon for a site with a different regular primary use (e.g., community centre or school) to serve as an asset for emergency response during a disaster such as a flood.

Other assets with data showing exposure were removed or modified due to change of use or lack of vulnerability. For example, the Okanagan Rail Trail was included as rail infrastructure in the data but was later identified as recreational, leaving no exposed working railways.

The resulting 15 asset inventories and data sources that were included in this study are presented as part of the risk modelling suites in Section 2.6.

2.4 Exposure

Exposure is the intersection of an asset's vulnerable attributes and the flood event magnitude (e.g., depth, velocity, debris, contaminants) at its location. The exposure metric for this FRA is limited to an assessment of flood depth.

The WSE and DEM files were used to derive the depth of flooding relative to each asset, as appropriate for each asset class. For example, building damage functions are based on depth relative to the floor, which is not the same as the depth on the ground. Therefore, the building elevation is derived as ground elevation plus the estimated floor height from ground.

The granularity of the asset model and can vary greatly and with it, the details of the exposure assessment and the delineation of asset exposure versus vulnerability. Buildings, for example, are one of the few assets with multiple components for which we can estimate direct damages based on flood depths. Therefore, if the associated vulnerability functions are for components (e.g., basement, garage, kitchen), rather than a composite (e.g., 'house'), then the exposure calculation would be at the component level.

For example, a single-family house with main floor height of 0.5m, a basement, and a double-car garage may have the following exposures to a flood event with a depth of 0.6m at that location:

- 150m^2 of main floor exposed to 0.1m flood depth
- Mechanical and 140m^2 of developed basement exposed to 2.8m flood depth ('maximum' depth, depending on ceiling height, or depth of basement)
- 35m^2 of garage exposed to 0.6m flood depth

However, when the relative heights of these building components are compiled at the property level (i.e., the building is the asset, not the components), they together become the vulnerability profile of that building to the single exposure of, in this example, 0.5m of flooding at grade. This process of compiling the "building vulnerability database" is described in Section 5.5.

For other assets, such as roads or crops, the asset elevation is typically assumed to be equal to grade (DEM). Additional information for each asset and associated exposure thresholds, where applicable, is provided in Section 6. The exposure calculation is conducted for each asset with the GIS risk modelling toolset (see Section 2.7).

2.5 Vulnerability

Determining vulnerability is essential to understanding and quantifying the impact of a flood, as it provides a means to assess the susceptibility and response of a system to the impact(s) of hazard(s). However, accurately capturing all of society's interactions with flooding as part of an FRA can be a challenge, due to their complexity.

To assist the process of understanding the range of flood impacts, the following six thematic dimensions (J. Birkmann et al. 2013) provide a useful framework when thinking about vulnerability:

Table 4: Vulnerability dimensions (J. Birkmann et al. 2013)

THEMATIC DIMENSION	DESCRIPTION
Social	The propensity for human well-being to be damaged by disruption to individual (mental and physical health) and collective (health, education services, etc.) social systems and their characteristics (e.g., gender, marginalization of social groups)
Economic	The propensity for loss of economic value from damage to physical assets and/or disruption of productive capacity
Physical	The potential for damage to physical assets including built-up areas, infrastructure, and open spaces
Cultural	The potential for damage to intangible values including meanings placed on artefacts, customs, habitual practices, and natural or urban landscapes
Environmental	The potential for damage to all ecological and bio-physical systems and their different functions. This includes ecosystem functions and environmental services but excludes cultural values that might be attributed.
Institutional	The potential for damage to governance systems, organizational form and function, as well as guiding formal/legal and informal/customary rules—any of which may be forced to change the following weaknesses exposed by disaster and response.

This illustrates vulnerability as a collection of interdependent systems as opposed to event outcomes like consequences. Framing vulnerability in these terms highlights the complexity of society's interactions with flooding, and the difficulty of capturing these interactions in FRAs. In relation to these dimensions, our understanding of flood vulnerabilities in the Okanagan is extremely limited and our ability to quantify or qualify them even more so.

Within the range of vulnerabilities, we can most readily identify and estimate vulnerabilities related to physical damage and the resultant repair costs. Considering this, most FRAs, including this one, are limited to quantifying this subset of the physical and economic dimensions and providing more basic exposure-based quantification for physical elements of the remaining dimensions.

The OFRM project attempted to incorporate as many assets as possible with available data. This included assets for which we have insufficient vulnerability knowledge about to report quantified consequences. Therefore, vulnerabilities are simplified with two types of functions applied, referred to as level one (L1) and level two (L2):

- L1 are simple binary-exposure functions which only consider the probability of an asset being exposed to flood waters (or not); and
- L2 or 'depth-damage' functions are depth-dependent vulnerability functions.

While some assets are limited to simple count of assets exposed, with L1 risk modelling others can be scaled with individually assigned values or relative scores as well as critical depth thresholds. In other words, if we can't readily quantify the consequence, we can still assign an 'importance' value to understand potential risks relative to other assets and inform further investigations.

For example, if a collection of pump stations or electrical transformers are represented by points, they could be relatively scored based on estimates of service area, providing some relative indicator of potential risk. Similarly, the exposure of people can be quantified as all persons equal or, using demographic statistics, factored to include consideration of relative potential vulnerabilities. See Section 2.6.1, Table 6 for a summary of model types employed in this study and Section 6 for a description of the application for each.

L2 vulnerability functions are typically building-related and constructed for a subset of archetypal buildings within a study area and extrapolated to cover all buildings based on available data. Development of L2 depth-dependent functions is resource intensive and rarely within the scope of individual FRAs. Therefore, most apply the best available existing functions transferred from other studies.

2.5.1 Depth-Damage Functions for Building Damages

The only L2 modeling for this study was for building and content damages, utilizing the most recent and geographically appropriate depth-damage functions, summarized below in Table 5 and further described below.

Table 5: Source of Building Depth-Damage Functions

SOURCE	FUNCTIONS	NOTES
BC Lower Mainland FRA (IBI 2020)	179 depth damage estimates from 29 composite models (21 residential, 8 non-res). Produced by cost consultants using Xactimate.	Component functions produced from composite models: • Basements: 20 • Common (mechanical, cleanup, mobilization: non-scaled): 54 • Garages: 16 • Main Floor: 58
Alberta Provincial Flood Damage Assessment (IBI 2015)	11 residential structures producing 19 functions (structure and contents), 5 non-res structures, 21 non-res contents.	Each residential building function comprised of four components: basement structure, basement contents, main structure, main contents. Garages and exterior included in main floor values.
This Study	3 non-residential composite functions for equipment, material, stock, and goods.	See Section 4.1

- **Alberta Curves**: Following the 2013 Southern Alberta Floods, the Government of Alberta commissioned IBI Group to develop a “user-friendly, made in Alberta approach to flood damage assessment” (IBI Group and Golder Associates 2015, 67). This yearlong effort resulted in 11 residential vulnerability functions which were developed to estimate direct tangible structural (S) and contents (C) damages to buildings from flood depth. These curves further divide damages by main floor (M) and basement (B).[5] Residential categories for the Alberta Curves were developed from expert knowledge of typical Canadian building typologies and divide buildings by 1) size; 2) quality; 3); and 4) number of stories. To develop the residential curves, 83 in-person surveys were conducted in 2014 of representative flood-unaffected homes in Calgary and Edmonton [rfda_200218].
- **Lower Mainland Curves**: For the recently completed Flood Risk Assessment of BC’s Lower Mainland, synthetic vulnerability functions were created using a novel method employing software and specialists from Canada’s emerging flood insurance industry (IBI Group 2021). First, a set of 179 hypothetical flood restoration estimates at different depths were prepared for 29 representative or archetypal structures by a building restoration specialist using the Xactimate software (Xactware 2020). These estimates were then combined and processed to produce a set of 138 vulnerability functions for four building sub-areas [FBC_200601].
- **Okanagan NRP Curves**: To better reflect the business in the study area, the vulnerability functions described in Section 4.1.4 were developed and employed in the buildings risk model [nrpVf_0405].

Legacy functions were scaled to adjust for temporal and regional transfers (e.g., Calgary 2014 to Okanagan 2021) following Natural Resources Canada and Public Safety Canada (2021). Legacy curve categories were collapsed into six categories by use type to construct composite curves, each with a minimum, maximum, and mean value – while ‘finish level’ (e.g., quality) and floor (e.g., main floor), and parent library group were preserved. This yielded 36 vulnerability functions for the full inventory [vfLib_0421].

To improve the consistency and accessibility of Canadian FRAs, NRCan is currently undertaking “A program for the Development of Flood Damage (Vulnerability) Curves for Buildings in Canada”. The resulting functions can be applied in the future to the building damage models produced by this study to provide additional results to further quantify other building-related vulnerabilities and consequences and comparisons with other future studies.

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

2.6 Consequences

Consequences are the combination of exposure and vulnerability to an individual flood event and represent the negative impacts of flood hazard. As consequences arise from vulnerabilities, the complexity of the dimensions presented in Table 4 above provide an indication of how vast and complex the potential consequences are, ranging from the benign to the devastating.

The dimensions of vulnerability, including elements of mental health, physical damage, economic, culture, environment, and governance, are also reflected in the commonly used classification of consequences as tangible or intangible and direct or indirect.

Tangible consequences are readily enumerated and generally expressed with a market or monetary value, such as repair costs or lost productivity. Intangible consequences do not have an established market value or no appropriate means of quantifying or monetizing, such as stress, loss of heritage or cultural artifacts, and community relations.

The categorization of direct and indirect has some variation in use but is delineated spatially (within or beyond the flooded area) and temporally (at the time of the event or later). Generally, direct damage is caused within the flooded area and due to contact with the flood water, debris, or ice, such as building damage. Indirect damage covers all other subsequent consequences, such as supply chain disruptions or recovery and governance issues.

A single asset can have consequences in multiple dimensions. A simple example is that a flooded home may result in the direct, tangible repair costs, as well as many potential indirect, intangible consequences such as lost family photos or worry about future flooding. Generally, the more direct and tangible the consequence is, the easier it is to understand and measure with available data, represented by the upper left quadrant of Figure 5.

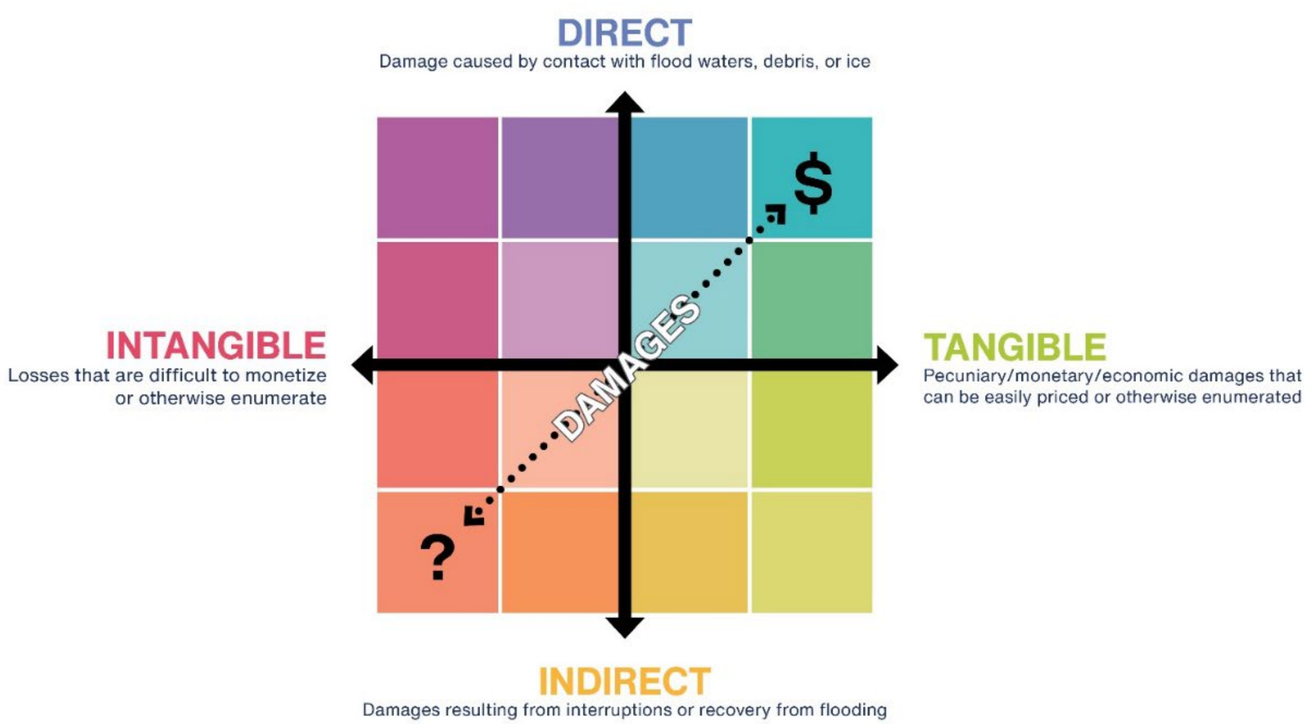

Figure 5: Matrix showing the relative ability to quantify flood damages

2.6.1 Summary of Consequences for the OFRM project

Because consequences are the combination of exposure and vulnerability, the consequences reported in this study are limited by the exposed asset dataset and our knowledge of the respective vulnerabilities as described above. Based on the asset selection process outlined in Section 2.3.1, available data, and the level of vulnerability knowledge (Section 2.5), the final collection of 15 risk models representing the consequences provided in this study are summarized in Table 6. Data sources are summarized in Section 4 and further detail on the models in Section 6.

Table 6: Summary of Consequences by Risk Model

RISK MODEL	MODEL TYPE	UNITS	CONSEQUENCE DESCRIPTION
affected population	**L1**	count	Population estimate within exposed residential dwellings
vulnerable population	**L1+**	weighted count	Weighted population estimate within exposed residential dwellings
building damage	**L2**	$CAD	Repair and replacement estimates based on depth-damage functions
crop damage	**L1+**	$CAD	Exposed crop value estimate by type, potential loss
park damage	**L1+**	$CAD	Restoration and cleanup cost estimate by type
recreation loss	**L1**	m^2	Exposed parks and recreation areas, potential loss of use
road disruption	**L1+**	weighted count	Road segments exposed to potentially impassible depth weighted by classification
power service disruption	**L1+**	weighted count	Exposed underground transformers
water service disruption	**L1+**	weighted count	Exposed facilities weighted by potential loss of service
wastewater service disruption	**L1+**	weighted count	Exposed facilities weighted by potential loss of service
wastewater release	**L1+**	weighted count	Exposed facilities weighted by potential volume of release
contamination release	**L1**	count	Exposed facilities with identified pollutants, potential for release
cultural facility disruption	**L1**	count	Exposure of buildings identified as cultural facilities, potential loss of use or service
archaeological sites exposure	**L1**	m^2	Exposed area of registered sites, potential loss or damage
historic building exposure	**L1**	count	Exposed buildings registered as heritage, potential loss or damage

The model type is categorized as L1 or L2, as described in Section 2.5, with an additional indicator for distinguishing L1 inventory detail as follows:

- **L1**: Exposure to inundation (e.g., count or area)
- **L1+**: Exposure with asset vulnerability thresholds (e.g., critical depths) and scales (e.g., weighting or scores)
- **L2**: Consequence with vulnerability (depth-damage) functions

The consequences above, as quantified here, can all be considered direct and tangible, even if they may be representative of potential indirect and/or intangible consequences. For example, we are simply quantifying exposure of cultural, archaeological, and historic sites, not the potential results of that exposure in terms of loss of meaning or value to individuals or communities. However, both the exposure based (L1) and the vulnerability (L2) consequences provide information that can be used to estimate a variety of indirect consequences.

Therefore, the categorization of consequences for this study is not by dimension, but for reporting purposes and follows the five consequence categories provided in the federal guidelines document, as summarized below in Table 7 with the respective models.

Table 7: Consequence categories and subcategories represented by risk models in the OFRM project.

PEOPLE	ECONOMY	INFRASTRUCTURE	ENVIRONMENT	CULTURE
• affected population • vulnerable population	• building damage • crop damage • park damage	• recreation loss • road disruption • power service disruption • water service disruption • wastewater service disruption	• wastewater release • contaminant release	• cultural facility disruption • archaeological sites exposure • historic building exposure

2.6.2 Economy Category – Monetized Consequences

When evaluating and monetizing the impacts of a flood, quantitative FRAs typically consider two appraisal philosophies, defined by Messner (2007) as follows:

- **Financial**: the aggregate "damage from a perspective of a single person or firm, neglecting public affairs and focussing on the actual financial burden"; or
- **Economic**: "the impact on national or regional welfare, including impacts on intangible goods and services".

To be perfectly equitable and estimate the total losses on the 'whole of society', an FRA used for mitigation planning would ideally adopt an economic appraisal. However, because Canadian flood management often involves multi-tiered funding programs, with public funds collected and distributed locally, regionally, provincially, and nationally, setting an appropriate boundary for an economic appraisal can be difficult or impractical.

An economic approach would also require consideration of depreciated values for property destroyed by floods. In a situation where a flood destroyed a five-year-old television, the wider economy would lose a five-year-old television of depreciated value; but would likely gain the purchase of a new television, of even greater value.

Also, while it is possible to purchase a (used) replacement television, it is not possible to re-apply five-year-old paint; and data on the respective age of building finishes and contents is not readily available. Therefore, the financial approach utilizes current replacement and restoration costs, but does not preclude the application of depreciation where appropriate for subsequent economic analysis.

On the other hand, incorporating the complexities necessary to model poorly understood and dynamic economic systems can be costly, with results that can ultimately contradict the interests of the affected stakeholders. For example, one community would not be well served by an FRA that concluded there is no economic consequence to their community, because their losses were more than offset by the gains experienced in an adjacent, unaffected community – perhaps one providing replacement goods and services, or restoration and recovery services.

For these reasons, tangible direct financial impacts form the basis for a range of economic analyses, considered appropriate for a variety of uses from economists and insurers to social services and urban planners. Considering the above, most Canadian practical FRAs, and this project, adopt a financial appraisal philosophy. As such, the depth-damage functions for buildings, and thus the reported consequences, are replacement, not depreciated, costs.

2.7 Modelling Flood Risk

Flood risk modelling is the process used to quantify the consequences of future floods based on their probabilities.

A hallmark of flood risk modelling is the integration of a wide range of event consequences and their probabilities, over multiple time periods. This helps decision makers to plan for a more realistic range of flood threats, rather than basing decisions around a single-design event which may not occur or may be exceeded.

The most common ‘risk-based’ metric used in flood risk models is estimated annual loss or Expected Annual Damage (EAD).

This calculation for EAD integrates the consequence of each modelled event, with its probability to return an average consequence, for each year. This can be visualized graphically as the area under the ‘risk curve’ shown in Figure 6 below, which plots the event probabilities on the x axis and the consequence (or damage) values on y axis.

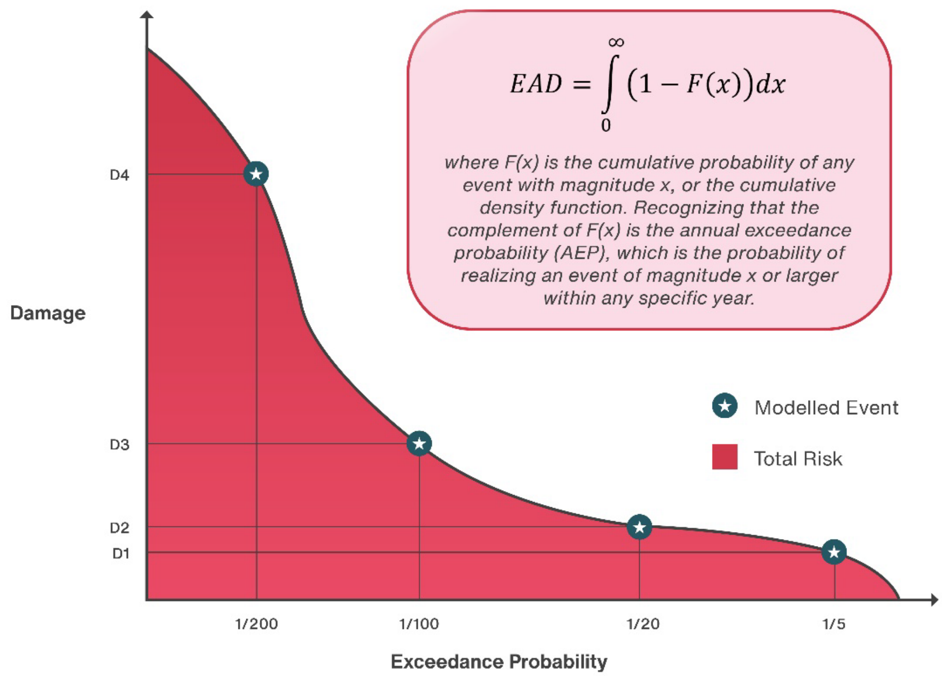

Figure 6: Damage-probability curve example, adapted from Messner (2007), and integration formula

Object-based models like the one employed in this FRA provide a common framework that utilise the exposure and vulnerability of certain assets to calculate the consequence(s) of an event, which is then integrated with the probability of that event occurring to derive risk-based metrics such as EAD. This is conceptually illustrated below in Figure 7.

