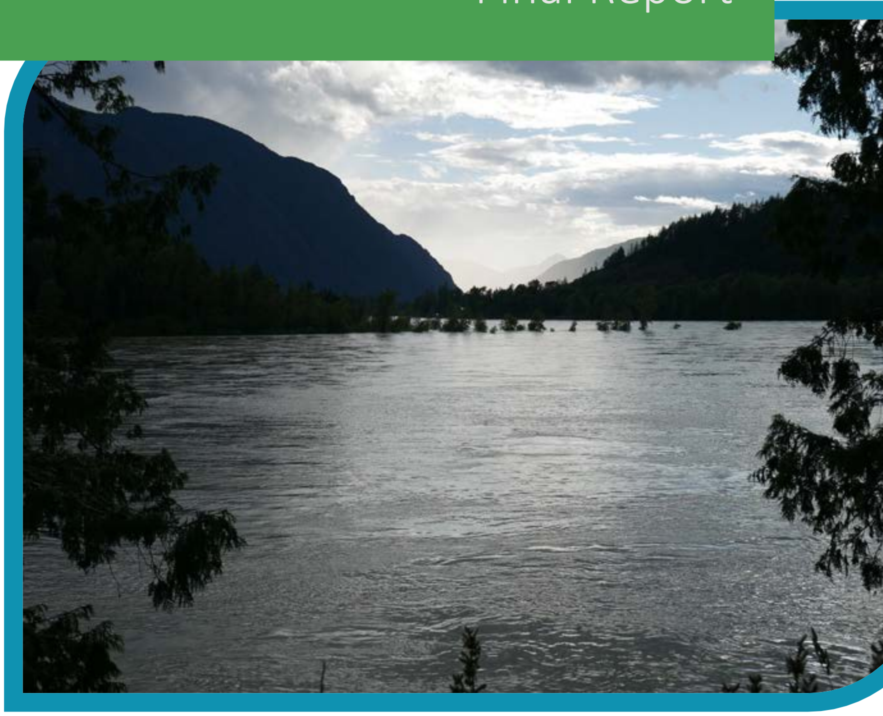
Fraser Basin Council
Investigations in Support of Flood Strategy Development in British Columbia
Issue B-3: Flood Risk Assessment
Final Report



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30 April 2021

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Acknowledgements

This project was supported by funding from the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) in British Columbia (BC). Previous research conducted for other projects (i.e., funded by others) was also leveraged and integrated.

The authors wish to acknowledge the support of Frances Woo and Steve Litke from the Fraser Basin Council (FBC), as well as the many collaborators and colleagues who provided time for interviews, repeated questions, and reviews. We would especially like to thank Kris Holm of BGC, David Sol of IBI, Seth Byrant (Independent), Steve Mark from the ICI Society, Murray Journeay, Nicky Hastings, and Jackie Yip all of Natural Resources Canada. Thorough and thoughtful reviews were also provided by Mitchell Hahn and George Roman of MFLNRORD.

This report was written by Silja Hund, Ph.D. and Tamsin Lyle, M.Eng., MRM, P.Eng (Principal) of Ebbwater Consulting Inc. (Ebbwater). Kayla Dawson, P.Eng. conducted the online search of recently completed projects, and Dickon Wells, M.Eng. produced mapping outputs.

The preamble for this report was provided by the FBC.

We would like to acknowledge that this report was written at the Ebbwater Consulting Inc. (Ebbwater) office and home offices, which are located on unceded and Traditional Territory of the Coast Salish people.

Executive Summary

Introduction

Floods are among the most commonly occurring natural hazard in British Columbia (BC) and account for the second largest portion of disaster recovery costs on an annual basis. Mitigating flood risk is key to increasing the resilience of affected communities and reducing pressures on the public purse. By proactively investing in flood mitigation activities, a community secures practical investments for its future growth and prosperity, reducing the risk of significant disaster recovery costs, productivity losses, economic losses, destruction of non-monetary cultural assets, environmental damage, injuries, and deaths. A key step in mitigating risk is to first understand the level and distribution of this risk across the province. At this time, given that intentional flood risk analysis and assessment are relatively novel, BC does not have this information in place to support risk reduction investments and decisions.

The Fraser Basin Council (FBC) has been retained by the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) to manage and coordinate research and engagement across a broad range of flood management issues relating to governance, hazard and risk management, forecasting, and emergency response and recovery. The FBC retained Ebbwater Consulting Inc. (Ebbwater) to conduct research in support of Issue B-3: Flood Risk Assessment, one of 11 interrelated projects. **The overall objective for this project is to explore the value, and potential approaches to execute risk-based flood planning in the province**. This is being explored through 6 separate investigations as determined by FBC and the Province:

1. **Investigation B-3.1:** Evaluate and compare the benefits and costs/limitations of taking a risk-based approach to flood management versus a standards-based approach.

2. **Investigation B-3.2:** Investigate the effort required to develop a maintain a province-wide asset inventory and /or exposure dataset covering flood-prone areas.

3. **Investigation B-3.3:** Investigate approaches to completing a province-wide FRA, addressing effort required, level of detail, types of flood risk, current and future scenarios, scale and any information required and data gaps.

4. **Investigation B-3.4:** Investigate the level of effort to develop a coarse local-scale FRA based on available flood hazard maps(s).

5. **Investigation B-3.5:** Determine the effort required to undertake a local-scale comprehensive FRA for multiple hazards (e.g., riverine, coastal) and for varying degrees of available data on flood hazard, exposure, vulnerability, and risk.

6. **Investigation B-3.6:** Investigate methods for valuing the benefits and costs/limitations of flood risk reduction actions in a holistic and consistent manner and develop a framework for project prioritization that could be applied or adapted across the province to reduce flood risk and improve environmental outcomes.

Results

Risk-based flood management is preferred around the world. There are clear advantages to this type of approach, especially in the face of climate change. A risk-based approach can manage the complexity of flood problems better than a standards-based approach, for example by recognising and considering the diversity of flood experiences and flood impacts. Further, it is posited that over time a risk-based approach will reduce losses and impacts from flood events more effectively than a standards-based approach.

However, there are many entrenched obstacles to the shift towards this type of approach in Canada and BC. These are identified in this report, primarily by drawing on recently completed risk assessments within the province. Many of these obstacles are related to the novelty of a risk-based approach, and a current lack of data, resources, and people to support these types of assessment as well as the existing governance structures.

Data Gaps and Challenges

Risk is calculated as the combination of hazard likelihood and consequences. And therefore, flood hazard data and consequence data, which itself is developed through an understanding of exposure and vulnerability are all need to support risk assessments. One of the current obstacles to consistently applying risk-based approaches to flood management in the province is a lack of comprehensive, consistent, and high-quality exposure and vulnerability data to support risk assessments. This data gap has created enormous costs in the development of robust risk assessments in the province as each project required significant resources to acquire, create and process appropriate datasets.

Provincial-Scale Risk Assessment

This report identifies the value in a comprehensive and consistent flood risk assessment that covers the province. This would provide a tool for prioritisation of resources, content for public education, and support local and First Nation governments to have initial conversations related to flood and flood risk. A number of options to achieve a provincial scale assessment were explored, and ultimately a top-down comprehensive and consistent risk assessment was preferred. This would provide a transparent, repeatable, and consistent information, and would require less funding and time.

Local Detailed Risk Assessments

The value of local, comprehensive, and detailed risk assessments is also covered in this report. These have a different purpose to coarser assessments, such as a provincial-scale assessment, in that they can support local planning and engineering decisions and design. These assessments require significantly more data, engagement, and general resources than coarser assessments, if they are conducted robustly. A review of recently completed risk assessments as well as international best practice highlighted the challenges faced by communities to produce high-quality and useful products given funding constraints, lack of guidance, and a newly evolving field of experts.

Use of Risk Assessment to Support Decisions

Risk assessments, which are resource intensive, are only useful if they meaningfully support decision and planning processes. This report also explores different decision processes that explicitly or implicitly incorporate risk information. This work highlighted the need for further guidance and study, but also the fact that the most robust decision processes, that meet a number of best practices and meaningfully draw in risk information, are the most resource intensive. Whereas, simple past processes (e.g., Cost-Benefit Analysis) can be efficiently conducted, but may not result in long-term risk reduction, especially with consideration of the uncertainty of climate change.

Recommendations

This report explored the value and potential approaches and tools required to execute risk-based flood planning in the province. It included a comprehensive review of work to date in the province as well as best practices carried out elsewhere. The following conclusions are drawn:

- Risk-based approaches for flood management are superior to current standards-based approaches.
- Risk-based approaches require that flood risk assessments are conducted to support actions on risk reduction.
- Flood Risk assessments are complex, resource intensive, and require deep and diverse expertise.

Despite the many obstacles in play, there is opportunity to have a paradigm shift in the province – more data is available to support risk assessment, there is clear direction from senior government that this is a preferred approach. Further, the Province itself promotes risk-based through the adoption of a Sendai approach to emergency management. The authors strongly encourage the Province to make a shift towards a risk-based approach.

Given the importance of a risk-based approach to the future of BC's flood governance model, the report suggests that:

- A provincial-scale flood risk assessment let by the Province, using a top-down, consistent approach is proposed to support large scale understanding or risk and prioritisation of activities across the province.
- Local and First Nation governments should continue to conduct local comprehensive risk assessments to support local decisions.

To enable the development of robust flood risk assessments:

- A flood risk assessment guideline, that leverages Federal draft and completed guidelines should be developed. Noting here that a strong finding of this report was that many recently completed local flood risk assessments are not robust.
- The Province should support the development and ongoing maintenance of a consistent and comprehensive exposure database.

Beyond the development of flood risk assessments, it is important to consider how these assessments can be used to support risk reduction, through risk-based planning, risk reduction targets, and risk-based decision frameworks.