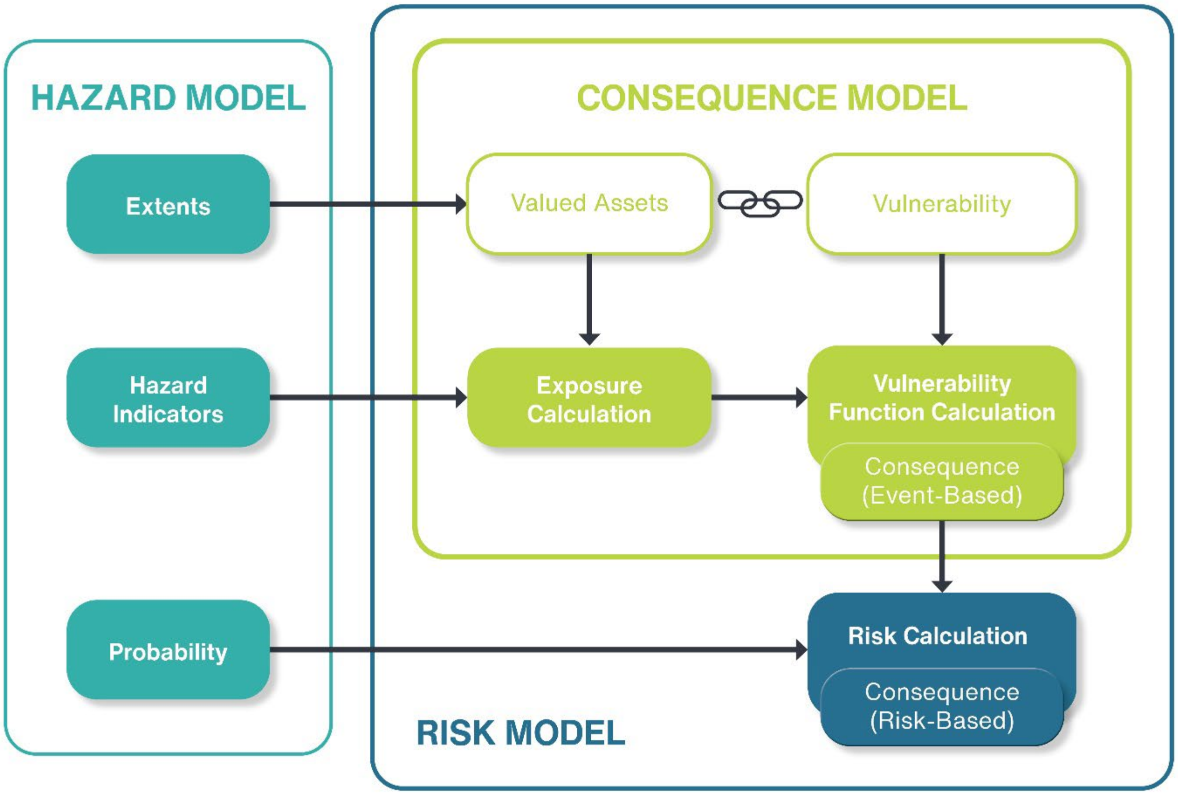

Figure 7: Object-based flood risk model conceptual diagram

Figure 7 consolidates and contextualizes the above sections on hazard, assets, exposure, vulnerability, consequences, and risk within an object-based risk model.

Hazard Model: The hazard data used for this FRA is summarized above in Section 2.2 and additional detail on the hazard model provided below in Section 3.

- Extents: the maximum flood extents were used to determine the study area and the potentially exposed assets within. The study is limited to these assets (i.e., direct damages).
- Hazard Indicators: this FRA uses flood depth as the exposure metric, derived from the WSE files for each event.
- Probability: The risk calculation for this FRA is based on four event probabilities, or ARIs: 20-, 100-, 200-, and 500-year.

Consequence and Risk Models: The assets in Table 6 were either linked to vulnerability functions (L2, buildings) based on their attributes or assigned L1 exposure scales. Based on the asset's location, height and scale, the exposure is calculated to determine the corresponding consequence for each event. Finally, consequence estimates for each hazard event are integrated with the corresponding hazard probabilities to calculate risk metrics.

2.7.1.1 *The CanFlood Toolkit*

NRCan has developed a national standardized flood risk assessment toolkit, CanFlood, which was first released in the spring of 2021, and continues to be updated. CanFlood is an open-source QGIS plugin that is available directly within the QGIS repository or as a download on GitHub. Documentation and tutorials are also available on the NRCan GitHub site.[6]

The CanFlood plugin (version 1.2) was used for all model packages in this study and the reproduceable CanFlood modelling packages, including parameter files, have been provided as digital deliverables.

2.8 Risk Evaluation

Risk evaluation is a latter phase of an FRA where the results are aggregated and communicated in combinations to assist in evaluation and prioritization. This phase should also recognize the preliminary role of a baseline FRA and facilitate its incorporation into the next phases of decision making and planning.

FRAs are one component in the process of mitigation and adaptation planning, which is often iterative, returning to explore risk under multiple scenarios and multiple stakeholder perspectives. As this study covers a broad area but with limited data and details, extra effort was extended to make it a valuable framework for future study – to provide dynamic and expandible deliverables as introduced here and further described in Section 7.

In addition to the risk quantification output, FRAs can provide valuable information that can be used as follows:

- ***Awareness and preparedness.*** This aspect helps to mitigate the flood consequences which can impact the well-being of the community, both with actions taken at the time of a flood and in the recovery process afterwards. With appropriate communication and outreach, FRA findings in combination with hazard mapping can be very effective at raising awareness and preparedness, informing official response plans as well as the actions, health, and relationships of property owners, operators, and all residents. Awareness and preparedness are key components of a community's coping capacity.
- ***Identification and prioritization of further study*.** FRAs require significant effort and resources to prepare, and the resulting risk reduction plan typically involves an iterative approach specific to the community. An FRA of limited but consistent scope, such as a regional study, can identify risks that warrant further investigation and prioritize them for mitigation planning. This applies to areas within a single study and among multiple consistent or standardized studies at a regional or provincial level.
- ***Mitigation assessment and adaptation planning**.* An FRA is most valuable as a tool to explore and assess options to reduce remaining risk efficiently and in terms of community priorities with adaptation strategies, beyond a focus on prevention alone.

[6] GitHub is a site that hosts software development and is a common repository for open-source projects. The CanFlood package, source code, documentation, bug tracking and feature development is available from NRCan at: https://github.com/NRCan/CanFlood

Figure 8: Illustration of risk assessment as a component of mitigation planning

Additional risk assessment scenarios can be used to compare different mitigation options and evaluate their associated benefits, or reduction in risks. Comparing values between the existing and potential scenarios by manipulation of the inputs provides an indication of benefits, making standardized modelling that is reproduceable with modified, *and improved*, inputs more valuable than a static FRA report.

Mitigation planning decisions depend on the existence of a value-based prioritization of the various risk variables to be addressed. This allows the monetary damages to public buildings to be evaluated against damages to private property, or to the release of contaminants, or the exposure of vulnerable populations.

A dynamic, multi-variable approach allows a wider range of adaptation and mitigation strategies to be explored and can illuminate non-structural exposure and vulnerability variables.

Therefore, in addition to providing the core deliverables of:

1. FRA input data: hazard layers, valued asset database, and vulnerability functions;
2. Risk modelling results: a suite of ready-to-use CanFlood model packages; and
3. Reporting and Mapping: this report documenting the context, methods, results summary and static risk maps, and results shapefiles for online mapping,

additional value-added deliverables are included, as illustrated in Figure 9 and described below.

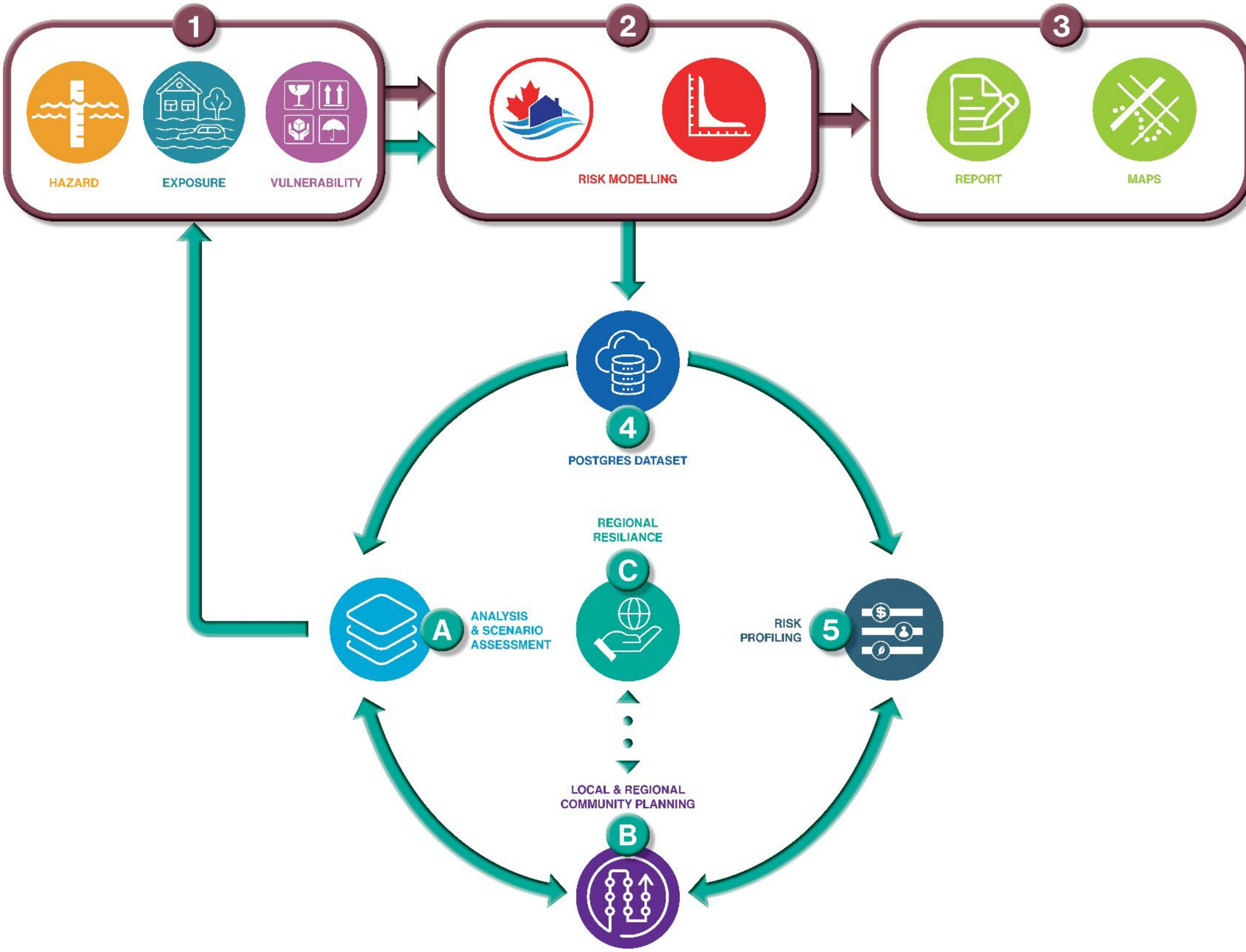

Figure 9: Illustration of relationship between standard deliverables (1, 2, 3), plus value-added deliverables (4, 5), and the objectives for future use (A, B, C).

To facilitate future analysis, spatial and value-based prioritization of risk reduction strategies, and regional or local planning decisions, this project has also produced the following:

4. A PostgreSQL dataset that can be hosted in the cloud, providing direct access to the suite of risk and impact model packages via QGIS and CanFlood.
5. A web-based multi-criteria risk profiling platform connected to the dataset.

As also illustrated in *Figure 9*, the intent of these two digital products is to leverage the FRA data from this study to:

A. Provide authorized analysts with efficient ability to update or improve data quality and/or resolution; to add additional assets or changes to assets and vulnerabilities over time; or to model additional hazard and mitigation scenarios; and

B. Allow decision makers and stakeholders without GIS and risk modelling experience to explore the risk data by hazard scenario and consequence category individually or in weighted combinations. This provides the opportunity for use of the FRA data for a wide variety of interests or perspectives. It's accessibility and options to isolate variables may also identify weaknesses in the baseline data to assist in identifying areas of unmet need and data gaps in this FRA.

The above FRA digital deliverables are all in service of the ultimate objective to:

C. Improve regional resilience to flooding by facilitating a sustainable, adaptive, and integrated planning activities. Use of a dynamic FRA platform is not limited to mitigating current risk but also includes the assessment of all relevant planning activities in the context of flood risk, such as area redevelopment and greenfield plans, site approvals, parks and recreation, or transportation. Therefore, the ability to test hypothetical scenarios with manipulation of the exposure and vulnerability data is an important consideration for future use.

The risk and impact results dataset and web profiler are further detailed in Section 7.

3 Hazard Assessment

The Okanagan Valley is exposed to a wide range of natural hazards, many of which can be devastating, with compounding vulnerabilities (e.g., increased runoff following a fire), dynamic (e.g., changes in flood frequency due to climate changes), and exacerbated by infrastructure failure (e.g., dike failure). For this study, we focus on flood hazards arising from the Okanagan River mainstem lakes and the Okanagan River from Penticton to Osoyoos (*Figure 1*). To supplement this, lake wave hazards and an assessment of river diking is also provided.

3.1 Lake and River Flooding

The Okanagan mainstem is subject to a system of dams and flow controls, the Okanagan Lake Regulation System (OLRS), operated by British Columbia Ministry of Forests (MoF). To develop regulatory maps and explore options for optimizing the OLRS for flood management in the current and future climate, a large data collection and modelling effort was undertaken by the Okanagan Mainstem Floodplain Mapping project (NHC 2020b).

Lake levels, river discharge, and OLRS operations were modelled in the Raven Hydrological Modelling Framework. To obtain hydrological estimates for different return periods of the current and future climate, the Raven model was driven by a 50-member climate ensemble obtained from Environment and Climate Change Canada and then downscaled. To estimate water levels in the Okanagan River floodplain from Penticton to Osoyoos Lake, a 1D-2D hydrodynamic model was constructed in the HEC-RAS framework. The model was constructed using bathymetric cross-section surveys and floodplain LiDAR and was validated against observations from the 2017 and 2018 high water events. For details on these models, see NHC (2020b).

To obtain the more representative set of possible flood events required for risk analysis, the results and models of the Okanagan Mainstem Floodplain Mapping project are expanded to include additional events and scenarios. To simulate the effect of OLRS operations in our risk assessment, two scenarios are considered: 1) the modified operations proposed by the Okanagan Mainstem Floodplain Mapping project in collaboration with MoF; and 2) the current operational rules of the OLRS developed in NHC (2022). Our risk assessment focuses on hydrologic forcings for the mid-century climate under high emissions. Along with the three return periods calculated by the Okanagan Mainstem Floodplain Mapping project (20, 100, and 200-year), our risk assessment includes an additional more extreme 500-year event as shown in Table 6. Resulting datasets are provided in GeoTIFF format catalogued in Appendix A with some additional description in Appendix B.

Table 8: Risk Assessment Scenarios, Flood Events, and Data Source

sub-area	Operations	20-YEAR	100-YEAR	200-YEAR	500-YEAR
Scenario A - NHC (2020) 'modified' operations (or open gates)					
Okanagan Lake	modified	NHC (2020)	NHC (2020)	NHC (2020)	this study
Wood/Kalamalka	modified	NHC (2020)	NHC (2020)	NHC (2020)	this study
Skaha Lake	open gates	NHC (2020)	NHC (2020)	this study	this study
Vaseux Lake	open gates	NHC (2020)	NHC (2020)	this study	this study
Osoyoos Lake	open gates	NHC (2020)	NHC (2020)	this study	this study
Okanagan River	open gates	NHC (2020)	NHC (2020)	NHC (2020)	this study
Ellison Lake	n/a	NHC (2020)	NHC (2020)	NHC (2020)	this study
Scenario B - current operations (or open gates)					
Okanagan Lake	current	this study	this study	this study	this study
Wood/Kalamalka	current	this study	this study	this study	this study
Skaha Lake	open gates	NHC (2020)	NHC (2020)	this study	this study
Vaseux Lake	open gates	NHC (2020)	NHC (2020)	this study	this study
Osoyoos Lake	open gates	NHC (2020)	NHC (2020)	this study	this study
Okanagan River	open gates	NHC (2020)	NHC (2020)	NHC (2020)	this study
Ellison Lake	n/a	NHC (2020)	NHC (2020)	NHC (2020)	this study

This study modeled consequences and risk based on the above four events (20, 100, 200, 500-year returns) and two operational scenarios (modified and current operations). The results summary in Section 6 provides a comparison of scenario risk values and consequences for two events, while full consequence results for all eight events and integrated risk for the two scenarios are available in the model packages, database, and profiler, as described in Section 7.

3.2 Additional Hazard Analysis

In addition to the lake and river flood hazard scenarios and events used to conduct the consequence and risk assessment for this study, information about potential wave effects or dike failures is also provided. This will assist in identification of areas that may be subject to increased risk not represented by flood depth alone and prioritization of further analyses.

Uncertainties, including the location and concurrent probabilities of these hazards, precluded the integration of these hazards into the above scenarios. This is a limitation of this study, as these hazard variables are real contributors to regional risk and its distribution.

3.2.1 Dike Fragility and “Dikes Down” Modelling

Much of the Okanagan River from Penticton to Osoyoos Lake was channelized and straightened in the 1950’s by installing roughly 60 km of dikes and 17 drop structures. To identify critical vulnerabilities and provide context for this infrastructure in the regional flood risk, a desk-top review and synthesis is provided in Appendix C.

For the Okanagan River, additional modelling was conducted to assess potential flood depths and velocities in the event of a dike breach. Using the 1D-2D hydrodynamic model, the simplified “dikes down” approach was used to develop a set of maximum depth and velocity maps. Resulting datasets are catalogued in Appendix A with additional description in Appendix D.

3.2.2 Wave Effects

To evaluate the effect of wind-driven waves on lake-shore flooding, like that which occurred in 2018 and 2019, NHC (2020b) evaluated a 200-year return period wind event for each lake. Following a statistical analysis of station observations during flood season, a spatially varying synthetic wind-field was constructed to force the nearshore wave model. Wave generation and propagation was simulated in the process-based SWAN (Simulating Waves Nearshore) platform. Finally, the two percent wave runup height was calculated from nearshore wave heights and local slope using the empirical USACE Coastal Engineering Manual method.

For this risk assessment, the same workflow as NHC (2020b) was used to calculate the two percent wave runup height for two compound events:

- 20-year still water and 2-year wind event
- 500-year still water and 200-year wind event

Details of these calculations are provided in Appendix E and resulting data files catalogued in Appendix A.

3.2.3 Penticton Beach Breach

An analysis undertaken to understand the potential impacts of a breach of flood protection barriers deployed along Penticton beach. For this analysis, a 500-year return period flooding under a mid-century climate was investigated using five scenarios composed of two Okanagan Lake operation schemes (modified vs. current) and four hypothetical Penticton beach protection/failure schemes. A summary of this analysis is provided in Appendix F.

4 Engagement

The objective of the engagement and communication component of this project was to solicit input that guides the project outcomes and increase understanding and buy-in for the project process and outcomes. In addition to working with OBWB, the advisory committee, and regional staff for specific data requests, the project team engaged a broader group of stakeholders identified by OBWB via direct communication, creation of a project information site, and two virtual workshops to date. This section summarizes these activities, the feedback received, and its incorporation where applicable.

4.1 Project Website

A Digital Engagement Venue (DEV) was created to host project information and the workshops. IBI's DEV websites contain a rendering of a room in which the attendee can navigate to view materials directly or via links to various media. A DEV application can take many forms but is generally used as an online imitation of the traditional "open-house" experience for project stakeholders. Some example images are shown in Figure 10 and the workshop content is further described below provided in Appendix K.

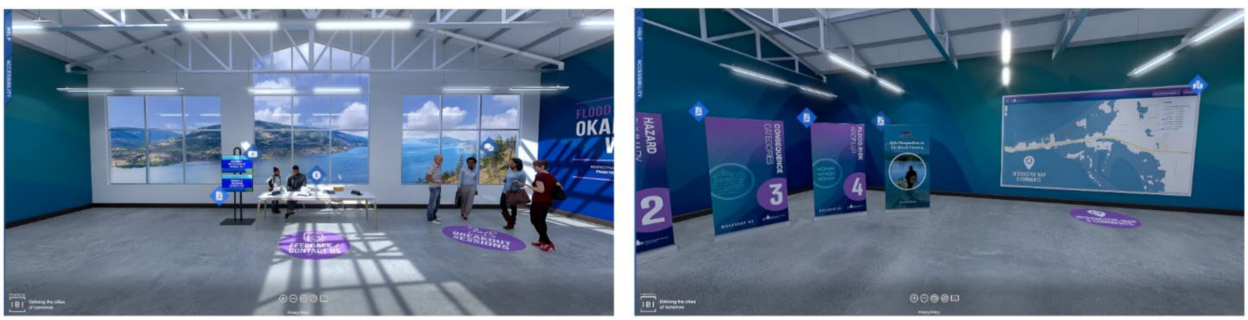

Figure 10: Sample Screen Images from Project Website

4.2 Workshop 1

The primary objectives of the first workshop were to:

- introduce the project scope, methods, and requirements to participants,
- confirm the project objectives,
- solicit feedback on the preliminary list of assets and consequences (see Section 2.3.1),
- request and provide an opportunity to share additional local knowledge on available datasets and vulnerabilities.

The workshop was held at 10:00 PDT on October 6, 2021, at the project DEV site. The workshop agenda included a presentation via MS Teams, breakout discussion in Wonder.me, and opportunity to review background information and provide feedback. Workshop 1 DEV materials are included in Appendix K, and the components are summarized below.

4.2.1 Information Panels

A set of five information panels were provided. Clicking on the panel image opened a popup or new tab with further details. An example of content is copy of the linked content is provided in Appendix K1.

1. *Workshop Overview*: Information about the workshop including Objective, Agenda, Format, and contact info.
2. *Project Background*: A summary of past work, the study area, risk modelling scope, deliverables, and schedule.
3. The background summary also included a link to the more detailed methodology memo previously provided to OBWB and the advisory committee. (Appendix K2)
4. *Project Requirements*: Expanded summary to include additional detail on the data requirements that attendees may be able to assist with.
5. *CanFlood:* Summary and links for information about the NRCan modelling toolset being used for this project.
6. *Feedback*: Link to a webpage form with an opportunity to provide information on the datasets discussed in the presentation; past flood impacts; any unique valued assets or vulnerabilities not identified or included in the existing data; as well as contact information.

4.2.2 Presentation

A live meeting/presentation with Q&A was held via Microsoft Teams. The MS Teams link was provided in the DEV on display image. This live link was replaced with a video recording after the event. The presentation included PowerPoint slides. A pdf of the PowerPoint slides is provided in Appendix K3. The Teams meeting was attended by approximately 53 individuals.

The meeting agenda included team introductions; a summary of project objectives, scope, and data requirements, and concluded with information on the project DEV site, breakout discussion, feedback opportunities, and contact information. Each section was punctuated with a Q&A session.

4.2.3 Breakout Session

Following the presentation, attendees were directed to a more informal and interactive conversation platform, wonder.me, by exiting the Teams meeting and clicking another link in the DEV. The Wonder platform facilitates concurrent virtual breakout conversations. Participants are represented as avatars that can move around the space. When they are near others, they can enter a conversation or join an existing group conversation. A screenshot of the wonder space is provided in Appendix K6.

At this event, attendees largely stayed in one group and engaged in an informal discussion of further introductions, roles, and interests in regional flood risk. It was an opportunity for the project team to learn more about local stakeholders and their respective organizations interests. Participants also asked questions relating to the project scope that were not raised in the Teams meeting environment. This conversation engaged several attendees who had little previous knowledge of risk assessments and were more comfortable asking basic questions in a more informal setting than the main presentation.

4.2.4 Workshop 1 Outcomes

The Q&A sessions were primarily clarifications of the scope and limitations. The project team was able to identify several active individuals for follow up requests. The feedback form was completed by three attendees, providing additional contacts for follow-up.

4.3 First Nations

Following OBWB direction and addendum to our proposal, IBI's First Nations (FN) engagement strategy was focused on identification of appropriate contacts and direct discussions with the Okanagan Nation Alliance (ONA) and the four First Nation communities within the project area.

The objectives of the FN engagement were as follows:

1. Introducing the Okanagan flood risk project and the project team.
2. Identifying staff or representatives that can work with flood risk or flood management that can serve as contacts for this project and OBWB moving forward.
3. Obtaining any missing data that is consistent with the regional data for equal representation across the study area.
4. Offering the opportunity to provide additional data on assets or vulnerabilities that are of specific concern to the FN communities.

Starting with a contact list provided by OBWB, IBI reached out via email and telephone, to identify appropriate contacts. After establishing contacts, the study team followed up with information about the data being used to determine if they had additional information.

We first provided a table and map of assets that we were collecting regionally, indicating what categories we had data for within their communities. After refining our regional data requirements and recognizing that the data tables and maps from the initial request may have been too detailed, we sent a second, simplified and targeted data request with a clearer map showing the community and the data we had.

When we were able to follow-up with contacts again, we did not receive new data and the assets that we were informed of were confirmed to be either already included in our data or outside of our study area (inundation extents).

4.3.1 FN Engagement Outcomes

While we did not receive any additional data from the FN communities, we did obtain a revised list of contacts and our communication with them raised awareness of the study. It is hoped that the modelling approach taken facilitates further opportunities for FN community involvement in regional flood management planning. In addition to inclusion in regional risk models, the modelling approach can readily be applied to any future FN-specific data or asset mapping available. Community-led FN asset mapping would require an engagement level and time that is beyond the scope of this project.

It is unknown if this study, limited to the mainstem lakes, is missing any First Nations assets from the set 15 asset models used. The Syilx Okanagan Flood and Debris Flow Risk Assessment (Ebbwater 2019) provides much better context on flood risk from First Nations' perspectives.

For the second workshop, we were fortunate to be able to include additional information from the Okanagan Nation Alliance (ONA). The ONA provided a series of four storyboards on the Syilx Perspectives on Flood Planning, included in the Workshop 2 summary below.

4.4 Workshop 2

The objectives of the second workshop were to present the risk metrics and methods, and to discuss and conduct a group prioritization or weighting exercise of the risk categories for aggregation. A review of the project background, objectives, scope, and methods was also provided.

The intent was to have all participants complete a multi-criteria exercise using AHP prioritization of the risk metric weights. The goal of this exercise was to raise awareness of ways to interpret FRA results with various metrics. It was also hoped that we could arrive at a weighting scheme that could serve as the basis for the default mapping requirements with a single risk profile combing the various metrics for a regional overview.

The workshop was held at 10:00 PDT on February 2, 2022 at the project DEV site. As with the first workshop, this event included a presentation via MS Teams, breakout discussion in Wonder.me, and opportunity to review background information and provide feedback. Screenshot images of the Workshop 2 DEV are included in Appendix K. The DEV featured updated graphics, including First Nations land acknowledgement and “view” of the Okanagan valley. The workshop components are summarized below.

4.4.1 Information Panels

A set of four project information panels and a set of Syilx Perspectives on Flood Planning were provided. Clicking on the panel image opened a popup or new tab with further details. A pdf document containing the linked content for the project and the ONA’s storyboards are provided in Appendix K**.**

1. *Workshop Information*: Information about the workshop including Objective, Agenda, and Format.
2. *Hazard Summary*: Information from NHC summarizing the background hazard modelling and the new modelling conducted for this risk assessment. Sections included an Introduction; Ellison, Wood/Kalamalka, and Okanagan Lakes, and Okanagan River; Wave Effects; Penticton Beach Breach; Dike Vulnerability; and Dikes Down Modelling.
3. *Consequence Categories*: A summary description and table of the risk models constructed for this assessment. Models are categorized by Economy (monetary results), Infrastructure (mixed metrics for potential disruption); People (affected populations); Environment (potential pollutant releases); and Culture (exposure of sites). This information was provided as reference for the workshop discussion of how to aggregate various risk metrics for a regional profile.
4. *Flood Risk Profiler:* An introduction to the proposed multi-criteria-prioritization or weighting method: Analytical Hierarchy Process.
5. *Sylix Perspectives on Flood Planning*: A set of four storyboards provided by ONA: Syilx siwɬkʷ (Water) Strategy; Syilx siwɬkʷ (Water) Declaration; t̓ik̓t (flood) Adaptation Project; and kłusxnitkʷ (Okanagan Lake) Responsibility Planning Initiative.

4.4.2 Interactive Map

The Workshop 2 DEV featured an interactive map allowing attendees to view the main flood mapping extents across the region. Users could zoom and pan to explore inundation for four mid-century events, each with current and modified operations displayed: AEP 5% (20-year RP), AEP 1% (100-year RP), AEP 0.5% (200-year RP), and AEP 0.2% (500-year RP).

The map also allowed for attendees to drop a pin and provide additional information or feedback. Comments and contact info were optional, and the user could select if the information was public to other attendees or private for the study team. No comments were provided.

4.4.3 Info Desk

An “information desk” was added to the DEV. At this desk, material from the first workshop was provided (info boards and recorded meeting). It also featured another opportunity for feedback via a web form. No feedback was provided via this form.

4.4.4 Presentation

A live presentation with prioritization workshop was held via Microsoft Teams. The MS Teams link was provided in the DEV on display image. This live link was replaced with a video recording after the event. The presentation slides are provided in Appendix K The Teams meeting was attended by approximately 45 individuals.

The meeting agenda included team introductions; workshop overview, project summary, risk evaluation, multi-criteria analysis (AHP), risk models summary, and Q&A sessions. A primary feature of the workshop meeting was the use of AHP prioritization by attendees.

For this project, IBI has developed a new Flood Risk Profiling tool for OBWB (Section 7.2), which was still in development at the time of the workshop. An established third-party online AHP tool was used for the workshop to validate the process and incorporate any feedback in the development of the Okanagan FRA platform. The "AHP Online System" (AHP-OS) provided by BPMSG was used and populated with the consequence categories and risk models from this project.[7]

Following the project summary and introduction to the AHP process, the consequence categories were reviewed one at a time with an overview of the data sources, limitations, and a preview of preliminary risk mapping. After each summary, participants used the AHP-OS site to complete pairwise comparisons or prioritizations for each set of metrics by category (or 'criteria').

The project team assisted with technical questions and project details while using the AHP-OS prioritization as participants completed each set. The AHP process consolidates group results and allows for statistical checks on consistency and group consensus. Illustrations of the AHP-OS input structure and result analysis is provided in Appendix K

The presentation portion of the workshop finished with a preview of the features being developed for the project's flood risk prioritization and profiling tool that will incorporation the AHP process, risk profiling, and the resulting rank displays.

The Teams session concluded with a Q&A session, next steps, and instructions for the opportunity for further conversation in the project Wonder space.

4.4.5 Breakout Session

As with the first workshop, the second concluded with an informal discussion and question period with the project team in the wonder.me space. An image of the wonder space is included at the end of the presentation slides in Appendix K.

4.4.6 Workshop 2 Outcomes

The objective of informing participants about the project, status, next steps, and an introduction to the AHP prioritization were successfully completed, which was valuable as many attendees were not present at the first workshop or otherwise had little knowledge of the risk assessment process and the requirements for risk analysis. However, and largely due to this lack of familiarity with the process and need for prioritization, the goal of obtaining a group-derived default weighting for use in the final report and results mapping was abandoned.

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[7] Website: https://bpmsg.com/ahp/
Goepel, K.D. (2018). Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS). *International Journal of the Analytic Hierarchy Process*, Vol. 10 Issue 3 2018, pp 469-487, https://doi.org/10.13033/ijahp.v10i3.590

Feedback from participants mainly expressed a lack of confidence in the ability to provide input that would be reflected in the risk assessment deliverables (individually or as a group). The project team offered a week of time for further discussions and AHP input opportunities, including invites for two hour-long sessions in the project's wonder space for assistance. There were no attendees at these sessions, but the project team did respond to several follow-up emails and held two meetings with representatives from Lake Country to provide additional information.

Based on participant feedback and completeness of the AHP results (in terms of number submitted and the consistency), the project team realized that participants would not be satisfied with the use of the group weighting for presentation of aggregated risk.

This realization was not surprising nor detrimental to the outcome of the project. Rather, it strengthens our rationale for the development of a dynamic prioritization and profiling tool for OBWB and other regional interests.

A combined risk profile of the region is not possible without the completion of prioritization and weighting, such as the AHP process. We cannot sum the disparate metrics, nor should the project team opaquely make these decisions for the diverse stakeholders of the region. Therefore, in addition to the profiler tools, AHP resources have also been provided (see Section 7.2.5 and Appendix N).

In summary, the workshop was valuable to increase knowledge of the project, to introduce the prioritization/weighting required, and to obtain important feedback on the treatment of results in the final reporting. It is hoped that this awareness will increase the use of the dynamic prioritization and profiling platform as a valuable outcome of this project and future work.

4.5 Non-Residential Property (NRP) Survey

This section summarizes the survey engagement generally, for details on the treatment of the results, see Section 5.1. One of the most important and tangible risk metrics is potential flood damages relating to buildings. Not only does this property damage account for a large portion of economic impacts, but it is also a key driver or proxy of the many impacts that are less tangible or that we simply have sparse knowledge or data sources for. The presence and density of buildings is directly related to many other activities, resources, and populations.

For structural damages, we have adopted robust modelling processes used by the insurance and restoration industries for estimating flood restoration costs for archetypical building structures. Flood losses for the contents of buildings is less well understood and lacking data sources. In 2014, IBI Group conducted detailed surveys of residential homes to construct damage functions. These functions can be reasonably indexed spatially and temporally to the study area and are considered the best source currently available. NRPs, however, are far less consistent and complex, with greater uncertainty in the available data.

Recognizing this gap in knowledge, IBI's risk assessment team has sought information on NRP flood vulnerabilities by conducting surveys of owners or operators. In B.C. we have conducted two such surveys, one for the Lower Mainland in 2020 and another in the Okanagan for this project. Our Lower Mainland survey was developed and administrated by BC Stats. The survey was a dynamic web-based questionnaire to elicit hypothetical flood outcomes. It was distributed to 10,000 properties with a response rate of approximately 8%, or 800. The Okanagan survey was based on the BC Stats learnings but administered by IBI Group independently. Invites were similarly distributed to approximately 10,000 properties based on Canada Post and Statistics Canada business registries.

The mail out invite is provided in Appendix K. The original invite was mailed mid-November 2021 and a follow-up reminder was sent mid-December 2021. As expected, the response rate was lower than the previous survey administered by BC stats, with approximately 125 complete responses. This is a very low response rate but an important, if minor, contribution to our understanding of local NRP vulnerabilities. The results supplemented the previous findings and has been used for the creation of monetary damage functions for this study, as described in Section 5.1.

A copy of survey questions is provided in Appendix K17*.* Note that this extract does not accurately reflect the survey formatting as seen online. The online survey was dynamic (responses dictated question inclusion and order), and colours and images are not accurately reproduced in this copy.

The charts produced by the survey instrument and the raw results in csv format are also included in Appendix K. The breadth of questions and results extended beyond the use for this study, and it is hoped it may prove valuable for future analyses.

4.6 Workshop 3 – Final Draft Presentation

A final DEV session with project partners and stakeholders is planned to present the final draft report and use of the risk models, regional results, and risk profiler, and a discussion of the use of these deliverables going forward.

The workshop will include a discussion on results analysis and options for presentation of the results that will supplement this report when completed.

5 Data Collection and Processing

The flood risk maps produced by this study are driven by a broad, extensive, and diverse collection of data describing the region and its assets. To assemble these datasets, the project team engaged dozens of governments and quasi-government data owners to obtain both open and protected data. In general, these data sets are complex, spatial, and not focused on flood vulnerability. A complete catalogue of the data collected by the project team is provided in Appendix G.

Extracting information relevant for flood risk modelling from the collected datasets required extensive cleaning and analysis by the project team. These efforts included for-purpose scripts developed in-house, manually cleaning and manipulating data, statistical modelling, conducting a mail and web-based survey of local business, and crowd-sourced image processing. These 'derived' datasets which contained the data used directly in flood risk modelling are described in the catalogue provided in Appendix H.

Table 9 provides an overview of the primary data and processing level for each of the 15 models developed for the OFRM, indicating derived data where applicable. The table also introduces the 'model tags' employed to identify the model in data file names.

All models used the Hazard data described in Section 3. Information about the processing and construction of the derived CanFlood asset inventories is provided in Section 6, with the respective subsection indicated under the model tag in Table 9.

The remainder of this section summarizes the data collection and processing for the major derived datasets developed and used in this study.

Table 9: Data collection overview by risk model

RISK MODEL	MODEL 'TAG'	PRIMARY EXPOSURE INVENTORY DATA
affected population	ppl.afct Section 6.1	BC Assessment residential data catalogue, StatsCan census of population
vulnerable population	ppl.vuln Section 6.2	NRCan National Human Settlement Layer, ppl.afct inventory
building damage	econ.bldg Section 6.3	**Derived:** Building Database – Section 4.5 (includes: NRP survey 4.1, Footprints 4.2, Heights 4.3, BCA 4.4)
crop damage	econ.crops Section 6.4	Agricultural Land-Use Inventory (ALUI), StatsCan yield and farm product prices
park damage	econ.parks Section 6.5	Open Street Maps, BC Local and Regional Greenspaces, Agricultural Land-Use Inventory (ALUI)
recreation loss	infr.parks Section 6.6	
road disruption	infr.roads Section 6.6	BC Digital Road Atlas
power service disruption	infr.power Section 6.8	BC Hydro, FortisBC, Municipal electric infrastructure shapefiles
water service disruption	infr.water Section 6.9	Water utility shapefiles
wastewater service disruption	infr.ww Section 6.10	Water utility shapefiles, BC Waste Discharge Authorization Management System, local reports
wastewater release	env.ww Section 6.11	
contamination release	env.pol Section 6.12	National Pollutant Release Inventory, BC Assessment data
cultural facility disruption	cult.faci Section 6.13	BC Assessment data
archaeological sites exposure	cult.arch Section 6.14	BC Archaeological and Heritage Register
historic building exposure	cult.hist Section 6.15	BC Archaeological and Heritage Register

5.1 Non-Residential Flood Vulnerability Survey

As described in Section 4.5, the study team designed and conducted a mail and web-based survey of non-residential property (NRP) managers to gain a better quantitative understanding of non-residential flood vulnerability in the study area. Participants were asked to provide impacts to their facility and operations from two hypothetical flood depths, the potential for hazardous material release, perceived business resilience, and any previous flooding experience. This section summarizes the collection and treatment of the data to supplement the existing NRP depth-damage functions transferred from Alberta (IBI 2015).

5.1.1 Survey Instrument

A dynamic web-based survey instrument was developed to elicit hypothetical flood outcomes from NRP representatives. Questions were designed from previous experience surveying NRPs in B.C. and methods and findings from similar European work (Penning-Rowsell et al. 2013; Kreibich et al. 2010). All questions could be skipped by the participant, and the instrument was programed to omit irrelevant questions based on previous responses. All response options were categorical, and graphics were included to reduce participant fatigue and confusion between similar questions. The questions can be summarized into the sections shown in Table 10. A print-out of the complete instrument is included in Appendix K17.

Table 10: NRP Survey question section summary

SECTION	DESCRIPTION
0	Intro
1	General
2	Flooding experience
3	Space and Building topology
4	Space and Building topology: Shared building
5	Space and Building topology: Yard
6	Space and Building topology: unshared building
8	Building Structure, Fabric, and Services Vulnerability
9.1	Equipment vulnerability: Inside
9.2	Equipment vulnerability: Outside
10.1	Materials and goods vulnerability: inside
10.2	Materials and goods vulnerability: OUTSIDE
11	Hazardous material release vulnerability
12	Mitigation
13	Risk transfer
14	Resilience to Disruption
15	Confidence
16	Closing

5.1.2 Survey Results

115 responses [IBI_0105] were collected from November 11th 2021, to January 1st with 53 answering the final question (see Figure 11 for spatial distribution).

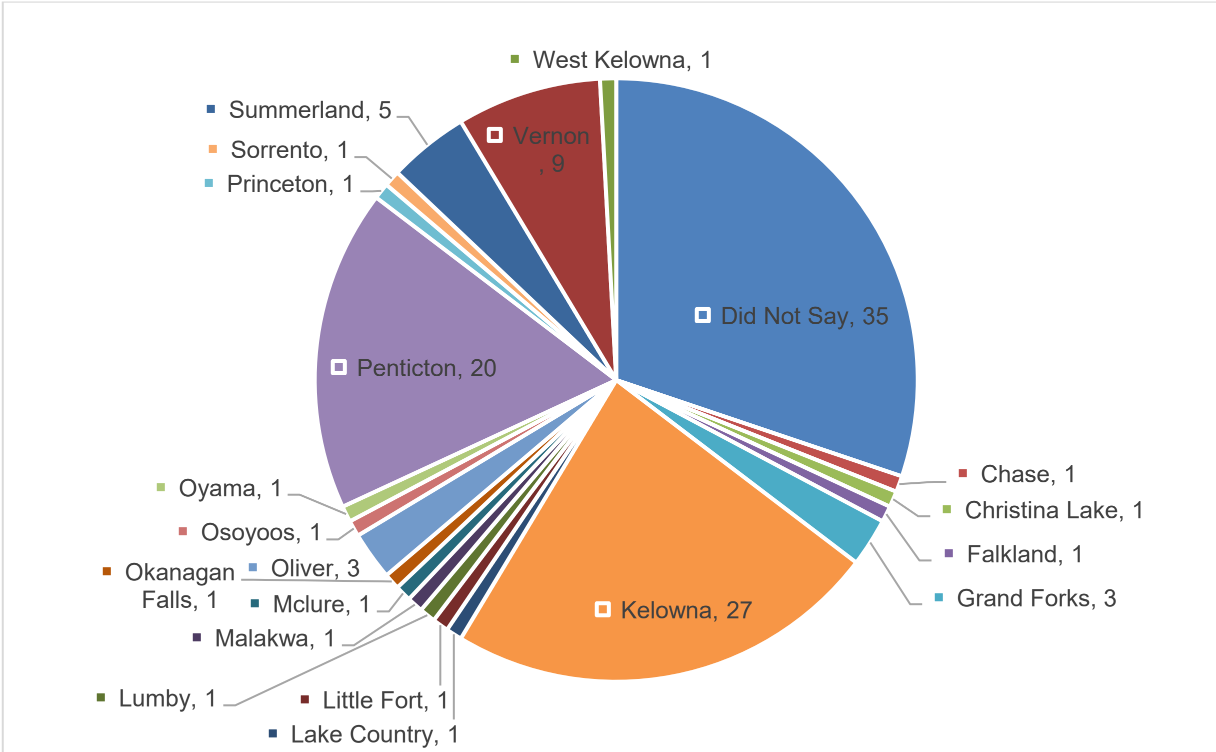


Figure 11: NRP survey participant summary by 'town'

Table 11: Response counts by sector and use category.

INDUSTRIAL SECTOR	RESPONSE COUNT	USE CATEGORY
n/a	33	n/a
Retail trade	13	retail
Other services (except public administration)	10	other
Professional, scientific and technical services	8	office
Construction	6	other
Manufacturing	6	other
Agriculture, forestry, fishing and hunting	6	other
Transportation and warehousing	6	other
Health care and social assistance	6	other
Finance and insurance	5	office
Accommodation and food services	4	other
Arts, entertainment and recreation	4	other
Don't know	4	other
Educational services	2	office
Real estate and rental and leasing	2	office
Wholesale trade	1	other

5.1.3 Depth-Damage Curves

Responses from the NRP survey were used directly in the construction of building-contents damages models for non-residential properties. Raw response data was first cleaned and categorized into one of the four categories shown in Table 12. Questions from section 9 and 10 (Table 10) were then used to calculate a lower and upper range of total hypothetical damage estimates for each cost element described in Table 12 for each response. Building footprint areas were then linked to each response manually using the addresses provided. From these, the damages per square meter for the two depths queried for each record were calculated. The mean and quantiles (0.4 and 0.8) of each use category were then calculated (see Appendix K18 for plotted results). Finally, these values were compiled into the eight CanFlood format vulnerability functions provided in [nrpVf_0405].

Table 12: NRP Survey cost elements

CODE	LOCATION	COST ELEMENT
inEq	inside	repair or replace damaged equipment
outEq	outside	repair or replace damaged equipment
inStk	inside	repair or replaced all damaged stock, finished goods, work-in-progress, and raw materials
outStk	outside	repair or replaced all damaged stock, finished goods, work-in-progress, and raw materials

5.2 Buildings Footprints

Building footprint polygons are a spatial representation of each building within the study area and provide a foundational data source for the construction of the building vulnerability database and many flood risk models. Therefore, obtaining an accurate and complete building footprint layer is essential for understanding flood risk in the Okanagan and considerable effort was invested in this pursuit.

Two data sources with national coverage were first investigated and found to be inadequate. MicrosoftBuildingFootprints [Micro_0908] had missing and inaccurate footprints while Statistics Canada's Open Database of Buildings (https://www.statcan.gc.ca/en/lode/databases/odb) had very little coverage of the study area. Following this, an effort was initiated to obtain building footprint data from the 15 local governments within the study area. Open access websites were first investigated before contacting representatives directly to request the data. The coverage of building footprint data obtained directly from local sources is indicated in Table 13.