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LIST OF ACRONYMS

AAL	Average Annual Loss
AE	Associated Engineering
AEP	Annual Exceedance Probability
AIDR	Australian Institute for Disaster Resilience
ALARP	As Low as Reasonably Possible
BC	British Columbia
CBA	Cost Benefit Analysis
CEPF	Community Emergency Preparedness Fund
DFAA	Disaster Financial Assistance Arrangements
EGBC	Engineers and Geoscientists British Columbia
EMBC	Emergency Management British Columbia
EPA	Emergency Program Act
EU	European Union
FBC	Fraser Basin Council
FCL	Flood Construction Level
FDRP	Flood Damage Reduction Program
FEMA	Federal Emergency management Agency (US)
FFRMS	Federal Flood Risk Management Standard
FHLUMG	Flood Hazard Land Use Management Guidelines
FNA	First Nations Adapt
GSC	Geologic Survey of Canada
GFDRR	Global Facility for Disaster Risk Reduction
GIS	Geospatial Information System
ICLR	Institute for Catastrophic Loss Reduction
ISC	Indigenous Services Canada
ISO	International Standards Organization
MCA	Multi-Criteria Analysis
NARRA	National Risk and Resilience Aggregation Tool
NDMP	National Disaster Mitigation Program
NHC	Northwest Hydraulic Consultants Ltd.
NRC	National Research Council
NRCan	Natural Resources Canada
OCP	Official Community Plan
OMNRF	Ontario Ministry of Natural Resources and Forestry
PIEVC	Public Infrastructure Engineering Vulnerability Committee
PSC	Public Safety Canada
RAIT	Risk Assessment Information Template
RD	Regional District
RFP	Request for Proposal
SDM	Structured Decision Making

UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
USACE	United States Army Corps of Engineers

Preamble

Many communities in BC are working to better manage their river and coastal flood risks through a wide range of flood management activities. But current approaches to managing flooding are not always efficient, coordinated, equitable, or cost-effective.

The **Investigations in Support of Flood Strategy Development in British Columbia** is a province-wide initiative aimed at developing a comprehensive understanding of current challenges and opportunities relating to flood management across BC. The focus is primarily on riverine, coastal, and ice jam floods, although other types of flooding are recognized where appropriate. This initiative recognizes that flood management is a multi-faceted, ongoing process requiring the coordination of many organizations, agencies, and orders of government and linked with broader processes, including climate change adaptation and disaster risk reduction, among others.

The BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development retained the Fraser Basin Council to manage and coordinate research and engagement across a broad range of flood management issues relating to governance, hazard and risk management, forecasting, and emergency response and recovery. Consulting teams were retained to undertake research and technical analysis with input from experts, practitioners, and stakeholders from all four orders of government, the private sector, and other organizations. Each investigation produced recommendations to inform flood management program improvements at multiple scales and across many jurisdictions.

Investigations were undertaken across 11 interrelated issues under 4 themes:

	Theme A – Governance	
A-1	**Flood Risk Governance**	Review current governance and delivery of flood management activities in BC involving all four orders of government and non-government entities, identify challenges, and recommend changes to improve coordination, collaboration, and overall effectiveness.

	Theme B – Flood Hazard and Risk Management	
B-1	**Impacts of Climate Change**	Investigate the state of climate change information and new and existing tools that can support authorities in integrating climate change impacts in flood management.
B-2	**Flood Hazard Information**	Examine the state of flood mapping and dike deficiency information and recommend ways to fill current gaps in flood mapping and manage and maintain information about flood hazards and dike deficiencies.
B-3	**Flood Risk Assessment**	Explore approaches to completing flood risk assessments at various scales, methods for prioritizing risk reduction actions, and standards- versus risk-based approach to flood management.
B-4	**Flood Planning**	Examine the ability of local authorities to undertake integrated flood management planning and opportunities to improve capacity.
B-5	**Structural Flood Management Approaches**	Assess the potential for improvements to dike management, improve the capacity of diking authorities, and implement innovative structural flood risk reduction measures.

B-6	**Non-Structural Flood Management Approaches**	Investigate current and alternative approaches to managing development in floodplains and opportunities for implementing non-structural flood risk reduction actions.

Theme C – Flood Forecasting, Emergency Response and Recovery		
C-1	**Flood Forecasting Services**	Identify gaps and opportunities for improvement in the province's flood forecasting services.
C-2	**Emergency Response**	Investigate roles, plans, and capabilities for flood response and opportunities for improving emergency response.
C-3	**Flood Recovery**	Examine approaches that would support recovery efforts and help reduce future flood risk.

Theme D – Resources and Funding		
D-1	**Resources and Funding**	Investigate resource and funding needs associated with actions to strengthen flood management and evidence in support of proactive flood mitigation.

1 Introduction

1.1 Project Background

Floods are among the most commonly occurring natural hazard in British Columbia (BC) and account for the second largest portion of disaster recovery costs on an annual basis. Mitigating flood risks is key to increasing the resilience of affected communities and reducing pressures on the public purse. By proactively investing in flood mitigation activities, a community secures practical investments for its future growth and prosperity, reducing the risk of significant disaster recovery costs, productivity losses, economic losses, destruction of non-monetary cultural assets, environmental damage, injuries, and deaths.

However, BC's floodplains are the commercial, social, and ecological arteries of the province. The assets, and communities they support, that sit on these floodplains are subject to damage and disruption when floods occur. We use floodplains for these purposes partly for historic reasons (e.g., for access to fresh water, transportation, flat and fertile land, etc.), but have continued to grow and entrench our communities into these areas because they are desirable places to live, work and play.

If we continue to use floodplains for these purposes, we need to acknowledge and plan for flooding. Some of the approaches that we have traditionally relied on, such as dikes and emergency protection and response, have limitations, especially in the face of climate change. An alternative is to manage instead for risk reduction, by considering a broader spectrum of responses that consider the placement of assets within flood hazard areas as well as their susceptibility to being flooded.

Risk-based or risk-informed planning requires that a baseline understanding of flood risk is available to support decisions on preferred actions to reduce risk. This is true for both provincial-scale prioritization as well as local flood mitigation projects. Flood Risk Assessments (FRAs) provide important information for flood risk reduction, as they indicate which assets and locations have the highest risk, and thus, require priority in flood risk reduction measures.

In BC, FRAs for communities are a relatively new flood mitigation tool, and have predominantly been conducted since the start of the National Disaster Mitigation Program (NDMP) in 2015, but several earlier FRAs also exist (e.g., Jakob et al., 2012). Also, it should noted that risk assessments have been conducted historically in related fields (e.g. geohazard (debris floods and debris flows) risk assessments, dam safety and reservoir assessments, as well as private-sector FRAs exist). There is a great diversity in approaches and outcomes in these assessments.

Currently, no detailed provincial guidance on FRAs exists (A guideline on *Legislated Flood Assessments in a Changing Climate in BC* by the Engineers and Geoscientists British Columbia (EGBC) (EGBC, 2018) contains a brief overview on FRAs but no detailed technical guidance). Federally, the *Coastal Flood Risk Assessment Guidelines for Buildings & Infrastructure Design Applications* from Natural Research Council (NRC) (Murphy *et al.*, 2020) have only recently been published, and two further federal guidelines are under development by Natural Resources Canada (NRCan) (*Flood Risk Assessment Guidelines*, and *Coastal Flood Risk Assessment Guidelines*).

1.2 Issue B-3: Flood Risk Assessment

The Fraser Basin Council (FBC) has been retained by the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) to manage and coordinate research and engagement across a broad range of flood management issues relating to governance, hazard and risk management, forecasting, and emergency response and recovery (see Preamble). The FBC retained Ebbwater Consulting Inc. (Ebbwater) to conduct research in support of Issue B-3: Flood Risk Assessment, one of 11 interrelated projects. **The overall objective for this project is to explore the value, and potential approaches to execute risk-based flood planning in the province**. This is being explored through 6 separate investigations as determined by FBC and the Province:

7. **Investigation B-3.1:** Evaluate and compare the benefits and costs/limitations of taking a risk-based approach to flood management versus a standards-based approach.

8. **Investigation B-3.2:** Investigate the effort required to develop a maintain a province-wide asset inventory and /or exposure dataset covering flood-prone areas.

9. **Investigation B-3.3:** Investigate approaches to completing a province-wide FRA, addressing effort required, level of detail, types of flood risk, current and future scenarios, scale and any information required and data gaps.

10. **Investigation B-3.4:** Investigate the level of effort to develop a coarse local-scale FRA based on available flood hazard maps(s).

11. **Investigation B-3.5:** Determine the effort required to undertake a local-scale comprehensive FRA for multiple hazards (e.g., riverine, coastal) and for varying degrees of available data on flood hazard, exposure, vulnerability and risk.

12. **Investigation B-3.6:** Investigate methods for valuing the benefits and costs/limitations of flood risk reduction actions in a holistic and consistent manner and develop a framework for project prioritization that could be applied or adapted across the province to reduce flood risk and improve environmental outcomes.

This report on Issue B-3, is interconnected with other issues and reports (see Appendix A for a full list). In particular, it is noted that the B-1 Issue on Climate Change (Associated Engineering Ltd., 2021) and B-2 Issue on Hazard Mapping (Northwest Hydraulic Consultants Ltd., 2021a) directly feed into this project, and that the Issues B-4, 5 and 6, which focus on planning and mitigation actions have direct linkages with the outcomes of this report. The analysis and reporting presented here was conducted as one of the first projects, and therefore was not able to fully benefit from the results of other works. However, the authors wish to acknowledge the efforts of the other report teams in supporting some collaboration and iterations to attempt to align the reports and recommendations.

1.2.1 Project Scope - Limitations

It is important to note that the goal of this report is NOT to provide a guideline for conducting flood risk assessments in the province. The focus is instead on assessing what has been done so far in BC, and to recommend ways forward with consideration of best practice approaches, current opportunities, and obstacles. While high-level recommendations are made based on national/international best practice approaches, the specific details of flood risk assessments are not discussed or developed, as this would require a longer process with stakeholder/advisory committee engagement.

Further, it should be noted that the report is based on specific tasks and questions, which were outlined for each of the 6 investigations by FBC and the Province, and this report aims to answer these questions first, prior to providing supplementary information.