Table 13: Building footprint data acquisition by jurisdiction

REGIONAL DISTRICT	DISTRICT MUNICIPALITY	CITY
• Central Okanagan • Okanagan Similikameen	• Lake Country • Summerland • Peachland	• City of Penticton • City of Kelowna • City of Vernon • City of West Kelowna

The raw data collections shown in Table 9 were mosaicked together. Where no data was obtained from a jurisdiction, data from MicrosoftBuildingFootprints [Micro_0908] was used. This mosaicked layer was further processed to: 1) remove overlapping and invalid geometries; 2) split buildings along property lines [ICI_0902c]; 3) some manual corrections; 4) trimmed to the study area; and 5) assign a unique identifier to each building polygon. This resulted in 47,561 features (see [bfprt_0122]).

5.3 Buildings Main Floor Heights

The elevation or height at which a building becomes susceptible to flood damage is a significant predictor of physical flood vulnerability (Abboud et al. 2018; Bryant 2019), and therefore flood risk. This important information is rarely digitized and existing methods are generally cost-prohibitive beyond a few hundred buildings.

While the entry point of floodwaters will vary by structure (e.g. basement window, sewer, or front door), the elevation of a structure is typically referenced from the main floor height above grade.

To obtain building main floor heights for this study, a novel method employing the Google StreetView API and Amazon's crowd-sourcing marketplace 'Mechanical Turks' was developed, tested, and executed using in-house scripts. To maximize and report on accuracy, an automated quality assurance program was implemented for each crowd-source survey that compared responses to a 'golden' or trusted set and against responses from peers. The complete process is summarized as follows:

1. A static GSV image was requested for each house/building (44,419) in the Okanagan region study area, with ~30,000 images being returned.
2. To pre-filter images, workers were asked to classify images based on whether the front door was visible.
3. From this filtered set, workers were asked to count the number of front doorsteps as a proxy for the main floor height [bmfh_0319].
4. Finally, the median value was selected for each asset and multiplied by 18 cm to obtain the main floor height in meters.

From these surveys, just over 9,000 images could be classified with an accuracy of 67.2% based on a control 'golden' set of pre-classified images. Main floor heights for the remaining buildings were imputed as discussed in Section 4.5. A complete discussion of the process and results is provided in Appendix I.

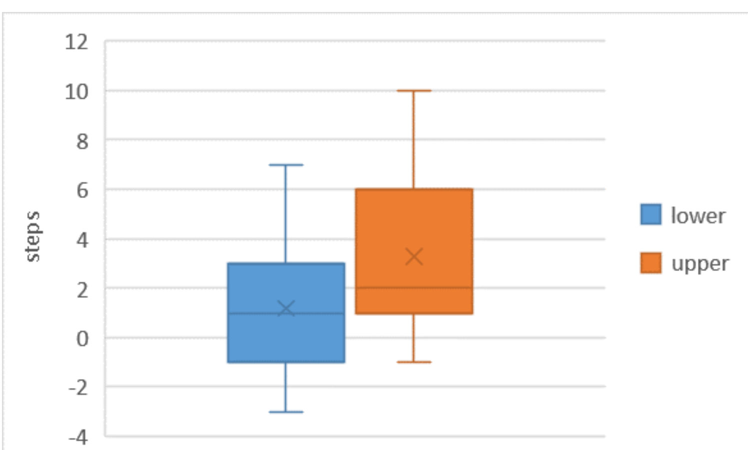


Figure 12: Building main floor height data summary

5.4 Property Assessment Records

Flood damage models related to buildings rely heavily on tax assessment data as the richest source of property-level data. In BC, assessment data is collected and maintained provincially by BC Assessment — primarily to support municipalities in land taxation. To build and maintain their property assessment database, BC Assessment collects data from:

- Building permits
- Land titles office
- Real estate transactions
- Property owner-initiated updates
- 3D modelling of Vancouver's downtown condos to determine views
- Requests sent to property owners
- A visit to the property
- Aerial and street-front imagery (BC Assessment 2020)

From this primary data, BC Assessment calculates additional fields (e.g., market value) using unpublished in-house methods. The main fields of interest extracted from the BC Assessment property data for the vulnerability database are summarized in Table 14.

Table 14: Summary of BC Assessment Property Data Fields

FIELD NAME	DESCRIPTION
Manual Class	Defined and assigned by BC Assessment. Categorizes a building's architecture style, number of storeys and the quality of its construction components and design. used to categorize buildings for administrative, valuation and statistical purposes.
Actual use	Primary purpose or activity that a folio is being held or used for
Bedroom Count	Number of bedrooms in the dwelling.
Foundation Type	Indicates type of foundation: (full basement, partial basement, slab, crawlspace)
Year of Construction	The year that construction began on the predominant improvement on the property.
Building Storeys	Indicates the number of storeys in the building. A storey is a distinct level of space above the basement, crawl space or slab foundation.
Total basement area	Area (in square feet) of a level partially or entirely below ground level.
Construction material type	Specifies the material framing the building: (A is Fireproof structural steel frame, B is Reinforced concrete frame, C is Masonry bearing walls, D is Wood or steel framed exterior walls, H is Hoop arch, M is Mill type, P is Pole frame, S is Metal frame, W is Metal frame and walls)
Property Class	Residential, Utilities, Major Industry, Light Industry, Business and Other, Managed Forest Land, Rec/Non-Profit, Farm
Property Subclass	Residential type

BC Assessment (BCA) data was provided through four datasets covering all of B.C.:

- **Assessment Fabric**: spatial polygons representing each folio in B.C. [ICI_0902c];
- **Data Advice**: XML dump (15 GB) containing a variety of property data, including improvement values, land values, sales data, legal descriptions [BCA_0924];
- **Residential Extract**: Text files containing data for residential properties for each BCA area, including floor area, yea built, number of baths, etc. [BCA_1007a];
- **Commercial Extract**: Text file containing data for commercial properties for all the BCA areas, including land area, gross building area, hotel units, etc. [BCA_1007b].

To convert the Data Advice to a usable format, the XML dump was parsed using in-house scripts before joining a selection of records to the Assessment Fabric.

5.5 Buildings Vulnerability Database

In the absence of a purpose-built dataset of flood vulnerability, this study maximized the use of existing data sources to obtain the best vulnerability indicators available for flood damage modelling and assembled these into the *buildings vulnerability database* [bvdb_0122]. This database provides a complete set of flood vulnerability indicators for each building in the study area, scraped from the best available data. Following a review of previous studies and a survey of data hosting platforms, the following datasets were selected for inclusion in the buildings vulnerability database:

- BCAssessment property records (Section 4.4)
- Buildings footprints (Section 4.2)
- Okanagan Agricultural Land-Use Inventory [AFF_1015]
- Building main floor heights (Section 4.3)

The following challenges were encountered when collapsing and cleaning these data sources:

- heterogeneous spatial components (e.g., building footprints, property parcels, agricultural fields, built-up areas);
- many missing/sparse attributes, some overly complex fields (e.g., 700+ ‘class’ codes);
- some complex relations to physical buildings (e.g., a single apartment building may have 500+ property records, or a single property record may have 500+ buildings); and
- information pertaining to floors above ground (which are less relevant to flood vulnerability).

To overcome these challenges and clean and collapse these ‘raw’ data sources onto a single record of useful attributes per-building, the following basic steps were undertaken using in-house scripts:

- An algorithm based on the relationships of building to parcels and the size of buildings was used to remove residential accessory buildings (e.g., garages)
- An algorithm based on the number of floors or storeys of a building and the number of assessment records per building was used to identify a ‘ground floor relation’ of each record (e.g., records pertaining to the ground floor were assigned a value of 1.0 and those with no relevance to the ground floor a value of 0.0).
- An algorithm for spatially joining records to each building footprint was used to collapse each ‘raw’ record. This required identifying the appropriate grouping statistic for each field (e.g., ‘improvement values’ were summed while ‘building quality’ was averaged) and weighting by the ground floor relation (e.g., ‘number of bedrooms’ includes all bedrooms in the building while ‘finished area’ only includes those on the main floor).
- To impute missing values, first additional data based on the jurisdiction and geometry of each building was attached (e.g., ‘building perimeter’ and ‘regional district’). From these, outliers were separated and imputed manually using expert judgement and google street view. The remaining values were imputed using statistical models or a default value.

This process resulted in a database of roughly 43,000 records (one per building) within the study area and the fields summarized in Table 15 [bvdb_0122].

Table 15: building vulnerability database field summary

FIELDNAME	DESCRIPTION	UNITS	TYPICAL FIELD VALUES
area	building footprint area	m2	1986.5
bdrms	total number of bedrooms	count	2
bgid_area	area of property	m2	1986.5
bid	project identifier for each building	indexer	1000, 2000, 3000
bsmt_type	basement type	category	none, crwl, or bsmt
fid	automatic feature identifier	indexer	0, 1, 2
finish_lvl	building finishing quality level	category	'hi' or 'std'
found	foundation type	category	Basement, Crawl, Partial Basement, mobile, Slab, deep
gvimp_gf	gross improvement value of the ground floor	$CAD	1,986.50
HAND	height above nearest drainage value for building	m (vertical)	1.9685
lcl_index	local government index	category	10
quality_gf	construction quality	category	std, cust, fair, excel, substd, better, low, avg, poor, good
quality_gf_score	1 to 5 construction quality score	category (continuous)	1,2,3,4,5
stories_gf	number of stories or levels	stories	2
use1_gf	use category 1	category	resi, nrp, util, ag
use2_gf	use category 2	category	sfd, mh, mf, retail, office, gar, comy, rec, rest, greenhouse, power,
steps_lb	steps up to main floor (lower bound)	steps	2
steps_ub	steps up to main floor (upper bound)	steps	2
mf_height	main floor height estimate ((steps_lb+steps_ub)/2*0.5)	m	1.2

6 Flood Risk Analysis

Each of 15 risk models represents and seeks to estimate a different metric of how floods can impact the region (e.g., building repair costs, persons affected) — the collection of these is referred to as the *Okanagan Regional Flood Risk Model suite* or ORFRM summarized in Appendix H. The compiled suite is provided in [cfSuite_2303] and the inventories and hazard layers used to construct the suite are provided in [finv_2303] and catalogued in Appendix A, respectively.

A grand total for each category or metric is informative, however for large-scale studies such as this it does not meet the objective of understanding the distribution of risk and prioritization for planning and further analysis. The raw consequence and risk results are calculated per asset, which is also not an appropriate scale for communication. Therefore, some form of spatial aggregation is required and may vary by purpose.

Flood extents rarely align well with existing statistical or political boundaries, an issue for both preparation and communication of FRAs. The result dataset (Section 7.1), has been aggregated at several levels to facilitate spatial analysis. The following four geographic scales have been provided in decreasing size:

- StatsCan Regional Districts (RD)
  There are three RDs within the study area: North Okanagan, Central Okanagan, and Okanagan-Similikameen.
- StatsCan Census Subdivisions (CSD)
  There are 25 CSDs within the study area. CSDs are the most recognizable StatCan geography because they reflect municipalities or areas treated as equivalent for statistical purposes (e.g., “Indian Reserves”, settlements, and unorganized territories). As such, they typically have recognizable names and boundaries.

  A map identifying the CSDs within the study area is provided as *Figure 13*.
- StatsCan Dissemination Areas (DA)
  A DA is a smaller unit, typically with a population of 400 to 700 persons. It is the smallest area for which all census data is provided. Because the boundaries are population-based, the size of DAs varies greatly.
- 500m x 500m Grid
  The 500-meter grid is an additional resolution added to this project which, unlike the statistical units, is consistent in size and shape, with no relation to population or administrative boundaries.

Although practical, such geographic aggregation has limitations and potential for misinterpretation. Users of this report should always keep in mind that these divisions have no relation to flood extents and are not evenly distributed in terms of exposure (i.e., not all equally inundated). Thus, they do not necessarily reflect a density of consequences and could dilute by division any “clusters” or “hot spots”. Furthermore, some of the statistical divisions within the study area have exposure in more than one non-contiguous reach of the lakes. The 500m grid was included to partially address this but likewise has no logic in its divisions other than scale. Additional geographies can be added, and results queried from the risk model and results dataset if required for other purposes.

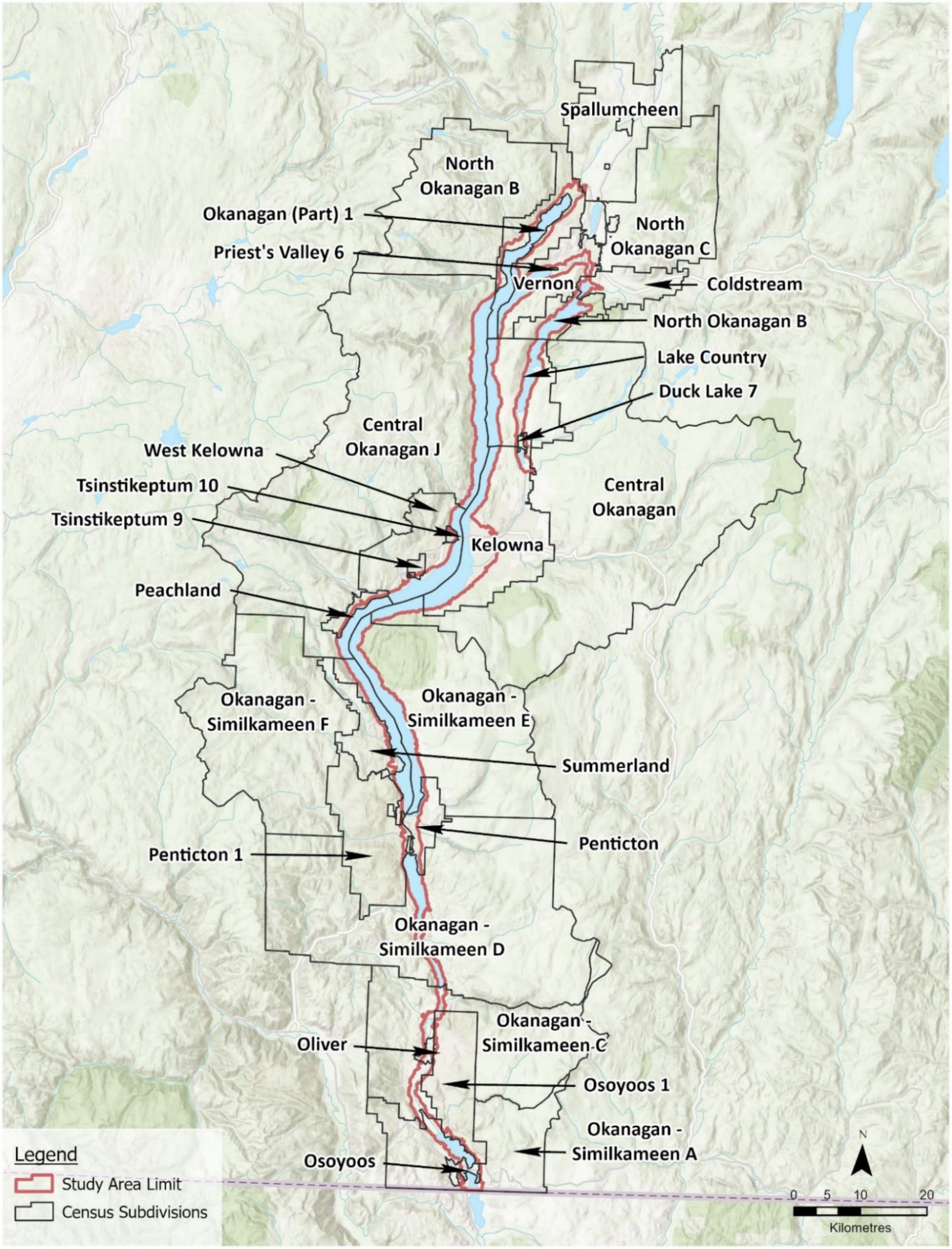


Figure 13 Statistics Canada Census Subdivisions within study area

As discussed in Section 2.8, a primary effort for this study was the provision of a regional flood risk model and dataset that can be used, updated, and built upon as the region's various flood risk and adaptation strategies evolve. In addition to the CanFlood risk model suite described above, this initiative includes the packaging of this data in a risk and impact results database for technical assessment and further development (Section 7.1) as well as a companion web-based 'risk profiler' interface to dynamically view the results from various perspectives (Section 7.2).

The emphasis on the modelling and risk evaluation deliverables notwithstanding, a report needs results, and t this section provides details on the static mapping products, followed by a summary section for each of the 15 models including a table of risk and select event and scenario consequence results.

PDF Maps

The spatial results of the 15 risk models were combined according to categories and metrics to produce a set of 7 PDF risk maps, provided in Appendix L.

The maps display the results as annualized risk (AED) for Scenario A (modified operations), with symbology deemed appropriate for the metric. The maps also include a depth layer for the 500-year ARI event for reference. This mapping can be reproduced in alternative combinations, resolutions, base layer, or symbology as needed using either the results database or the set of model results shapefiles provided.

The following is a brief description of the provided pdf files:

1. People – Affected Population: results of ppl.afct model, aggregated by a 500m-by-500m grid.
2. People – Vulnerable Population: results of the ppl.vuln model, aggregated by a 500m-by-500m grid.
3. Economy – Buildings, Crops, Parks: results of the econ.bldg, econ.crops, and econ.parks models, combined and aggregated by a 500m-by-500m grid.
4. Infrastructure 1 – Water, Wastewater, Power: results of the infr.water, infr.ww, and infr.power models, individually by site.
5. Infrastructure 2 – Recreation, Transportation: results of the infr.parks and infr.roads models, individually by site and segment, respectively.
6. Environment – Wastewater, Contamination: results of the env.ww and env.pol models, individually by site.
7. Culture – Facilities, Heritage, Archaeological: results of the cult.faci, cult.arch, and cult.hist models, individually by site.

Web Mapping

The digital deliverables include spatial result files for each modelling package [cfSuite_2303]. These shapefile layers can be added to web mapping applications with the desired symbology to illustrate the risk or event consequences.

Geographically aggregated results can be obtained for risk and consequence values for all events and both scenarios via the results database described in Section 7.1.

Additional results mapping for individual or weighted combinations of consequences is available via the Flood Risk Profiler web tool, described in Section 7.2.

Model Summaries

The following subsections provide additional information about each of the 15 risk models. The risk models and results summary are presented in the following format:

- ***Model at-a-Glance***: summary info about the model
- ***Model Description***: brief description of the model
- ***Model Limitations***: identified limitations of the model
- ***Model Results***: summary table and brief discussion

Hazard events and scenarios summarized:

As described in Section 3, the Okanagan mainstem is subject to a system of dams and flow controls, the Okanagan Lake Regulation System (OLRS), operated by British Columbia Ministry of Forests (MoF).The Okanagan Mainstem Floodplain Mapping project (NHC 2020b) included modified OLRS operations.

To simulate the effect of OLRS operations in this risk assessment, two scenarios are considered: 1) the modified operations proposed by the Okanagan Mainstem Floodplain Mapping project in collaboration with MoF; and 2) the current operational rules of the OLRS. As listed in Table 8, this study modeled consequence and risk based on four events (20-, 100-, 200-, and 500-year returns) for both the modified and current operational scenarios.

The digital deliverables contain the results for all events and both scenarios and the above geographies. This creates many combinations in which to view the results. This report, however, contains a limited set of result tables as described below.

1. Total Event and Risk Results, Current Operations. This is a simple summary of total consequences for each event and the annualized risk value (EAD). See Section 2.7 for an explanation of annualized risk.

Table 16: Model Result Table 1 Description

Model: (tag) (units)		
Event (ARI)	20-yr	total value per event
	100-yr	
	200-yr	
	500-yr	
Annual Risk		total EAD

2. Comparison of Risk by Scenario and Modified Event Impacts by CSD top five. This table provides an alternative view of the results by geography, focusing on Modified Operations and a comparison of risk between scenarios. Table 16 provides an explanation of the results shown in these tables.

Table 17: Model Result Table 2 Description

Model: (tag) (units)					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
CSD Name (see Figure 14)	EAD: modified operations scenario (see Table 6) all results sorted by this column, highest to lowest)	EAD: Current operations scenario (see table 6)	EAD difference between scenarios (current - modified), expressed as % of current.	consequences 100-year ARI event modified operations.	consequences 500-year ARI event modified operations.

6.1 Affected Population

Model at-a-Glance

tag	ppl.afct
category	people
sub-category	affected
type	exposure (L1)
metric	affected persons
unit	count
description	population within or associated to exposed dwellings
Primary data source	BCA Residential Inventories [BCA_1007a]

Model Description

This model estimates the population affected by flooded buildings, not physically exposed. It is not a life-safety estimate.

While it is safe to assume people would be greatly affected if their home was flooded, it is limited as an indicator of “affected” alone considering all the social and physical dynamics of people. Indirectly, flooding potentially affects people in innumerable ways within the study area and beyond. Physically, the population is not stationary and typically move throughout the area and beyond for employment, services, recreation, and social activities. Nonetheless, the indirect impacts on people from flooding of their homes and belongings is of significant concern.

Information on the population from census data is not available at the resolution required to capture just the flood extents or application to an object-based model. Furthermore, the population is not evenly distributed within statistical boundaries, particularly along flood prone watercourses or conversely a division that includes both a developed waterfront and an undeveloped mountainous area. Therefore, to estimate the affected population, some assumptions and method of estimating the population by building is necessary.

Affected Residents – Dwelling Exposure

Statistics Canada publishes several products from the census of population and other surveys that combine population and housing statistics. Data availability and detail vary by geographic division, often with less detail provided for smaller divisions. At the census subdivision (CSD) level, which is typically aligned with administrative boundaries and for which there are 25 within the study area, data is available that can associate dwelling characteristics with number of occupants.

StatCan data table 98-400-X2016220 was cross tabulated to provide information on the average household size by both dwelling structural type and number of rooms. Table 17 provides a sample from one of the 25 CSDs.

Table 18: Sample of Census Subdivision Household (HH) Size by Structural Type and Number of Bedrooms

STRUCTURAL TYPE	NUMBER OF BEDROOMS									
	ALL		0-1		2		3		4 +	
	Total HHs	AVG HH Size	Total HHs	AVG HH Size	Total HHs	AVG HH Size	Total HHs	AVG HH Size	Total HHs	AVG HH Size
All	15740	2.1	2500	2.2	5850	1.7	4240	2.4	3150	3
Single-detached house	6745	2.4	120	1.4	1625	1.8	2420	2.4	2585	2.9
Apartment 5+ storeys	955	1.5	325	2.2	605	1.7	30	1.8	0	0
Other attached dwelling	7460	1.8	2045	2.3	3195	1.7	1660	2.4	560	3.4
Movable dwelling	580	1.6	20	1.5	430	1.6	130	1.7	0	0

The Building Vulnerability Database (Section 5.5) provided the primary source of the building attributes (type, number of bedrooms) to estimate number of people for buildings using this average household size. However, due to the method of processing for buildings with multiple assessment records (multifamily buildings – apartment and attached in Table 18), the resolution of bedrooms by unit was lost. i.e., the building record contained a summed total number of bedrooms. In these cases, the number of people per room was estimated with a weighted average for apartments. This weighted value was determined for each CSD using the total number of households by type and bedroom count along with the total population for each (not shown in Table 18).

Accounting for "non-permanent" Population:

The Okanagan is a popular vacation destination within reach of major urban centres. As such, it is likely that there is a significant number of dwellings within the study area that are vacation homes, either second homes for residents from outside the area and occasionally occupied, and/or operated as short-term vacation rentals by investors.

Information on property ownership is generally divided between ownership by "individuals" (e.g., owner occupied) or "non-individuals" (e.g., investors). The latter cannot be used to make a distinction between rentals for permanent residents or other uses and would potentially combine dwellings with high rent to income tenants as well as high income owners of second properties for their own or vacation rental purposes.

Population and housing data from Statistics Canada, such as the average household sizes used for this estimate, applies only to households with permanent ("usual") residents or, in other words, primary dwellings. Therefore, its application evenly to all buildings may result in a misrepresentation of local impacts.

While there is no official count of vacation homes, the federal census includes counts of the total number of private dwellings as well as the number of "private dwellings occupied by usual residents". The definition of this statistical unit is as follows:

> ***"Private dwelling occupied by usual residents*** *refers to a private dwelling in which a person or a group of persons is permanently residing. Also included are private dwellings whose usual residents are temporarily absent on May 10, 2016. Unless otherwise specified, all data in housing products are for occupied private dwellings, rather than for unoccupied private dwellings or dwellings occupied solely by foreign residents and/or by temporarily present persons."*

The 2016 census provides the total and occupied dwelling counts at the Dissemination Area (DA) level. Within the study area, the occupancy as a percentage of total private dwellings occupied by usual residents ranges from around 40% (along the northwest shore of Lake Okanagan or RV parks) to near 100% in more typical subdivisions of larger communities. An illustrative example of three adjacent DAs with a relatively wide range of occupancy and the study area total is shown in Table 19. The three example DAs are illustrated on a map in Figure 14.

Table 19: Example of Total Private Dwellings and Dwellings Occupied by Usual Residents by Dissemination Area

DISSEMINATION AREA (CSD_DA)		POPULATION	PRIVATE DWELLINGS	OCCUPIED BY USUAL RESIDENTS	PERCENTAGE OCCUPIED
1	Kelowna_59350210	422	316	197	62%
2	Kelowna_59350213	643	390	365	94%
3	Kelowna_59350249	1233	801	594	74%
Total of 170 DAs in study area		114,276	60,794	52,109	86%

Figure 14: Illustration of DAs featured in Table 18

For each of the 170 DAs (with exposed dwellings) in the study area, the percentage occupied was applied as a factor to the total household estimate, in turn adjusting the total population estimate by type. A limitation of this approach is that it doesn't account for dwelling type which may be correlated with the use we are trying to account for (i.e., if, for example, most unoccupied dwellings are apartments). However, the DA scale is small and relatively homogeneous in the prevalent land use.

Finally, because the population estimates were aggregated from buildings, rather than distributed from actual census totals, a control check was made against the census totals for 66 DAs that are wholly within the study area (fully inventoried). After adjusting for occupancy, the total population for these areas from this method produced a population estimate that was within 2% of the Census population.

Compared to the preliminary assessment using a count of bedrooms alone (i.e., 1:1 bedroom to people), the structure type, household size, and occupancy analysis yielded significant improvements for the 66 test DAs compared to the Census population, as illustrated in Table 20.

Table 20: Comparison of Building-Based Estimates to Census Population (66 sample DAs)

POPULATION (2016)	BEDROOMS ONLY		STRUCTURE AND HOUSEHOLD ADJUSTED		OCCUPANCY ADJUSTED	
	count	difference	population	difference	population	difference
42,974	56,272	31%	47,387	10%	41,992	2%

The resident scales for each building were used to create a CanFlood L1 exposure inventory with a depth threshold of 10cm.

Model Limitations

Including uncertainty of resolution using CSD and DA averages noted above and inherited uncertainties within the building database, there are additional limitations with this metric, the importance of which depending on the intended use, including the following:

- The incorporation of bedrooms per household only partially addresses the (assumed) issue of larger homes having less people per room. The averages would not account for a disparity of occupancy within the large dwelling category between, for example, a wealthy "empty nest" couple or high occupancy lower income large multi-generational families or shared accommodations of seasonal workers.

  In the statistics, "housing suitability" is an indicator of whether the dwelling has enough bedrooms for the size and composition of the household. Although subject the same limitations associated with averaging, this factor is considered at the DA level in the vulnerability score employed in that model (ppl.vuln, 6.2).
- Although the use of the occupied dwelling statistics to estimate the proportion of permanent residents is common, it is not an official count of vacation, vacant, or second homes. There may be other conditions influencing the values at the DA level, including the status of properties at the time of census.

- For an FRA, it is not only the proportion of vacation homes that may be of concern, but also the locations, given the value placed on waterfront properties for this use. For the vulnerable population model, this is also a concern for assumptions regarding the distribution of usual residents because the housing market values the same attributes.
- This model only considers residential dwellings as an indicator of “affected”.

Other limitations pertaining to the use of affected population with this method for indirect social consequences are further discussed in the next section on vulnerability.

Model Results

Table 21: Total Affected People: Current Operations

Model: ppl.afct (people)		
Event (ARI)	20-yr	3,111
	100-yr	6,719
	200-yr	10,239
	500-yr	12,779
Annual Risk (EAD)		**534**

The indirect impacts to affected people and households, such as stress of the flood and getting back to normal, having to leave home, and persistent worrying about flooding have been shown to potentially be more severe than the direct tangible flood damage itself (UK EA & DEFRA 2003). Following the 2013 flooding in Calgary, Alberta, demand and funding for mental health supports increased (CCC 2015; GoA 2013) and even a rise in domestic violence was attributed to the stress of the event (CTV 2014).

More broadly, a major flood can negatively impact community-wide relations. If affected people were previously unaware of the risk, a flood event can be a shock to their sense of place and security, and when flooding impacts only a portion of the community, a feeling of isolation and division can occur (Tapsell et al. 2009).

A relatively recent Canadian study found that 56% of the flooded households surveyed in Burlington (of those that had at least one working member) took an average of seven days off work. This number was 10 times the average number of days taken off work for non-flooded Ontario households (Decent & Feltmate, 2018). Additionally, the study proposes that when these workers return to work, they will still be worried and distracted due to lingering financial impacts and stress from the flood event.

Awareness and preparedness are clearly important variables, not only to inform contingency actions to reduce physical damage (e.g., sandbagging, moving contents out of basements), but significantly to reduce the indirect impacts. In other words, mitigation of health impacts, especially mental health, is not merely a matter of protection from floodwaters. The factors that contribute to these impacts are significantly affected by preparedness and support. Thus, the most efficient mitigation may be educational and social supports rather than structural options.

As noted above, the assignment of people per building based on averages presents a significant limitation in resolution for assessing the relative severity of consequences to households due to uncertainty of socioeconomic conditions and household vulnerability to the building (e.g., vacation homes). The vulnerability weighting, 6.2, is intended to address some of these.

Table 22: Affected People: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Model: ppl.afct (people)					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	324	534	39.4%	3,852	8,309
1. Kelowna	102	211	51.5%	993	2,564
2. Penticton	78	100	22.4%	1,126	2,402
3. Osoyoos	36	36	0.0%	473	845
4. Okanagan-Similkameen C	34	34	0.0%	329	447
5. Okanagan-Similkameen A	18	18	0.0%	200	286

Further uses:

The exposed population estimates could be used to prioritize awareness and preparedness efforts. This outreach should combine general education on local flood risk with practical advice about actions to reduce damages, such as property level mitigation, contingency planning, and business continuity.

This FRA is limited to a quantification of direct consequence indicators, but this metric is a necessary foundation for the estimation of a range of indirect consequences. Two tangible uses described in the *Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure* (NRCan 2021a) include household displacement and business interruption, both based on the population and assumptions of restoration time which is related to the building damages model. The space per worker estimates facilitates estimation of business loss by value added, which is the most appropriate metric and derived from productivity per worker statistics.

6.2 Exposed Vulnerable Population

Model at-a-Glance

tag	ppl.vuln
category	People
sub-category	vulnerability
type	exposure (L1)
metric	affected persons
unit	weighted count
description	social vulnerability indexed exposures
primary data source	National Human Settlement Layer (Social Fabric) [NRCan_0223]

Model Description

Social vulnerability is the degree to which some people, or classes of people, are more susceptible to, or suffer a greater degree of harm from, some hazards than do other people. Effectively addressing social vulnerability decreases both human suffering and the economic loss related to providing social services and public assistance after a disaster (Flanagan et al. 2011). In exploring vulnerability, the intention is to identify combinations of people and events that will result in unusually severe impacts (Messner 2007). Quantifying vulnerability compares population groups relative to other groups and does not make assumptions about individuals.

Vulnerability is a complex interaction of physical and social systems that is difficult to correlate to an event such as flooding. However, there are some statistical indicators generally acknowledged to reduce ability to cope with the broad range of impacts flooding can have on a household or individual. Income and wealth data are directly available and are known to be key vulnerability indicators. Of particular concern for the economically vulnerable is the potential for floods to throw households into a poverty trap in which the initial set-back creates further obstacles for recovery in an amplifying feedback loop (Hallegatte et al. 2016).

For this study, the National Human Settlement Layer (NRCan 2020) was applied to quantify the relative proportion of the affected population from the previous model, total affected population. The dataset includes a Social Fabric Layer, which:

"…*utilizes Census demographic data to evaluate broad spatial patterns of vulnerability, and neighbourhood-level capacities to withstand and recover from disaster events based on intrinsic characteristics of housing, family structure, individual autonomy and financial agency*" (Journeay et al. 2022)

Comprised of scores for:

- Financial agency,
- Housing condition,
- Social connectivity, and
- Individual autonomy,

the data layer also includes a “total social vulnerability score”, which is described as:

“A composite indicator to represent the Settled Areas relative level of social vulnerability compared to other Settled Areas of the same community archetype across Canada. This is equal to the number of social vulnerability indicators that exceed their associated indicator threshold values. The threshold value equals the indicator population average +1 standard deviation.”

An L1 CanFlood exposure inventory was created using the total population inventory as a base, including the adjustments for ‘permanent population’. The total social vulnerability score (svit_score) was applied at the DA level in the following manner:

- Converting the svit_score value to a multiplier (svit_score/10). This maintains proportionality and a clear relationship to the total affected estimates including scores of zero.
- Applying the multiplier to the building population for the scale. For example, if a building had a population count of 20 and is within a DA with an svit_score of 2, then the social vulnerability scale would be 4 (2/10*20).

Model Limitations

This model inherits all the limitations of the general affected population model upon which this is based. Additional limitations include:

- The svit score used incorporates a broad range of national scale indicators that are not specific to the dynamics of flooding nor the communities in the Okanagan.
- The effects of applying the score in the method above as a weighted factor are unknown in terms of comparing relative vulnerability. As a positive multiplier, aggregating the results by geographic divisions may disproportionately scale areas with more exposure rather than more vulnerability. This may exacerbate the aggregation issue noted above.
- There may be meaningful variations in the distribution of the population within housing types. Depending on the geographic scale, this can create sharp spatial contrasts within a division for which averages have been used. The spatial nature of flooding and property values could exacerbate this issue. A hypothetical example would be a lower income neighbourhood that includes an exclusive lakeside enclave.
- At the scale DA divisions and application to object-based modeling, the indicators used may result in unintended contrary results. Independent wealth, for example, may be represented as a vulnerability in terms of income to high monthly housing costs. A luxury private seniors’ housing complex may be such an example.

The appropriate use of vulnerability indexes is to provide a lens through which we may identify areas of concern to direct further efforts and investigation at the local level. In this way, the inclusion of this metric is very much aligned with the appropriate use of this study and its inherent limitations.

Model Results

Table 23: Total Affected Vulnerability Score: Current Operations, with ratio of total affected

Model: ppl.vuln (weighted people)			relative to total ppl
Event (ARI)	20-yr	772	0.25
	100-yr	1,744	0.26
	200-yr	2,750	0.27
	500-yr	3,371	0.26
Annual Risk (EAD)		**136**	0.25

The results table above is provided alongside an indication of the scores relative to the total affected people estimate. This is because the svit score was a factor applied to the total population estimates and the results of this model are best understood in conjunction with the total exposed. This relationship is the original intent of the svit scores alone as a “lens” through with to view the local populations. Combining this “lens” with the flood exposure provides some indication of potentially disproportionate impacts by event or annualized risk.

For example, if the more frequent 100-year flood had a much higher score to total people exposed ratio than the 20-year event, we might be able to prioritize further social impact investigations into the areas that are inundated only at the 100-year event. The total study area scores above, however, are likely too course to reveal anything from this metric which was applied to populations at the small Dissemination Area scale.

Therefore, rather than events alone, it would be more useful to look for disproportionate impacts among geographies as well. An example of geographic variation is provided below in Table 24, which compares the total affected and vulnerability scores for the top five CSD areas for the 500-year event, current operations.

Table 24: Comparison of Total Affected and Vulnerability Score by CSD (Current, 500-year)

Census Subdivision	ppl.afct	ppl.vuln	vuln/afct
Kelowna	5518	1295	0.23
Penticton	2494	870	0.35
Osoyoos	845	360	0.43
West Kelowna	639	101	0.16
Summerland	546	121	0.22

As illustrated, the vulnerability score does not alone provide an indicator of the relative potential vulnerability. Furthermore, the svit scoring data was provided at the DA level and is effectively averaged and of less comparative value at the CSD level. However, given the nature of this indicator at this level of study, we do not want to report here on small, identifiable populations.

The simple use of the total score was identified as a limitation above regarding flood impacts. Further application of these metrics may be improved by examining the dimensions in relation to the other household or community flood consequences.

For example, the set of indicators within the dimension of “financial agency”, may be a useful lens to apply in conjunction with the building damage values to determine a ratio and highlight high cost/low agency areas. Another example may be social capital and autonomy indicators against the total displaced households and local availability of alternative accommodations to highlight potential recovery issues.

Table 25: Affected Vulnerability Scores: Comparison of Risk by Scenario and Modified Even Impacts - Top 5 CSD

Model: ppl.vuln					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Grand Total	88	136	35.2%	1,083	2,377
1. Penticton	28	32	14.0%	402	852
2. Kelowna	22	49	54.5%	208	612
3. Osoyoos	14	14	0.0%	191	360
4. Okanagan-Similkameen C	8	8	0.0%	86	113
5. Okanagan-Similkameen A	4	4	0.0%	43	67

6.3 Damage to Buildings and Contents

Model at-a-Glance

tag	econ.bldg
category	economy
sub-category	buildings
type	depth-damage (L2)
metric	repair/replacement cost
unit	$CAD
description	damage to buildings and contents
primary data source	Buildings Vulnerability Database [bvdb_0122]

Model Description

Buildings and their contents often contribute the largest share of direct economic losses in flood disasters and therefore are a common focus of many FRAs (many studies rely on this as the sole indicator for flood risk). To estimate the direct financial loss of potential flooding to these assets, information from the buildings vulnerability database (Section 5.5) was combined with models for estimating building impacts as a function of depth (‘vulnerability functions’) to construct a CanFlood inventory. The depth-damage vulnerability functions are summarized in Section 2.5.1. The inventory was divided into the four components shown in Table 26.

Table 26: Buildings inventory component summary.

Description	nest_ID	Impact Cap	Impact Scale	Elevation
main floor structural	0	gvimp_gf	area	mf_height
main floor contents	1	1.00E+06	area	mf_height
cellar/basement structural	2	max(gvimp_gf*0.5, 1e4)	area	mf_height – 2.7
general	5	max(gvimp_gf*0.5, 1e3)	area	mf_height

- nest_ID refers to the position in the CanFlood inventory input file
- Impact Cap is the maximum damage value returned and is based on improvement values from the assessment records. This prevents restoration costs from exceeding structure value.
- Impact Scale is the unit value of the depth-damage function scales for each building.
- Elevation is used to derive the depth of flooding for each component.
- See Table 15 and Natural Resources Canada (2022) for further details

Using combinations of these four components significantly increases the flexibility and applicability of the functions to the range of building types in the study area. Additionally, the separation of the components allows for more appropriate scaling. The “general” component includes costs related to items such as mechanical equipment or clean up and mobilization, which are not scaled in the same way as flooding, for example.

Vulnerability functions were assigned to each asset using relevant attributes shown in Table 15. The complete L2 CanFlood model package for building contents and structure impacts contains roughly 43,000 building polygons.

Model Limitations

- A primary limitation of this model is the accuracy of the building attributes (Section 5.5) and the resultant application of the damage functions – including the functions appropriateness even if the building is accurately captured.
- In addition to classification, the model is sensitive to the depths derived from the estimated heights of components (Section 5.3). Quality checks were made throughout the process however, due to the scale and scope of this project, this uncertainty and sensitively was not evaluated "in depth".
- Related to the above limitation in the building information and vulnerability data, is the resolution of exposure, or mechanism of flooding (i.e., the combined uncertainty of hazard and vulnerability data). The degree to which overexposure and underexposure were modelled isn't known.
- The building inventory is a representation of current, existing conditions with which we are evaluating a range of future events and climactic conditions. The built environment is dynamic – the exposure and vulnerabilities will change over time.

Despite these limitations, the quantity and distribution of buildings receiving consistent treatment should not reduce the value of this model for assessing relative damages throughout the study area.

Model Results

Table 27: Total Building Damages: Current Operations

Model: econ.bldg		
Event (ARI)	20-yr	$489,716,000
	100-yr	$736,620,000
	200-yr	$953,048,000
	500-yr	$1,218,398,000
Annual Risk (EAD)		**$71,350,000**

For the current scenario the 500-year event exceeds $1 billion in damages. This amount is the result of over 9,500 buildings inundated. Approximately 8,800 buildings are residential, split between approximately 8,200 single-family type including mobile homes and the remaining 600 multi-family including apartment or strata complexes.

As expected, the most significant damage density for the extreme 500-year event (current operations) occurs in the areas of highest building densities. Aggregated to the 500-metre grid, the top 20 grid areas are split between three urban areas, as illustrated in Figure 15.

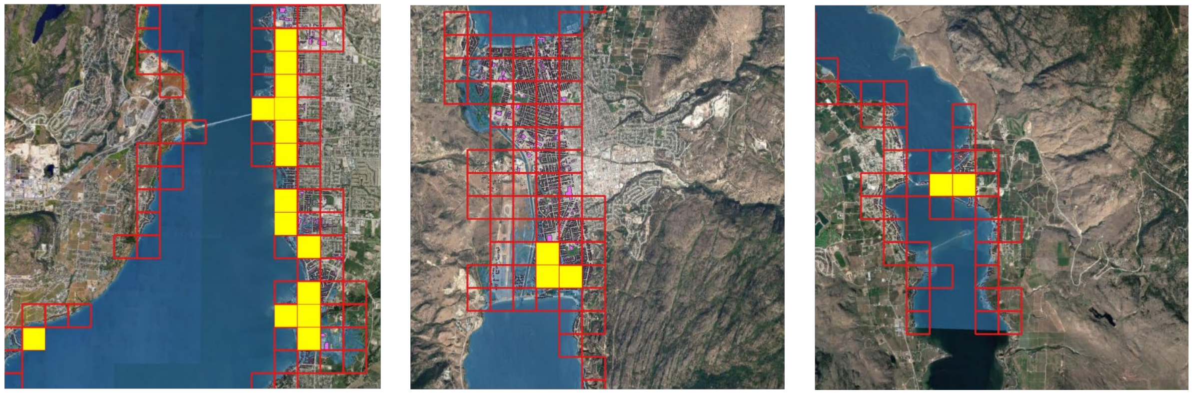


Figure 15: Top 20 Building Damage Sums: 500-year current operations, 500m grid,

These areas also exhibit higher damage densities for the more frequent events and benefits from the modified operations, as illustrated in Table 28.

Table 28: Building Damages: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Model: econ.bldg					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	$58,337,000	$71,350,000	18.2%	$574,181,000	$860,689,000
1. Kelowna	$23,814,000	$29,807,000	20.1%	$209,796,000	$260,666,000
2. Penticton	$8,649,000	$8,792,000	1.6%	$93,700,000	$154,290,000
3. Osoyoos	$5,760,000	$5,760,000	0.0%	$69,859,000	$121,938,000
4. Okanagan-Similkameen C	$3,257,000	$3,257,000	0.0%	$31,420,000	$44,297,000
5. West Kelowna	$2,567,000	$4,663,000	45.0%	$23,908,000	$54,178,000

The use of buildings to provide a measure of “affected” population is indicative of the degree to which building damage can be used as proxy or a basis for related indirect damages. Buildings alone, for example, represent or facilitate myriad aspects of society including, but not limited to, our:

- homes and workplaces;
- Investments as owners, financers, or insurers;
- history, culture, community, and faith;
- public institutions: education, healthcare, governance, and social services;
- environmental footprint; and
- recreation and commercial services.

Therefore, in addition to the impacts on people discussed above, direct building-related damage may serve as a proxy or be the foundation for understanding other consequences, such as:

- impacts to an economic system: disasters are complex economic disturbances and purely economic modelling could even produce a net benefit in terms of GDP. This depends on many dynamic factors such as scale (e.g., local, regional, national); capacity at the time (i.e., are resources diverted or activated for recovery?); complementary or substitute goods and services; and post-recovery productivity gains from new equipment
- Opportunity costs for public funds diverted to disaster relief or mitigation projects to protect buildings
- Governance and community relations due to liabilities for development planning, recovery response, and disparate impacts within a community

Building damage values are often the primary monetized input for the benefit/cost analysis component of mitigation assessments. It is recommended that, in addition to the assessment of structural options to reduce the hazard, the building inventory is used to assess a variety of property level mitigations. For example:

- Flood construction levels. The main floor elevation of buildings can be manipulated to determine the resultant benefits. This should be done in conjunction with a verification of the existing elevations estimates here.
- Other regulations such as raising of mechanical equipment can similarly be evaluated but require a more detailed modification to the inventories.