It should also be noted that this report focuses predominantly on risk resulting from clearwater flooding, in contrast to considering all flood-like processes and secondary hazards (e.g., erosion or slope stability), which are outside the scope. Some flood risk assessments considered in the report include debris flows in addition to clearwater flooding. More details on different flood hazards are provided in the B-2 Flood Hazard Information issue.

Another limitation in scope is that this project is focused on flood risk assessments for communities and is not intended as a review for dam safety, regulated reservoirs, or flood risk assessment for linear infrastructure, or tailings dams.

Emergency Management British Columbia (EMBC) is guided by four pillars, including Mitigation, Preparation, Response, and Recovery. The work conducted for this project is primarily situated within the Preparation pillar. Some discussions in Investigation B-3.6 on valuing costs and benefits of flood risk reduction measures also reach into the realm of Mitigation.

Lastly, note that specific limitations related to flood risk assessments themselves are covered in later sections.

This report was researched and written in Spring and Summer 2020, with some minor revisions after this point. And therefore, although it alludes to work conducted under other Issues, it does not necessarily fully reflect work conducted for the broader Investigations into a Flood Strategy in BC.

1.2.2 Project Scope - Evolution

The original project scope is focussed on *risk* (please see Chapter 2 for detailed definitions), however some of the project investigations lend themselves to further exploring concepts of *resilience.* This is in line with recent provincial strategy like the proposed *Emergency Program Act* modernization. Concepts of resilience and resilience assessments are therefore discussed in brief in this report.

Further, some of the analysis and discussions in this report require consideration of various types and scales of flood hazard analysis and mapping. Specifically, the use of provincial-scale, high-level flood mapping to support similarly scaled risk assessments, and the consideration of multiple scenarios and events to support full-statistical accounting within risk assessments. Consideration of this type of hazard mapping was deemed out-of-scope by the B-2 project team. And therefore, effort was made to fill these gaps within this current report.

1.3 A Note on Terminology

Many technical terms are used throughout this report. The authors have been deliberate in their use of language, especially for terms that are often used interchangeably or for different purposes in colloquial communication. Definitions, as used in this report, along with background information on these terms is provided in Section 2; these are predominantly based on terminology used by the United Nations Office for Disaster Risk Reduction (UNDRR).

1.4 Summary of Methods

In this section, an overview of methods that are consistent across all investigations is presented. This starts with the methods to assess the availability of FRAs in BC (Section 1.4.1), followed by the literature review approach and consultation with practitioners (Section 1.4.2), Indigenous inclusion (Section 1.4.3) and lastly, discussion of challenges and limitations (Section 1.4.4). Additional methods as applied to individual investigations are described elsewhere in the report.

1.4.1 Assessment of Availability of Flood Risk Assessments in BC

As a first step, the current availability of flood risk studies across BC was assessed. Of interest here are not only where flood risk assessments have already been conducted throughout the province, but also what methodologies were used (e.g., quantitative versus qualitative, local versus regional studies). This information was sought to support answers to several investigations. Specifically, this approach provides information on the scope, scale and cost of work currently being conducted to better understand how this might be leveraged in support of broader provincial work, and to understand the required resources (data, methods, human resources, and costs) needed to conduct these specialist assessments.

To obtain relevant information on FRAs in a systematic manner, the various recent public funding programs (National Disaster Mitigation Program (NDMP), Community Emergency Preparedness Fund (CEPF), and the First Nation Adapt (FNA) program) were contacted. The authors sent an information request memo for NDMP and CEPF-funded FRA projects to FBC and MFLNRORD, which was forwarded to EMBC. A detailed list of funded NDMP projects (Stream 1 – Flood risk assessments) as well as CEPF-funded projects were received from EMBC. A list of FNA-funded projects is available online[1], from which the authors selected all studies which might have contained an FRA component or be otherwise relevant. The authors contacted Indigenous Services Canada (ISC) to obtain further information on the studies, but, as the department does not have the authorization to release reports, were not able to obtain further information.

[1] Crown-Indigenous Relations and Northern Affairs Canada (previously Indigenous and Northern Affair) First Nation Adapt Program: Selected projects 2016-2017 (https://www.aadnc-aandc.gc.ca/eng/1521204135511/1521204193844); Selected projects 2017-2018 (https://www.aadnc-aandc.gc.ca/eng/1522157553041/1522157576757); Selected projects 2018-2019 (https://www.aadnc-aandc.gc.ca/eng/1558113374675/1558113396940). Accessed in March 2020.

Based on the NDMP, CEPF and FNA lists of funded projects, the authors conducted a detailed online search to obtain further information on these studies. The goal of the search was first and foremost to obtain the final report of the study. When this was however not available, other information such as council notes, the Request for Proposal (RFP), or communication material for the general public was downloaded. All material was documented in a detailed inventory database (this is available to share).

Next, each listed study was associated with a category (describing the type of FRA). Studies that focused on flood hazard assessments, or otherwise did not contain an FRA component, were excluded. Types of FRAs included regional, local/qualitative and local/quantitative (please see later sections for a discussion of the differences in these types of assessments). At this initial round of categorization, it was in most cases, not possible to assign more detailed tiers of analysis (as are being developed as part of the NRCan National Flood Risk guidelines, see also Section 2.3.1), as often, categorization relied on a short project description, the study title, or other available information. For the studies with FRA component for which reports were available, the authors conducted a more detailed assessment of the methodology for regional studies (as part of investigation B-3.3) and for local studies (as part of investigations B-3.4 and B-3.5).