Assessing non-structural options also requires some assumptions regarding implementation timelines. Implementation typically occurs with site redevelopment or major renovations. Assumptions on rates can be developed using planning documents, economic and development trends, and site attributes such as age and improvement to land value ratios. See Bryant et al. 2022 for an example of such modelling of regulations.

In addition to the assessment of changes to the existing building stock, the risk modelling should be applied to new development proposals and area plans. Hypothetical building configurations can be evaluated and optimized to reduce risk in more effective ways that a regulatory overlay.

6.4 Crop Damage

Model at-a-Glance

tag	econ.crops
category	economy
sub-category	agriculture
type	exposure (L1 with threshold and $/m^2 value by type)
metric	potential lost revenue
unit	$CAD
description	exposed crop value
primary data source	Okanagan Agricultural Land Use Inventory [AFF_1015]

Model Description

The unique climate and geography of the Okanagan Valley has made agriculture a major economic driver in the region. In tandem with other natural attractions of the area, the high-value tree-fruit and grape production also contributes greatly to the tourism industry.

Buildings within agricultural land use areas are included in the building damage model (econ.bldgs, Section 6.3).

Seasonality, duration, floodwater type, and commodity type are identified as key variables for direct agricultural loss. There have been several investigations into flood damage estimation for agricultural production in Canada (e.g., NHC 2016) but data formats and methods to readily include this component in general FRAs are lacking.

The variables are also as complex as the variety of crops. For example, an annual crop may be more vulnerable to flooding, but the loss would not exceed the season's value. On the other hand, a perennial may be less vulnerable, but a long duration or contaminated flood could result in damages exceeding multiple years of revenue due to replanting and maturation requirements.

With the data available within the scope of this project, an L1 model was developed to quantify potential crop loss in terms of gate receipts, or revenues. The Okanagan Agricultural Land-Use Inventory was used to create an inventory base of principal crop coverage. Data from StatCan on farm product prices and yields were then used to estimate a revenue value for each crop category. The ALUI and StatCan data did not feature the same classifications for some specialty crops so a grouping and recategorization with some averaging was required.

The ALUI was used for a preliminary exposure analysis (scale=1) to first determine the type and area of crops to categorize and obtain values for. StatCan data on area of production and farm gate value was used to estimate a $/ m^2 value. Parcels containing use types without corresponding values, such as "transition" or "fallow land" were given a value of zero.

A CanFlood inventory was created with the gate value/ m^2 as the 'scale' factor for each crop feature/parcel from the ALUI. The results of the model are calculated for each polygon crop feature as:

% inundated * total area * $/ m^2

Model Limitations

- The value per square metre was derived from gate values and
- Livestock or other non-building farm assets were not included.
- There is a significant range of values for the agricultural products grown in the study area. Therefore, the results of this method will reflect these values and not necessarily total farm impact.
- Actual farm losses are complex and net profit or gross margin is also different than net income for the farm including accounting for amortization of equipment, various taxes, etc. At the farm level, most input expenditures are others' gains in sales, salaries, taxes, or transfers and this could be to anywhere in space and time.
- In addition to the potential for crop damage, Agri-tourism is a value-added industry in the Okanagan. As for all other businesses in this study, only direct impacts are measured.

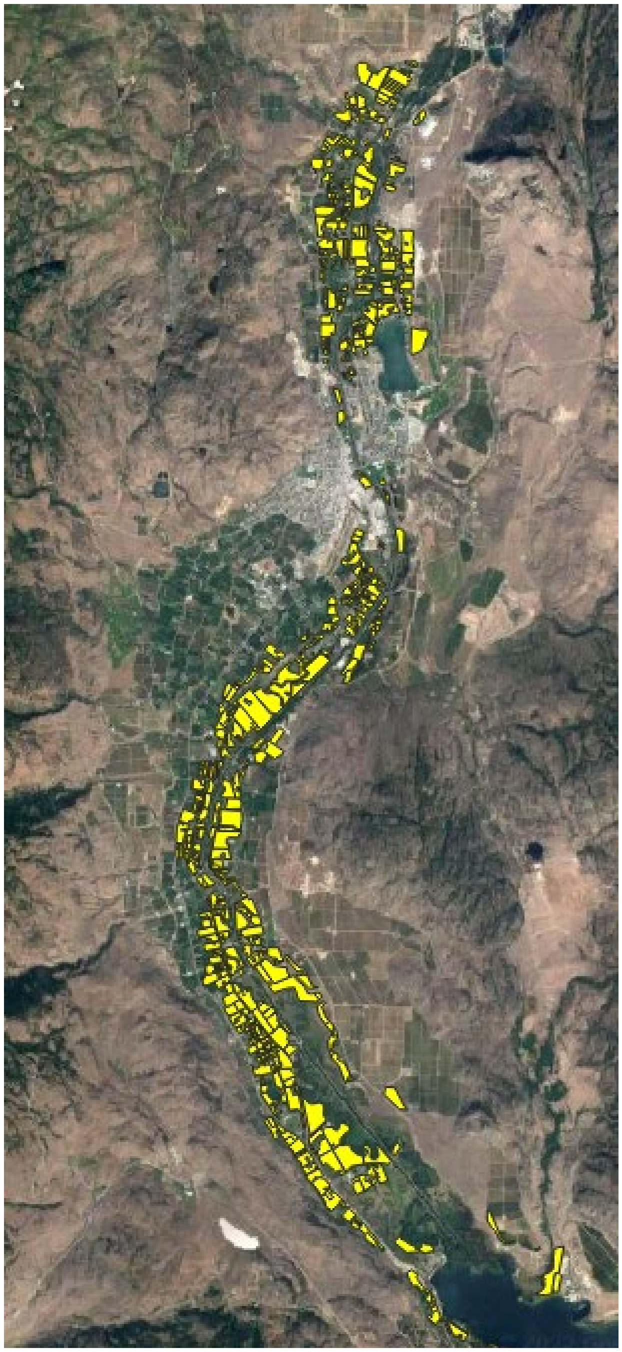
Despite these limitations, exposed value is a clear and consistent indicator and avoids confusion with mixing financial and economic values.

Model Results

Table 29: Total Crop Value Exposed: Current Operations

Model: econ.crops		
Event (ARI)	20-yr	$1,378,000
	100-yr	$1,929,000
	200-yr	$2,330,000
	500-yr	$2,691,000
Annual Risk (EAD)		**$193,000**

Figure 16: Agricultural Parcels Along Okanagan River near Oliver



Discussion

It is notable that most of the exposed crop value is within a strip of high value crops around Oliver, in the valley between Vaseux and Osoyoos Lakes. This area and the agricultural parcels are shown in Figure 16.

As noted above, there is a significant range of values for the agricultural products grown in the study area. As expected, the results of this model reflect that variation as shown in Table 30, which is sorted by annualized value exposed.

This list also illustrates the limitation of this model as exposed value and not necessarily vulnerability. The top three values (cedar hedge, peppers, and grass), represent trees, annuals, and perennials, which have different variables such as growing cycle, depth thresholds, and salvageability.

Table 30: Crop Inundation and Gate Values Exposed - 500-yr flood and EAD, current operations

description	Hectares Inundated (sb 500-yr)	Gate Value per Hectare	Exposed Value (sb 500-yr)	EAD (sb)
Cedar hedging	5.3	$72,600	$386,474	$41,211
Peppers	9.5	$40,600	$384,350	$24,834
Grass	218.7	$1,200	$262,457	$23,635
Grapes	17.9	$15,700	$281,598	$20,914
Mixed grass / legume	165.9	$1,200	$199,096	$14,108
Misc. vegetables	9.4	$19,000	$178,831	$10,741
Apples	10.5	$15,798	$166,296	$10,085
Cole crops	5.3	$18,600	$99,181	$8,941
Cherries	4.8	$23,600	$112,506	$5,756
Plums	8.3	$9,900	$82,212	$5,384
Mixed vegetables	4.6	$19,000	$87,052	$5,169
Peaches / nectarines	3.7	$15,600	$57,963	$4,248
Tomatoes	1.9	$33,800	$65,291	$4,199
Mixed fruits	4.1	$15,800	$64,150	$3,409
Root vegetables	0.6	$26,800	$16,615	$2,077
Cucurbits	2.3	$16,900	$38,106	$2,036
Pears	1.7	$20,300	$33,953	$1,711
Fruit / berry stock	0.9	$72,600	$65,520	$869
Sweet corn	1.9	$8,700	$16,181	$793
Grass / open treed	5.2	$1,200	$6,257	$596
Alfalfa	8.5	$1,200	$10,205	$552
Trees (plantation)	0.1	$72,600	$6,170	$405
Echinacea	0.5	$15,800	$8,058	$312
Blueberries	0.2	$16,100	$3,018	$301
Apricots	0.4	$15,800	$6,666	$279
Nut trees	0.4	$15,800	$6,953	$169
Ornamentals and shrubs	0.3	$72,600	$23,193	$115
Mixed nut trees	0.4	$15,800	$6,480	$63
Christmas trees	0.0	$72,600	$1,636	$55
Nursery	0.0	$72,600	$363	$2
Rye	0.0	$1,200	$50	$1

The concentration of crop value exposed in the valley between Vaseux and Osoyoos Lakes is also clear in Table 31 which shows results by CSD. Also apparent is that the operational changes (at Okanagan and Wood/Kalamalka) have little benefit for this area.

Table 31: Crop Exposure: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Model: econ.crops					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	$185,000	$193,000	4.1%	$1,858,000	$2,567,000
1. Okanagan-Similkameen C	$159,000	$159,000	0.0%	$1,577,000	$2,154,000
2. Okanagan-Similkameen A	$15,000	$15,000	0.0%	$131,000	$161,000
3. Oliver	$6,000	$6,000	0.0%	$62,000	$91,000
4. Okanagan-Similkameen D	$3,000	$3,000	0.0%	$23,000	$25,000
5. Okanagan (Part) 1	$2,000	$8,000	76.1%	$43,000	$85,000

6.5  Damage to Public Parks

6.6  Disruption to Recreation

The damage and disruption models for public parks are based on the same inventory but with a different scale. Therefore, these models are presented together under the combined heading.

Model at-a-Glance

tag	econ.parks, infr.parks
category	economy, infrastructure
sub-category	parks
type	exposure (L1)
metric	restoration costs and exposure per square metre
unit	$CAD, square metres
description	damage and exposure of public parks and recreation sites
primary data source	OSM [OSM_1119], MoFLNR [FLN_1001b], ALUI [AFF_1015]

Model Description

Public parks, athletic fields, playgrounds, plazas, and other outdoor recreation areas can sustain substantial damages during flood events and require cleanup and restoration. While inundated and being cleaned and restored, they are unavailable to the public.

Monetary Damages:

To estimate monetized impacts to parks, an L1 asset model was assembled where each asset was scaled by its total area and the average estimated restoration cost for the type of landscaping.

The inventory base shapefile was created from a combination of select Open Street map layers (park, pool, pitch, playground) and subcategories from the provincial Local and Regional Greenspaces (local park) and Agricultural Land Use Inventory (parks, zoos, fields, gardens). The

Landscape architects familiar with park construction and restoration costing, provided high level estimates for four types. Based on previous experience and judgment, the flood damage was assumed to be 1/3 of construction cost, as summarized in Table 22.

Table 32: Public park construction and restoration estimates by category

TYPE	CONSTRUCTION $/M^2	RESTORATION $/M^2
Sports fields and facilities	$25	$8
Formal Park	$90	$30
Typical Park	$40	$13
Pathways and naturalized	$35	$11

Disruption to Recreation

Recognizing the significance of indirect impacts on a community and the importance of public open spaces and park facilities on a range of activities from residents recreation to tourism and aesthetics, this model quantifies the exposure of the econ.parks model without monetary repair costs to provide a different dimension for assessment.

Therefore, this model duplicates the economic parks inventory without a monetary scale, returning the exposure results in m^2.

Model Limitations

In addition to the following limitations, the relative value of this model is discussed in the next subsection.

- the vulnerability of the surfaces and features will vary greatly within and between specific parks. The data sources used are likely too general to capture these details
- The accuracy of the areas and categorization of surfaces in uncertain. Parks are commonly adjacent to watercourses for good reason and may have more naturalized (i.e., less vulnerable) areas along the shore that flood more frequently. This may even include some beach areas.
- This model's vulnerability is based on inundation extents alone. Actual damage to parks is highly variable with velocity and debris.

- Considering the above limitations, the general restoration costs may overstate damages in areas that experience frequent flooding, thus inflating the annualized risk estimate.
- For recreation loss, there is no consideration of the value to residents based on type.

Model Results

Table 33: Total Park Damages: Current Operations

Model: econ.parks		
Event (ARI)	20-yr	$3,241,000
	100-yr	$7,375,000
	200-yr	$11,053,000
	500-yr	$15,676,000
Annual Risk (EAD)		**$576,000**

Table 34: Total Park Exposure: Current Operations

Model: infr.parks (m^2)		
Event (ARI)	20-yr	199,000
	100-yr	416,000
	200-yr	588,000
	500-yr	825,000
Annual Risk (EAD)		**34,000**

Monetary damage and recreation loss estimates for this land use have been included primarily because the data was available. However, in relation to the lack of such data and knowledge for many other damage categories, there is a risk of disproportionate attention to these high-level park repair cost estimates and recreation value after a flood event. Given the nature of these assets, with no residents and few buildings, it may in fact be considered a more acceptable risk and recovery cost and thus appropriate land use.

Penticton has high exposure by virtue of the prominent park and recreation areas on both Okanagan and Skaha Lakes, as well as riverside. In Oliver, damages are primarily driven by the park and campground on the west side of the river. In Table 35 and 36 by CSD, Kelowna is of note for having the most significant total range between current and modified scenarios and the increase at the extreme 500-year event. Park risk in Kelowna is largely driven by less frequent events causing significant damage to large parks not on the lakeshore.

The difference in relative results between the recreation and the restoration cost is due to the equal value placed on all types, thus more naturalized park spaces have equal contribution.

Table 35: Park Damage: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Model: econ.parks					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	$293,000	$576,000	49.0%	$3,469,000	$7,938,000
1. Penticton	$74,000	$84,000	11.6%	$746,000	$1,485,000
2. Oliver	$60,000	$60,000	0.0%	$647,000	$862,000
3. Kelowna	$41,000	$209,000	80.2%	$682,000	$2,717,000
4. Okanagan-Similkameen D	$38,000	$38,000	0.0%	$414,000	$521,000
5. West Kelowna	$33,000	$63,000	46.9%	$345,000	$696,000

Table 36: Park Exposure: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Model: infr.parks					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	15,892	33,694	52.8%	200,242	438,458
6. Kelowna	2,863	13,187	78.3%	52,524	155,883
7. Penticton	2,792	3,583	22.1%	29,780	61,613
8. West Kelowna	2,674	4,999	46.5%	27,699	55,232
9. Okanagan-Similkameen D	2,118	2,118	0.0%	22,644	28,443
10. Oliver	2,067	2,067	0.0%	22,191	29,592

6.7 Disruption to Road Transportation

Model at-a-Glance

tag	infr.roads
category	Infrastructure
sub-category	roads
type	exposure (L1)
metric	exposed road segments
unit	count
description	count of public road segments inundated >30cm
primary data source	MoFLNR Road Atlas [FLN_1001a]

Model Description

To quantify the relative potential risks to the road network throughout the study area, an exposure model was created using the digital road atlas GIS layer of road segments.

Ideally, the ‘segments’ in the road data would consistently represent lengths of road between intersections, regardless of relative individual length, and represent a link within the network. Unfortunately, the data had no such logical delineation of segments. Therefore, each road segment was discretized into 10m segments and scaled by its hierarchical classification (values 1 to 6, from local to highway) for the scale within the CanFlood inventory.

A depth threshold of 30 cm was selected for inundation. This depth is commonly used as a threshold for unpassable roadway for private vehicles (Ontario Ministry of Natural Resources 2002). The results indicate a count of these segments with inundation greater than 30cm.

Model Limitations

- Although weighted by classification, which typically represents a relative volume, this does not alone account for the importance of the roadway during a flood event. The value of a segment may significantly change during a flood, due to many factors including critical linkages, redundancy, and potential for longer disruption due to damage to the roadway.
- Related to the above, the method of discretizing segments for resolution within the study area disregards the function of a “segment” in terms of connecting two access points, or alternative routes. Therefore, a longer segment with a large portion inundated may be unduly weighted or counted disproportionately.

Model Results

Table 37: Total Road Exposure: Current Operations

Model: infr.roads (weighted segments)		
Event (ARI)	20-yr	872
	100-yr	3,143
	200-yr	5,911
	500-yr	8,990
Annual Risk (EAD)		**211**

As a count of scored 10-metre road segments, these results are best viewed spatially for areas of relative concentrations.

Exposure of roadways and their respective traffic volumes do not follow the same distribution as consequences related to building density. Instead, they tend to reflect the connections between areas of density (i.e., origins and destinations) where traffic is concentrated. This is often intensified by geography, especially one such as the Okanagan Basin. Much like the water, our transportation routes have followed the path of least resistance.

This observation is represented in the results, which indicate areas where both the water and roadways are concentrated within the valley along the corridor between Osoyoos and Vaseux Lakes, and through Penticton.

Despite the weighting, the results at a small scale appear dominated by any class road that experiences flooding at frequent events. An illustration of some top annualized road scores by 500m grid are provided in Figure 17, which illustrates a developed area near the south shore in Penticton, a rural agricultural access road north of Osoyoos Lake, and a lakefront area in Oliver.

The model would be improved with further investigation to determine critical segments that would impact access or emergency services.

Figure 17: High-Impact Road Segments

Table 38: Exposed Road Segments: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Model: infr.roads					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	149	211	29.1%	2,006	5,235
11. Okanagan-Similkameen A	28	28	0.0%	277	703
12. Okanagan-Similkameen C	26	26	0.0%	260	532
13. Penticton	25	25	0.8%	474	849
14. Oliver	19	19	0.0%	197	285
15. Osoyoos	19	19	0.0%	388	1,176

6.8 Disruption to Power Supply

Model at-a-Glance

tag	infr.power
category	infrastructure
sub-category	power
type	exposure (L1)
metric	number of transformers
unit	count
description	potential loss of service from inundated transformers
primary data source	ICI - FortisBC [ICI_0902d], ICI - BCHydro [ICI_0902e], Penticton Transformers [Pent_0711}

Model Description

Electrical services can be vulnerable to flooding and loss of service can lead to other losses such as communication system interruption and loss of power to equipment such as pumps can increase damages.

The distribution system is typically a network of substations, lines, and transformers. The substations step down the transmission voltage and feed distribution lines which are either overhead on poles or underground. The transformers within the distribution network further reduce voltage for secondary connections to end users.

Using a combined dataset from the three local power utilities (Fortis, BC Hydro, and Penticton), a preliminary analysis was conducted to determine what assets were potentially exposed. It was determined that transformers were the asset that may be vulnerable within the study area. Overhead distribution was not considered vulnerable.

The dataset did not include the number of customers served by the transformers and had incomplete details on the voltage or other characteristics that could assist in estimating the relative service provided by each.

Therefore, to scale the potential risk posed by each transformer, a count of people served was estimated based on the spatial relationship of all transformers (above or below ground) and the population distribution developed for the population exposure model (ppl.afct). The service area was approximated by creating a set of Voronoi polygons around all transformers and summing the population estimate.

Outside of a few uniformly developed areas, the results using the above weighting methods proved to be very unrealistic and not feasibly refined. Therefore, the weighting was removed from the model and each transformer considered equal. The advantage of this simpler approach is that it is much clearer to understand. It may further be defensible to assume a relationship of higher dependency on transformers serving fewer homes or facilities. For example, an isolated rural property may be more vulnerable to power loss than a set of six urban properties without power, especially if the rest of the urban area is still powered.

To quantify potential risk to electric service loss, an CanFlood inventory of all underground transformers in the study area was created with equal scale for each. The depth threshold for exposure was set at 10cm, to account for some uncertainty in depth and duration as well as a degree of assumed protection due to pad-mounting and enclosures.

The “underground” classification refers to the transmission lines and the associated transformers are typically at grade, mounted on concrete pads. Figure 18 provides an illustration of an exposed underground transformer in a Kelowna lake-front residential area.

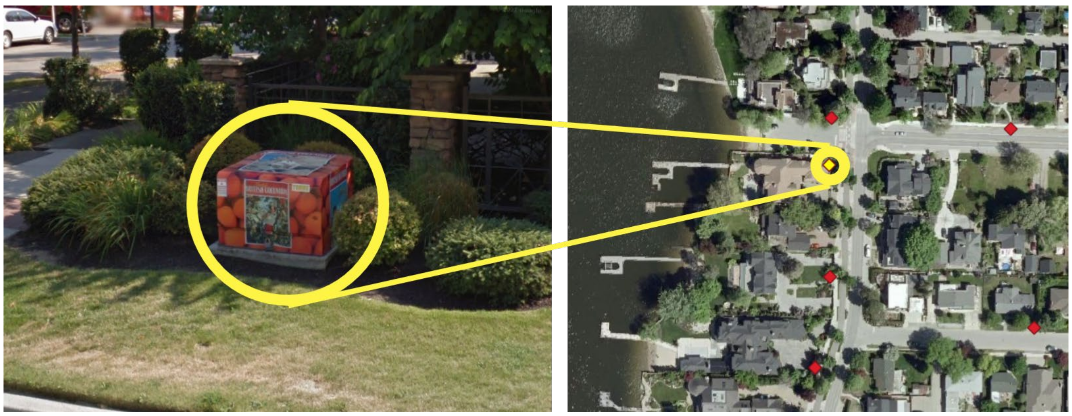


Figure 18: Example of an Exposed Underground Transformer

Model Limitations

- Exposure to flooding >10cm may not reflect the vulnerability to disruption for transformers in the study area. Although the inventory was limited to underground transformers, some may be flood protected, for which data was not available.
- It is suspected that the dataset contained at least a few overhead transformers erroneously identified as underground. It was not feasible to ground truth this data.
- All transformers are weighted equally. The relative vulnerability of those served is unknown.
- There is normally a degree of built-in redundancy connecting substations and some switching capability to isolate areas of flooding to limit service loss. As with roads, the relative network vulnerability could not be assessed for this study.