The FRA studies are also presented spatially, by associating them with the municipal boundary, reserve lands, or regional district boundary, for which the study was conducted (see for instance Section 5.2 for maps).

1.4.2 Literature Review, Consultations with Practitioners, and Cross-Fertilization with Other Investigations

To ensure that the recommendations are based in best national and international practice, relevant international guidelines and frameworks, as well as nationally and provincially relevant documents were considered:

International Guidelines and Frameworks:

- United Nations: *Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reductio*n (UN, 2016).
- United Nations Disaster Risk Reduction (UNDRR):
    - *Sendai Framework for Disaster Risk Reduction* (UNDRR, 2015);
    - *Technical Collection of Concept Notes on Indicators for the Seven Global Targets of the Sendai Framework for Disaster Risk Reduction* (UNDRR, 2016);
    - *Words into Action Guidelines: National Disaster Risk Assessment: Governance System, Methodologies, and Use of Resul*ts (UNISDR, 2017); and other material.
- Global Facility for Disaster Risk Reduction*: The making of a riskier future: How our decisions are shaping future disaster risk* (GFDRR, 2016).
- International Organization for Standardization (ISO): *ISO 31000:2018 Risk Management – Guidelines* (ISO, 2018).
- Australian Institute for Disaster Resilience: *National Emergency Risk Assessment Guidelines* (AIDR, 2015).

- British Standards Institute: *A new standard for flood resistance and resilience of buildings* (Bowker, Escarameia and Tagg, 2007; Tagg, 2017).

National Guidelines and Documents:

- National Research Council of Canada (NRC): *Coastal Flood Risk Assessment Guidelines for Buildings & Infrastructure Design Applications* (currently in development; Ebbwater is one of the co-authors, (Murphy *et al.*, 2020)
- Natural Resources Canada (NRCan): *Federal Flood Mapping Guidelines Series – Flood Risk Assessment Procedures* (currently in development; Ebbwater is part of the advisory committee).
- NRCan: *Federal Flood Mapping Guidelines Series – Federal Land Use Guide for Flood Risk Areas* (NRCan, 2019; not public yet, however, Ebbwater was the first author).
- NRCan: *Canadian Guidelines and Database of Flood Vulnerability Functions* (Natural Resources Canada, 2017; currently retracted); updated draft (2020) was also reviewed.
- NRCan: *Disaster Resilience by Design: A Framework for Integrated Assessment and Risk-Based Planning in Canada* (Journeay *et al.*, 2015).
- Public Safety Canada: *All Hazards Risk Assessment Methodology Guidelines* (Public Safety Canada, 2012; Verga, 2013).
- Public Safety Canada: *Draft National Risk and Resilience Aggregation and Return on Investment Tool* (Stantec Consulting Ltd. and Ebbwater Consulting Inc., 2017).
- NRCan: *Way forward for Risk Assessment Tools in Canada* (Lyle and Hund, 2017).

BC Provincial Guidelines and Documents:

- Engineers and Geoscientists British Columbia (EGBC): *Legislated Flood Assessments in a Changing Climate in BC* (EGBC, 2018).
- BC Climate Action Secretariat: *Strategic Climate Risk Assessment for British Columbia* (BC MECCS, 2019).

Furthermore, methodologies used in flood risk assessments throughout BC were considered, in so far as the information was available in final reports. The authors further followed up with individual consultants to learn about specific risk assessment methodologies that they had applied. Specifically, the authors met with Kris Holm from BGC Engineering Inc. (BGC) to hear about the regional risk assessment approach that BGC has been applying for several regional districts in BC. The authors also met with Seth Bryant and David Sol from the IBI Group, along with the FBC, to learn about their flood damage curve work as part of the Lower Mainland Flood Risk Assessment. As part of this meeting with FBC and the IBI Group, lessons learnt from the Lower Mainland Flood Risk Assessment were also discussed.

The authors further consulted with Murray Journeay, Jackie Yip and Nicky Hastings from NRCan with respect to the work NRCan has been doing on developing exposure and vulnerability data models, as well as on coastal flood risk assessment guideline work being done by the NRCan team. The authors consulted as well with Steve Mark from the Integrated Cadastral Information Society (ICI Society) on their exposure database and data management systems for exposure in general. Further, we consulted with JBA Risk Management with respect to high-level flood hazard mapping for all of BC.

Lastly, another component for successful flood risk investigations is the cross-fertilization with other investigations. A memo to highlight cross-fertilization potential with other issues was develope, and the authors took part in FBC-led meetings with Northwest Hydraulic Consultants Ltd. (NHC), who conducted the B-2 issue on Flood Hazard Information and Associated Engineering & Associated Environmental (AE), who conducted the B-1 issue (Impacts of Climate Change), as well as another meeting with the B-1 and B-2 team, as well as email exchanges with Kerr Wood Leidal Associates Ltd. (KWL), who conducted the B-4 Flood Planning Investigations issue.