Model Results

Table 39: Total Exposed Transformers: Current Operations

Model: infr.power (exposed transformers		
Event (ARI)	20-yr	36
	100-yr	109
	200-yr	178
	500-yr	243
Annual Risk (EAD)		**7**

The results indicate that there are transformers located within the 20-year flood, with some clustered along the Kelowna shore south of the bridge, the south shore of Penticton, and Osoyoos. These areas also account for increasing exposure for larger floods and the top risk. The reduction in flooding in Kelowna with the modified operations, however, is apparent in Table 40, which is ranked by risk for the modified scenario.

Table 40: Exposed Transformers: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Model: infr.power					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Grand Total	5.19	7.50	30.8%	69	150
Penticton	1.72	1.75	1.7%	24	58
Penticton 1	0.97	0.97	0.0%	10	10
Osoyoos	0.75	0.75	0.0%	11	18
Oliver	0.50	0.50	0.0%	6	11
Okanagan-Similkameen C	0.34	0.34	0.0%	5	5

6.9  Disruption to Drinking Water Supply

6.10  Disruption to Wastewater Service

6.11  Release of Untreated Wastewater

The water infrastructure models were developed concurrently, and the wastewater results for service disruption and untreated release use the same exposure calculations. Therefore, these models are presented together here, under the headings for all three.

Models at-a-Glance

tag	inf.water, infr.ww, env.ww
category	infrastructure, environment
sub-category	water, wastewater
type	facility exposure (L1 with height threshold & score)
metric	exposure scale
unit	consequence scale per facility
description	potential release of wastewater into environment
primary data source	operator data [obwb – data – water inf.xlsx] and Waste Discharge Authorization Management System [MOE_1129].

Water infrastructure includes the network of pipes, pumps, and treatment facilities that deliver potable water to properties and collect wastewater. The vulnerability of these systems and the potential consequences are highly variable and no standard FRA methods are established. Pressurized water delivery systems are typically only vulnerable at facilities for pumping and treatment or if the intakes are damaged or contaminated, while wastewater systems may be vulnerable to surcharging with flood water and backflowing into properties or damage to pumping stations and treatment facilities causing release of sewage.

To understand the level of exposure and appropriate effort to assess water infrastructure regionally for this study, the locations of linear infrastructure and facilities within the study area were collected from municipalities [obwb – data – water inf.xlsx] and the provincial Waste Discharge Authorization Management System [MOE_1129]

As noted in Section 4, the study team did not receive any flood vulnerability information from the regional operators and had to rely on a combination of data sources to identify relevant facilities. The infrastructure GIS data and publicly available reports or descriptions were reviewed by IBI Group water resource engineers to determine vulnerability and exposure criteria for the selection of facilities for risk evaluation. A preliminary set of 41 water and 120 wastewater facilities was compiled. Additional facility locations not included in the datasets were manually added to the combined GIS layer.

A CanFlood exposure calculation was conducted to provide flood depth at each to further filter the list for more detailed investigation. The exposure analysis revealed the exposed and potentially vulnerable facilities to all be pumping or lift stations. A set of 9 water and 43 wastewater facilities was selected.

Because the spatial data for the water infrastructure of interest was the same (point files) and consistent attributes not available, L1 depth thresholds were estimated on available data, visual inspection via satellite or street view imagery, or assumptions based on typical comparable averages. The thresholds included heights of critical components including outdoor electrical units, access shaft lids, air vent outlets, and associated building structure, if present.

Figure 19 provides an illustration of the depth exposure analysis with vulnerable component heights for a sample set of wastewater lift stations.

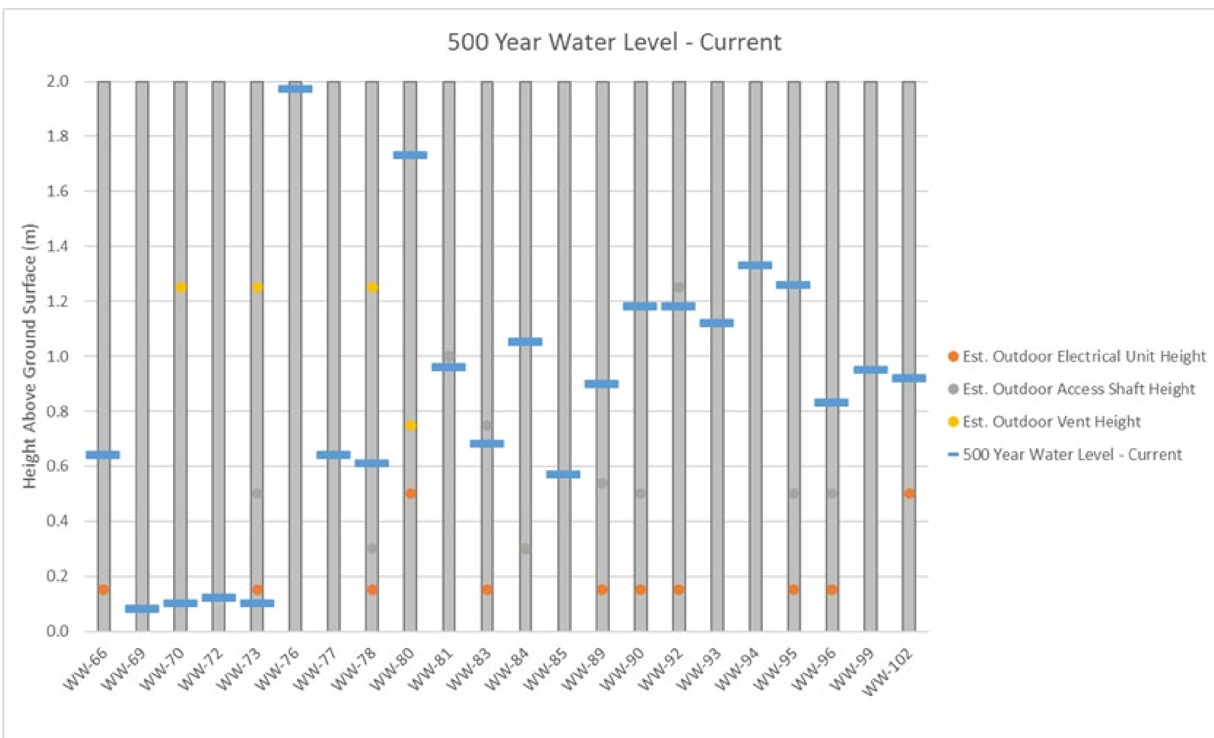


Figure 19 Illustration of lift station component exposure to flood depths during 500-year event, current operations

L1 analysis can also include a scale or scoring factor. For pumping stations this was based on estimates of service area, raw water intake for supply pumps, and nearby agricultural operations and facilities for wastewater stations.

In the absence of information on these heights or scoring attributes from the datasets, reports, or imagery, the default values were used based on other known attributes or typical standards.

The water supply inventory included nine facilities with scales ranging from 0.5 to 7. The wastewater inventory included 43 stations, with scales ranging from 0.5 to 2.75.

The resulting inventories were formatted to provide three CanFlood model inventories in two consequence categories:

- Infrastructure (indicator of potential service disruptions)
  - water supply ([cfSuite_0422] finv_infr.water)
  - wastewater ([cfSuite_0422] finv_infr.ww)
- Environment (indicator of potential untreated wastewater release)
  - Wastewater ([cfSuite_0422] finv_env.ww)

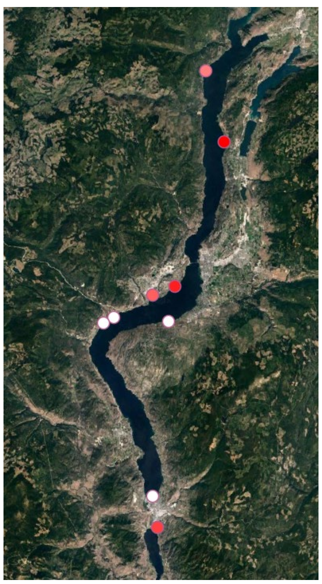
Model Limitations

- The study team did not receive information related to potentially vulnerabilities of these systems. Therefore, we relied significantly on desktop searches and judgement to complete the inventories and are only able to present an exposure assessment here. This does not provide damage values or quantify the potential disruption.
- While most properties in this mainstem study are in fully serviced subdivisions, there are many properties that have onsite sewage systems (septic tank) and, to a lesser extent, onsite water supply. The registered discharges used here were for volumes greater than an individual residence. Therefore, the number of potentially exposed septic systems is unknown and not considered in this study.
- The use of this model for potential wastewater release is subject to the same limitations as for service disruption and additional uncertainty regarding potential environmental or health impacts, including where the impacts may be realized (i.e., onsite, or downstream). Similarly, the water service impacts do not consider potential contamination.

Model Results – Water Supply

Table 41: Total Impacted Water Supply Facilities (weighted): Current Operations

Model: infr.water		
Event (ARI)	20-yr	0.00
	100-yr	0.70
	200-yr	3.50
	500-yr	5.00
Annual Risk (EAD)		**0.05**



In the final modelling, four of the nine facilities inventoried returned no impacts, including the facility with the highest scale (Penticton, near Rotary Park). This likely indicates that they are assumed to be at safe elevation. Of the other five, only one was impacted at the 100-year event, two additional at the 200-year event, and the remaining two at the 500-year event, current operations. The locations are illustrated in Figure 20.

Under the modified operation scenario, only two facilities are impacted, represented by only two CSDs with results in Table 42.

Figure 20: Locations of Impacted Water Supply Facilities

Table 42: Impacted Water Supply Facilities: Comparison of Risk by Scenario and Modified Event Impacts

Model: infr.water					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	0.011	0.049	77.6%	0.0	1.7
1. Penticton	0.008	0.008	0.0%	0.0	1.0
2. Lake Country	0.003	0.021	85.7%	0.0	0.7

Model Results – Wastewater

Table 43: Total Impacted Wastewater Stations (weighted): Current Operations

Model: infr.ww & env.ww		
Event (ARI)	20-yr	3.33
	100-yr	13.04
	200-yr	18.40
	500-yr	29.21
Annual Risk (EAD)		**0.79**

In the final modelling, 17 of the 43 facilities inventoried returned no impacts, including most of the stations with the highest scales, indicating that they are assumed to be at safe elevation. The remaining impacted facilities are distributed throughout the study are with clusters Osoyoos and Kelowna areas. The Kelowna area, however, sees a significant reduction under the modified operation scenario, with the Kelowna CSD dropping from the top five in Table 44.

Table 44: Impacted Wastewater Stations: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Models: infr.ww & env.ww					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	0.505	0.795	36.5%	9.34	18.40
1. Okanagan-Similkameen D	0.187	0.187	0.0%	2.18	3.36
2. Osoyoos	0.131	0.131	0.0%	3.41	7.59
3. Oliver	0.069	0.069	0.0%	0.55	0.55
4. West Kelowna	0.043	0.209	79.4%	1.10	3.30
5. Penticton	0.038	0.038	0.0%	1.00	2.00

It is recommended that the regional operators utilize the available inundation mapping and their knowledge of assets to assess potential system vulnerabilities. In addition to informing internal resilience planning, this information would be readily incorporated into future flood risk and mitigation assessments.

6.12 Pollutants

Model at-a-Glance

tag	env.pol
category	environment
sub-category	pollutants
type	exposure (L1)
metric	sites exposed
unit	count
description	potential release of hazardous goods from industrial & reporting facilities
data source	National Pollutant Release Inventory [ECC_1012]

Model Description

In addition to the potential for release of untreated wastewater, flooding of facilities containing hazardous materials can disperse the pollutants into the environment having local and distant downstream impacts on aquatic and terrestrial life that be acute or chronic.

To identify locations of known pollutants, the National Pollutant Release Inventory (NPRI) was obtained, and a spatial inventory of locations created for the study area, distributing NPRI points to industrial facilities using the BC Assessment and building layers to better reflect the distribution where NPRI addresses were provided as a single address point.

The NPRI inventory contains information on pollution from facilities that release, dispose, transfer, manufacture, or use substances that may pose a risk to the environment or to health. Within the study area, the sites included the following commercial sectors:

- Veneer, plywood, and engineered wood product manufacturing
- Cement and concrete product manufacturing
- Water, sewage, and other systems
- Other professional, scientific, and technical services

The list of unique substances in the registry for the study area is illustrated in Table 45.

Table 45: List of Substances in National Pollutant Release Inventory, study area

Substance Name
Ethylene glycol
Carbon monoxide
Nitrate ion in solution at pH >= 6.0
PM10 - Particulate Matter <= 10 Micrometers
Ammonia (total)
Nitrogen oxides (expressed as nitrogen dioxide)
Speciated VOC-beta-Pinene
Speciated VOC-beta-Phellandrene
Speciated VOC-Methanol
Speciated VOC-alpha-Pinene
Volatile Organic Compounds (VOCs)
Total particulate matter
PM2.5 - Particulate Matter <= 2.5 Micrometers
Antimony (and its compounds)
Arsenic (and its compounds)
Cadmium (and its compounds)
Chromium (and its compounds)
Cobalt (and its compounds)
Copper (and its compounds)
Lead (and its compounds)
Manganese (and its compounds)
Mercury (and its compounds)
Nickel (and its compounds)
Selenium (and its compounds)
Silver (and its compounds)
Zinc (and its compounds)
Thallium (and its compounds)
Phosphorus (total)

The modified NPRI site file was converted to a CanFlood inventory for exposure modelling with a scale of 1 and depth threshold of 10cm.

Model Limitations

- There was no weighting of the potential impacts based on either the materials present or the nature of the facility. Furthermore, the method of spatially assigning the address point data to facilities may inadvertently weight the impacts. For example, a single pollutant registration could have been assigned to multiple buildings at the address, which may not be reflective of the risk relative to a site with a single building.

- The NPRI thresholds are facility or operation based. This means that the risk is considered at the individual site, and not the cumulative impacts of many smaller sites inundated in a major flood event.
- The vulnerability of people or the environment to release of any registered pollutants is unknown, including the realization of any impacts in space or time.

Model Results

Table 46: Total Pollutant Sites Exposed: Current Operations

Model: env.pol		
Event (ARI)	20-yr	1
	100-yr	3
	200-yr	5
	500-yr	7
Annual Risk (EAD)		**0.2**

This model indicated that very few of the identified pollutant sites are exposed to flooding. The most significant registered site exposed is the Tolko Kelowna Mill, which has been decommissioned and the 40-acre site subject to a major waterfront redevelopment plan. The industrial area around the Oliver Public Works site is also exposed to flooding and a potential source of pollutant release.

Table 47: Pollutant Sites: Comparison of Risk by Scenario adn Modified Event Impacts

Model: env.pol					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	0.09	0.21	56.0%	2	7
1. Oliver	0.08	0.08	0.0%	2	5
2. Kelowna	0.01	0.13	93.6%	0	1
3. Osoyoos	0.00	0.00	0.0%	0	1

6.13 Exposure of Cultural Facilities

Model at-a-Glance

tag	cult.faci
category	culture
sub-category	facilities
type	exposure (L1)
metric	sites exposed
unit	count
description	potential loss of cultural services and cultural organizations
data source	BCAssessment [BCA_0924]

Model Description

In addition to the costs, post-flood restoration leads to a temporary, possibly extended, or even indefinite period of loss of use. In this regard, some buildings are more important to a community. This includes residents directly impacted themselves because many cultural facilities such as community centres become official or unofficial recovery centres, as well as the broader community that previous enjoyed or depended on the services. As with the parks and recreation model, inclusion of cultural facilities in addition to repair costs is intended to quantify the indirect community impacts due to exposure of buildings identified as cultural.

The BCA Assessment data layer was filtered for NAICS classification codes within the cultural sector (performing arts, amusement, recreation industries, museums, libraries, religious, community cultural centres). A total of 212 buildings were identified and a CanFlood inventory for exposure modelling was created with a scale of 1 and the critical depth threshold of 50cm.

Model Limitations

- This model is simply using the categorization of primary uses from the assessment records. This does not capture other potential uses of such facilities.
- The primary uses are all considered equal, regardless of their relative value to the local community or the vulnerability of the owner/operator.

Model Results

The results indicated very few buildings in this category exposed and that all were waterfront recreation sites. Although these sites fit the categorization criteria as public recreation amenities, they do not represent the intention of this model to identify additional uses not assessed in other models, particularly community and cultural facilities. Furthermore, most of the sites were already captured in the parks and recreation model. It was decided that reporting these results as risk to “cultural facilities” would be of little value and misleading.

6.14 Exposure of Archaeological Sites

Model at-a-Glance

tag	cult.arch
category	culture
sub-category	archaeological
type	exposure (L1)
metric	site area exposed
unit	square meters (m^2)
description	potential damage to registered protected archaeological site areas
data source	MoFLNR - Heritage Register [FLN_0908].

Model Description

Physical archeological sites are an invaluable component of the cultural heritage of the Okanagan and include burial grounds or historical habitation. To quantify the risk of flooding to these assets, an extract of the Provincial Archeological Register was obtained from the Provincial Archaeology Branch [FLN_0908]. This data layer contains polygons of both registered and candidate sites. The following data processing was applied to construct a model of flood exposure:

- sites flagged as 'heritage' or below ground were removed (the heritage sites are covered in the cult.hist model)
- replace any polygons with area<19 m^2 with a circle polygon with radius = 2.5m
- crop out areas within 1m vertical of the normal water level
- crop out areas within 1m horizontal of a building
- multipart to single part, then remove any features with area <10 m^2.

This resulted in a CanFlood risk model package with130 polygons within the study area where the percent inundated is multiplied by the area of each polygon to calculate an impact.

Model Limitations:

This model is limited to the registered sites and the data provides no indication of the physical vulnerability to flooding, the site boundary accuracy, location of cultural value within the boundary nor relative value to other sites. Therefore, the simple metric of area inundated treats every square metre as equal, which in unlikely to be true from any perspective.

Model Results

Table 48: Total Archaeological Site Area Exposed: Current Operations

Model: cult.arch			Sites
Event (ARI)	20-yr	5,530	16
	100-yr	7,820	27
	200-yr	10,530	31
	500-yr	12,810	33
Annual Risk (EAD)		**790**	

As with the source data, this model provides very little insight into the value or vulnerability of the exposed sites. However, it remains in line with the intent of the registration data to identify potential risks to archaeological resources. The model results in square metres do not indicate the number of sites, so this has been added to the table above.

The largest site in the study area has the largest exposure as well, located along the shore of Tuc-el-nuit Lake in Oliver. A smaller site at Deadman Lake between Osoyoos and Oliver is the most at risk in terms of annualized exposure as a proportion of total area. These two sites are illustrated in Figure 21.

Figure 21: Exposed Archaeological Sites

The model could be useful in the future by those familiar with the value and vulnerability of the sites for their purpose/perspective with an additional scale factor or scoring, rather than m^2 alone.

Table 49: Archaeological Site Area Exposed: Comparison of Risk by Scenario and Modified Event Impacts - Top 5 CSD

Model: cult.arch					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	697	790	11.8%	5,814	9,187
1. Osoyoos 1	421	421	0.0%	3,460	4,111
2. Okanagan-Similkameen C	232	232	0.0%	1,856	1,856
3. Okanagan-Similkameen D	18	18	0.0%	225	750
4. Okanagan-Similkameen F	5	22	76.1%	80	375
5. Summerland	5	43	87.9%	0	1,242

6.15 Exposure of Historical Buildings

Model at-a-Glance

tag	cult.hist
category	culture
sub-category	historic
type	exposure (L1)
metric	buildings exposed
unit	count
description	potential damage to registered heritage buildings
data source	MoFLNR - Heritage Register [FLN_0908]
assets inventoried	616

Model Description

Historic buildings are a visible and typically functional and valuable part of our communities' heritage. Due to historic settlement and development patterns, many are located along watercourses and in floodplains. The extract of the Provincial Archaeological Register used for Archaeological sites (Section 7.1) was used [FLN_0908]. The data contains information regarding both historic and archaeological sites. The historic site category can include land and locations or objects for which flood vulnerability is uncertain, so this model attempts to capture only buildings. The following data processing was applied to construct a model of flood exposure:

- sites flagged as 'heritage' were selected (archaeological removed)

- remaining polygons were visually inspected to remove any that clearly did not apply to buildings such as natural features or land-use, such as the Kettle Valley rail right of way.
- the cleaned polygons were used to identify buildings within, and the building centroid (point) selected for the inventory of historic buildings.

This resulted in a CanFlood risk model inventory with 616 points within the study area where the binary inundated/not inundated is used to quantify an impact.

Model Limitations

- As with the archaeological model, the primary purpose of the dataset is to identify, rather than evaluate or measure a site. Therefore, the polygon may identify the location but not be an appropriate representation of the historic feature.
- All sites are treated equally with no consideration of relative value or vulnerability.

Model Results

Table 50: Total Historic Buildings Exposed: Current Operations

Model: cult.hist (building count)		
Event (ARI)	20-yr	3
	100-yr	13
	200-yr	32
	500-yr	48
Annual Risk (EAD)		**0.9**

A cluster of historic homes near the lake south of the bridge in Kelowna are responsible for most of the risk under current operations. As illustrated in Table 51, the modified operations significantly reduce the exposure of these buildings.

Table 51: Historic Buildings Exposed: Comparison of Risk by Scenario and Modified Event Impacts

Model: cult.hist					
Census Subdivision	Annualized Risk (EAD)			Select Event Impacts	
	Modified↓	Current	% reduction	100-year Modified	500-year Modified
Total	0.10	1.68	93.8%	2	12
1. Kelowna	0.10	0.83	88.4%	2	10
2. Central Okanagan J	0.00	0.03	86.7%	0	1
3. Penticton	0.00	0.03	86.7%	0	1

7 Flood Risk Database and Profiling

As introduced in Section 2.8, one of the most valuable objectives and efforts expended for this project was to facilitate further analysis and future study across the region through the provision of dynamic digital deliverables, including:

1. A PostgreSQL dataset that can be hosted in the cloud, providing direct access to the suite of risk and impact model packages via QGIS and CanFlood.
2. A web-based multi-criteria risk profiling platform connected to the above dataset.

7.1 Risk Model and Results Database

The flood risk modelling suite described in Section 6 yielded a set of CanFlood model packages and results composed of roughly 500 tabular, graphical, and spatial data files [cfSuite_2303]. To facilitate the analysis of these risk model results, a relational database was constructed using an inhouse script. Four additional polygon layers were included to facilitate grouping spatial summarizing of the results. This database formalizes the relationship between data layers (e.g., linking assets to their results). This facilitates updates and efficient, automated, and logical analysis of the results using SQL queries. The database was compiled in postGIS 3.1 and is provided in cfDB_2303 and includes the following tables:

- **riskmodels**: summary of each risk model (e.g., 'econ.bldgs' and 'infra.roads')
- **finv**: collection of all CanFlood inventories and their geometries
- **scenario**: the two scenarios modelled (s1 ‘modified’ and s2 ‘current’)
- **events**: 4 hazard events modelled (e0 20-yr, e1 100-yr, e2 200-yr, e3 500-yr)
- **cf_assets_impacts**: results per-asset for each scenario+event+riskModel
- **cf_assets_risk**: risk metric ('EAD') results per-asset for each scenario+riskModel
- **smry_polys**: melt of 4 geometry collections
- **smry_poly_meta**: description of summary polygon layers

The geographies used for the spatial aggregations are summarized in Table 52 and the entity relationship diagram is provided in Appendix H.

Table 52: Description of summary polygons included in results database

SUMMARY POLYGON LAYER NAME	DESCRIPTION
StatsCan_da	StatsCan Dissemination Areas
StatsCan_csd	StatsCan Census Sub-Divisions
RD	Regional Districts
grid500	500x500 m grid

7.2 Flood Risk Profiler

Section 6 provided summaries for each of the 15 risk models, a set of tabular results, and brief discussion of results and limitations. While this information is an important part of understanding the results of this study, it fails to recognize the dynamics of values and priorities and can be difficult to understand or visualize for such a large study area. It is thus of further interest to spatially view the results individually, and in various combinations, or weightings.

The risk and results database described above allows technical users to access the modelling data directly for additional GIS analysis and development of new or improved models or mitigation scenarios. The risk profiler, on the other hand, leverages that dataset to provide a web-based spatial analysis tool for non-technical users with various purposes and perspectives.

7.2.1 Intended Uses

In addition to being an efficient means to host, maintain, and distribute FRA results, the inclusion of a dynamic profiling tool toll is intended to facilitate two important processes, as follows:

1. ***Easy generation of custom views***.

   With a large study area covering many communities, a hazard set containing two operational scenarios with four events each plus EAD, and 15 risk models of varying size and quality, and four geographic scales, static mapping and tables can only provide a very limited set of potential views. The risk profiler portal allows non-technical users to explore the entire range of results by individual model or category for a variety of purposes.

   For this use, the relative weighting and subsequent ranking of the consequences is tremendously helpful as a navigation or exploration tool, rather than a value-based prioritization of total risk. It allows a user to readily select any scenario and consequence set to view the results spatially and by magnitude.

2. ***Risk Prioritizing and Mitigation Assessment.***

   This use of the profiler is significantly more complex as it attempts to represent a balance of values for overall risk by comparing metrics and thinking about both their relative importance and limitations. Despite the challenges, this process is fundamental for understanding and addressing flood risks. We cannot simply sum the results as even those with the same units (e.g., repair costs for expensive homes and community centres). Establishing a prioritized risk profile contextualizes the current risk understanding for the local community, organization, or individual and allows for effective and appropriate evaluation of mitigation plans.

   Multi-Criteria Analysis (MCA) is commonly used for these objectives. MCA refers to a class of evaluation methods to rate or prioritize alternatives against a given set of criteria. MCAs are commonly used to identify a preferred option, or decision[8], but the evaluation process is well suited for flood risk evaluation to transparently rank the level of risk between areas or between mitigation options. A robust MCA is strongly recommended for this process, further described in Section 7.2.5.

[8] The use for decision support is reflected in alternative terminology, such as Multi-Criteria Decision Making (MCDM) methods. MC Analysis was chosen here to reflect the broader application in understanding existing risk, as well as the future use in mitigation evaluations and decision making.

As illustrated in Figure 22, the profiler combines various results of the risk model, geographic aggregates, and user-selected weightings or values.

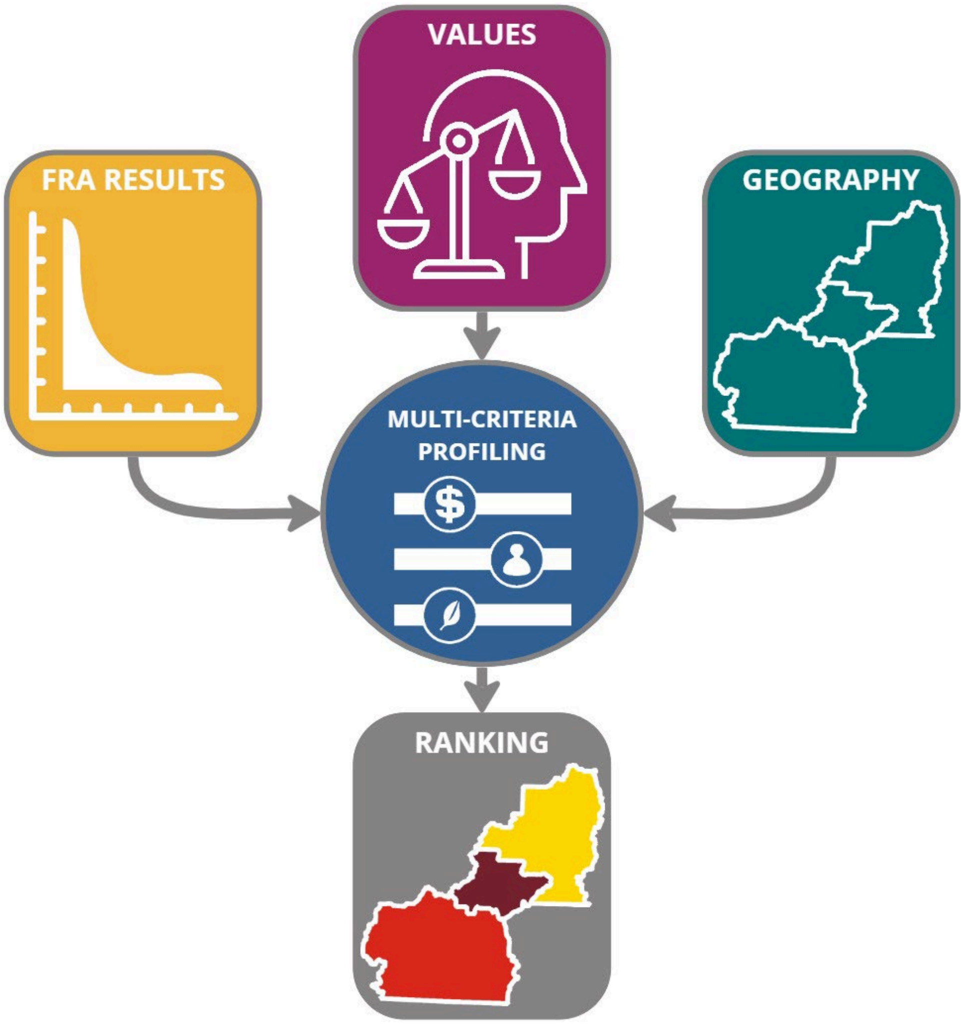


Figure 22: Flood Risk Profiler Conceptual Process

7.2.2 Overview

This section provides a general overview of the components and the underlying methods. A screenshot of the draft application is shown in Figure 23, followed by a description of each main component (labels A, B, and C added to figure).

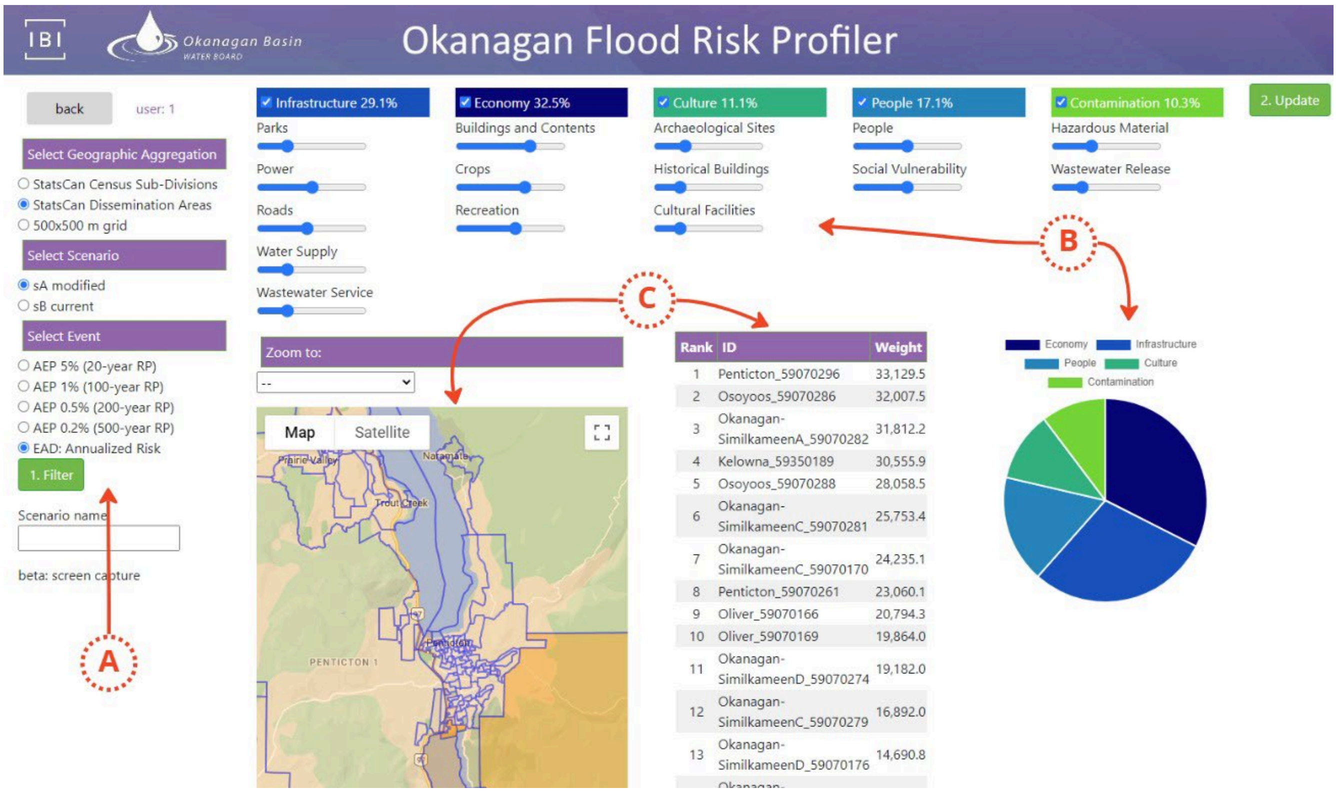


Figure 23: Screenshot of Draft Risk Profiler, ranking process

A. Selection of Geography, Scenario, and Event or Risk. The results in Section 6 were presented by Census Subdivision for consistency, quantity, and because in non-spatial format CSDs are recognizable by name. However, users may have interest in different geographies and many of the metrics may be better suited to other scales. This may be based on the small sample number, such as water facilities, or alignment with the data source, such as the vulnerability scores as discussed in Section 6.2. Within the profiler, the user can select between Census Subdivision, Dissemination Area, or a 500m-by-500m grid.

   Similarly, the profiler provides multiple options for hazard selections. Users can select either of the two operational scenarios as well consequences for each of the four individual events or the annualized risk or EAD.

B. Weighting of Risk Model Results. The results of the 15 models can be given relative weightings to view in isolation or in various combinations. The individual model sliders produce weighting of the normalized results (see 7.2.3 below). The users relative weighting of the is then reflected in the consequence ranking (C) by the selected geography and hazard (A). The individual slider weighting is also represented in the total weight by category as a percentage in the category header and graphically in the pie chart.

C. Ranking of Selected Geographies. The selection of geography, hazard scenario, and the user's weighting of the risk models produces a ranking by relative combined totals. This ranking is represented spatially on a heat map as well as in a ranked table. The ranking method is described below in Section 7.2.3.

From the ranked list and map, the profiler offers several ways to view or download the ranking as well as the raw (not weighted or normalized) results for the selected geography and scenario/event. These are identified in Figure 24 and described below.

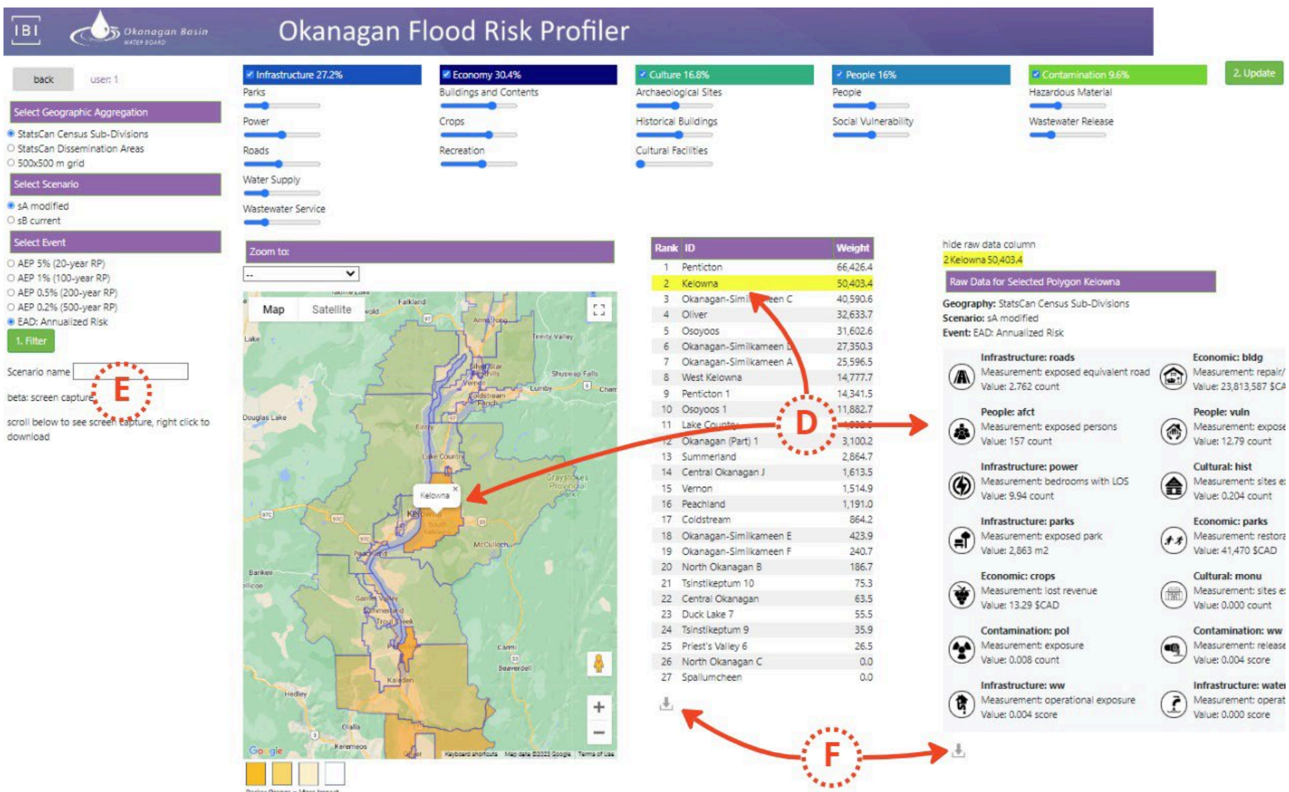


Figure 24: Screenshot of Draft Risk Profiler, data view and download

D. Selecting a geography from the rank list will zoom in and identify it on the map and vise versa. Selecting from either will display the raw results for all the risk models that contain results for the selection.

E. The user can name and save a screenshot of the current view.

F. The user can download the ranked table or the raw results for the selected geographies and current scenario.

7.2.3 Ranking Process

The web profiler by itself employs a simple method of MCA. As identified above and discussed in Section 7.2.5, a more robust MCA application is recommended for the establishment of an overall risk profile, prioritization, and mitigation planning.

To enable the combination and comparison of the different result types and ranking of areas, the web profiler's functionality resembles the very common Simple Additive Weighting (SAW) method. This method typically includes the following steps:

- Identify the criteria (the 15 risk models).
- Assign relative weighting to each criterion (the value sliders).
- Normalize the data (see below).
- Calculate the weighted score by multiplying the normalized scores by the criteria weights (weighted scores displayed in rank table).
- Rank the alternatives ("alternatives" here are the selected geographic units, ranked in the table and map).

This SAW process is "simply additive" because the results from individual criteria weights and resultant scores are summed, and the user is not constrained by a total or other 'trade-offs' and raising one weight does not come at the expense others. In other words, the criteria are considered independent and the weighting of equal value, which may represent a significant limitation in this application (see 7.2.4).

7.2.3.1 *Normalization*

In addition to having varying importance, the methods used to quantify consequences for each of 15 models produced a range of metrics, or units, that vary greatly in range and meaning. As such, they cannot be compared directly to one another, and a method of normalizing is required to obtain a common scale and units, prior to applying relative weighting.

For the purposes of this application and its use in conjunction with a Multi-Criteria Analysis (MCA, see 7.2.1), the "linear max", or "max linear scale transformation", method was deemed most appropriate, transforming the values in a linear way (Vafaei et al. 2016; Celen 2014).

The results within each model are first aggregated for the selected geography and hazard scenario. Each result is then divided by the highest value in the set, its respective model. This process produces values with a range of 0-1, with the highest consequence being 1. The advantage of this linear transformation is that maintains proportionality with the model (i.e., an area with half the raw consequence score will maintain a score half as large).

7.2.4 Limitations

The profiler's normalization and ranking methods are well established, easy to understand and use, and are practically the best fit combination for this application. They present negligeable issues when used for the first objective of exploring results by metric and event combination.

However, the limitations of the data models may be exacerbated if the profiler is used alone without context for the relative valuation of risk with the current results. The treatment of all criteria as independent and of equal value for weighting does not account for quality of the model, both in terms of potential for error and omissions, but also the appropriateness of the quantified metric to represent a consequence (e.g., simple exposure).

As communicated in the Workshop 2 materials and presentation, the weighting must consider the value of the consequence in the context of how, and how well, it was captured, either by this study or future improvements. For example, it is important to consider not only:

“Which is more important: Economy or Environment?”

But also:

“Which is more important to understand from this FRA: repair costs to buildings estimated with depth-damage functions or potential environmental damage from a count of business types that may release hazardous material?” (Appendix K10)

Proper assessment and relative valuation of the range of consequence results from an FRA requires consideration of multiple components or dimensions of the data, including:

- The relative importance of the consequence,
- The relative quality and completeness of the data,
- The relative value of the metric as a representation of the consequence.

A more robust MCA method is recommended when a formal risk prioritization is undertaken with this dataset or with improved higher-resolution local use of this model for mitigation planning.

The Analytical Hierarchy Process is a method that addresses the identified limitations and can be used to incorporate the multiple components of FRA results, as discussed in the next section.

7.2.5 Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) in an MCA method that is well-suited for groups and unstructured problems such as flood risk consequence and mitigation analysis. It is based on the concept that decision making involves a hierarchy of interrelated criteria. Pairwise comparisons are made between each criterion considering the relative importance and interactions within a subset. AHP translates these inputs into measurable relationships and a global weighting structure, or matrix. The pairwise comparisons also allow for the inclusion of a consistency index to ensure logical results.

The integration of AHP was proposed in the original methods and introduced as part of the second workshop. It was hoped that this would familiarize participants with this process of further evaluating FRA results and provide a regional “default” value for the risk profiler. The latter was not feasible as discussed in Section 4.4.6.

There are many resources available for guidance in structuring an AHP framework. One particularly accessible example is bpmsg.com, offering an online tool (Goepel 2018) and an excel AHP workbook. The workbook and documentation have been provided in Appendix M.

To add the consideration data quality and representational scores, parallel hierarchies should be built for each. The importance weighting should then be multiplied by the quality and representation weights to provide an adjusted weight for the overall scoring, taking all three into account.

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Appendix A Hazard Data Catalogue

obwb - haz production data catalogue

Appendix B NHC Memo: Lakes and River Inundation

Appendix C NHC Memo: Dike Vulnerability Assessment

Appendix D NHC Memo: Dikes Down Modelling

Appendix E NHC Memo: Two Percent Wave Runup Height

Appendix F Penticton Beach Breach Analysis

Appendix G Data Catalogue

1. Micro_0908
2. ICI_0902c
3. IBI_0105
4. BCA_0924
5. BCA_1007a
6. BCA_1007b
7. ICI_0902b
8. AFF_1015
9. FLN_0908
10. FBC_200601
11. rfda_200218
12. Eco_1020
13. OSM_1119
14. FLN_1001b
15. FLN_1001a
16. ECC_1012
17. BC_0125
18. StatsCan_0106
19. ICI_0902d
20. ICI_0902e
21. Pent_0711
22. ECC_1012
23. obwb – data – water inf.xlsx
24. MOE_1129
25. NRCan_0223

Appendix H Derived Data Catalogue

1. bmfh_0319
2. bfprt_0122
3. aoi04_0901
4. bvdb_0122
5. nrpVf_0405
6. cfSuite_2303
7. vfLib_0421
8. cfDB_2303
9. finv_2303

Appendix I Non-Residential Survey Instrument

Non-Residential Survey Instrument

Appendix J Buildings Main Floor Heights Data Collection

Building Main Floor Heights Data Collection

Appendix K Engagement Material

1. Workshop 1 Info Boards and Feedback Form
2. Workshop 1 Methods Memo
3. Workshop 1 Presentation Slides
4. Workshop 1 Presentation Recording
5. Workshop 1 Teams Attendance Report
6. Workshop 1 Wonder.me Screenshot
7. First Nations Contact Record
8. First Nations Data Request
9. Workshop 2 Project Site Images
10. Workshop 2 Info Boards
11. Workshop 2 ONA Syilx Story Board
12. Workshop 2 Presentation Slides
13. Workshop 2 Presentation Recording
14. Workshop 2 Teams Attendance Report
15. Workshop 2 AHP Group Results
16. Non-Residential Property Survey Invite
17. Non-Residential Property Survey Questions
18. Non-Residential Property Survey Result Charts
19. Non-Residential Property Survey Results (.csv)

Appendix L PDF Risk Maps

1. People – Affected Population
2. People – Vulnerable Population
3. Economy – Buildings, Crops, Parks
4. Infrastructure – Water, Wastewater, Power
5. Infrastructure – Recreation, Transportation
6. Environment – Wastewater, Contamination
7. Culture – Facilities, Heritage, Archaeological

Appendix M AHP Resources

1. Goepel, K. D. (2018)
2. AHPcalc – Excel and documentation