1.4.3 Indigenous Inclusion

The scope of work undertaken by Ebbwater did not allow for Indigenous engagement during the development of this report (similarly, it was not possible to engage local government). Initial Indigenous engagement related to flood risk assessment and flood mitigation were undertaken by the FBC in the form of a survey that considered the broader Provincial Strategy development. Unfortunately, the responses were extremely limited.

Some initial recommendations on Indigenous engagement and inclusion in flood risk assessments have been made where appropriate based on the experience of the authors, available literature, and the minimal responses to the survey. However, this is by no means comprehensive, and the authors believe that significant future effort should be focussed on meaningful learning from and engagement with a diversity of Indigenous voices must be completed.

1.4.4 Challenges and Limitations to Methods

One of the main limitations for the B-3 issue was that it was one of the first issues to be investigated, and could therefore not yet draw from the results of other investigations. For instance, final information from issues B-1 (Impacts of Climate Change) and B-2 (Flood Hazard Information) should inform some report sections but were not yet available at time of writing this B-3 issue.

Further, the development of the new NRCan Flood Risk Assessment guidelines are in progress, but a draft was not available until October 2020 when this report was predominantly complete, and it was therefore not be possible within the timeline of the B-3 issue to incorporate this information.

Another limitation for the assessment of currently available FRAs in BC was the availability of information. Reports could not be obtained for all identified FRA studies. Especially for projects funded under the FNA program, not many reports were available. Without a report and more detailed information on a project, there are many uncertainties when assigning FRA type categories, determining the extent of the FRA, or estimating if the project budget was used for an FRA, or for instance, mostly for a flood hazard study, with a small qualitative flood risk component included. Considering the many diverse methods applied for FRA studies across BC and considering that many studies did not only focus on FRAs alone, but also included other studies, it was challenging to compare the FRA studies both in terms of their methodology and the associated costs.

As discussed in the section above, another major challenge was the adequate inclusion and consideration of Indigenous values without engagement.

Lastly, while comprehensive lists of FRAs funded through the NDMP, CEPF and FNA programs were available, other FRA studies which had been funded through other mechanisms, could only be included to our knowledge, i.e., this remains a non-comprehensive list.

Nevertheless, it is hoped that the analysis in this study can provide a first overview of FRA availability and methodologies throughout BC and recommend steps towards provincial and local FRAs, as well as provide a path towards a risk-based approach.

1.5 Report Organization

This report has been organized with the expectation that the reader will have a base understanding of the overarching Investigations in Support of Flood Strategy Development (see Preamble). Further, the authors have organized the report with the expectation that readers will read through this as a single comprehensive report. Each investigation (see Section 1.2) has been addressed separately. However, overarching background information that supports all investigations is first presented in Section 2. This is then followed by issue specific Sections:

- Section 3: Investigation B-3.1 Risk-based versus Standards-based Approach to Flood Management.
- Section 4: Investigation B-3.2 Province-wide Exposure and Vulnerability Database.
- Section 5: Investigation B-3.3 Provincial Flood Risk Assessment
- Section 6: Investigation B-3.4 Coarse Local Flood Risk Assessment
- Section 7: Investigation B-3.5 Comprehensive Local Flood Risk Assessment
- Section 8: Investigation B-3.6 Valuing Costs and Benefits of Risk Reduction Actions

These investigation specific sections are then followed by overall concluding remarks in Section 9.

To reduce repetition and bulk in the report, common ideas and results are not repeated. Instead, the authors have made an effort to cross-reference between investigations. The investigations build on each other and should be considered as a whole. Investigation B-3.1 provides the rationale why a risk-based approach to flood management should be considered, and why therefore, FRAs, as discussed in the next sections, are an important component of flood risk reduction. To conduct FRAs, flood hazard as well as exposure and vulnerability data are essential inputs. Flood hazard is addressed in the Issue B-2 (Flood Hazard Information), while investigation B-3.2 provides details on exposure and vulnerability data availability in BC, and discusses the potential to develop a province-wide data base. The following 3 Sections (B-3.3, B-3.4 and B-3.5) discuss different geographic scales of FRAs, while the last investigation B-3.6 discusses the next step towards risk reduction actions (mitigation), and how FRAs can inform such actions.

2 Risk & Resilience Primer

Risk exists not because hazards exist, but because these hazards sometimes interact negatively with assets and other elements within hazard areas. These negative interactions can be reduced through intentional decisions that decrease risk and increase the resilience of the system. The following section provides some context on the terminology used in the field of disaster risk reduction and climate adaptation; understanding the nuances of the terminology is key to understanding the process of risk and resilience assessments as well as risk reduction actions. This primer is intended to inform all the project investigations.

2.1 Terminology for Risk and Resilience

For the purposes of this project, the authors have relied on international best practice (e.g., UNDRR, GFDRR) as well as the dominant usage of terminology in Canada (e.g., NRC guidelines, Risk Assessment literature from Geological Survey of Canada (GSC), etc.) to develop the information below. However, the authors note there is variation in how terminology is applied in Canada; there are some prominent BC examples of flood risk assessments that apply terminology differently (e.g., the Lower Mainland Flood Risk Assessment).

2.1.1 What is Risk?

Risk is a function of both the *likelihood* of an event occurring (i.e., what is the chance of an event occurring?), and the *consequences* (or impacts) if that event occurs. C*onsequence* is defined as a function of the *hazard* (where and how severe is the event?), and *vulnerability*. *Vulnerability* can be further described as a function of *exposure* (what is in the way?) and the susceptibility (or inversely the capacity) of the exposed elements to the hazard (UN, 2016). Figure 1 provides one conceptual model for natural hazard risk.

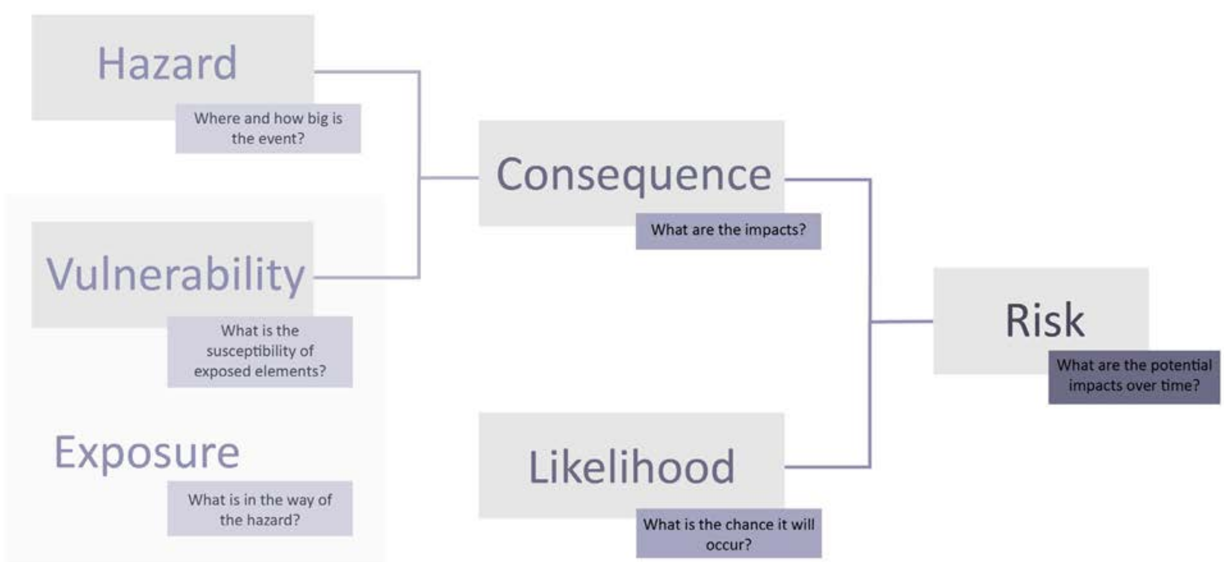

Figure 1: Risk as a function of consequence and likelihood (simplified).

Note that the terminology used in this report is based on the definitions used by the United Nations Office of Disaster Risk Reduction in their international guidance material (UN, 2016; UNDRR, 2017), and for clarity, these definitions have been provided below.

Hazard is a "process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation." (UN, 2016; UNDRR, 2017)

Exposure is the "situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. Measures of exposure can include the number of people or types of assets in an area." (UN, 2016; UNDRR, 2017)

Vulnerability describes the "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards." (UN, 2016; UNDRR, 2017)

Capacity is the "combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience." (UN, 2016; UNDRR, 2017)

It should be noted that sometimes, these terms are used differently. In studies that focus on economic damage assessments there is a tendency to include all asset characteristics (that is the location, type, and attributes of each object) in the exposure category. For instance, building characteristics, which make a building more vulnerable to flood damages, would be included in the exposure category. In this line of thought, vulnerability focuses on what happens if that asset experiences flooding and refers to the specific vulnerability functions (for instance, a depth-damage function that relate flood depth to expected building damage). However, please note, that this is NOT how the terminology is applied in this report. Instead, definitions here are used in line with UNDRR terminology, as indicated in the text box above.

2.1.2 What is Resilience?

Where risk describes the negative impacts associated with the acute shock of a flood event, resilience describes the positive responses to both the shock and recovery periods. Resilience is considered in this report, specifically under Investigation B-3.6, as an evolution of risk assessments and risk reduction actions to further consider how communities can better respond and to and recover from flood events.

Resilience is defined internationally as the "ability of a system, community or society exposed to hazards to **resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard** in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UN, 2016). Resilience can be framed around the ability to withstand and bounce back from both acute shocks (natural and manmade) such as floods, earthquakes, hurricanes, wildfires, chemical spills, power outages, as well as chronic stresses occurring over longer time scales, such as sea level rise, or socio-economic issues such as homelessness and unemployment.

For flood hazards specifically, the federal flood mapping framework states: "A community achieves an elevated level of resilience when its risks are proactively managed, it is adequately prepared for known and potential disaster events and it demonstrates an ability to recover after such events have taken place. In order to become resilient, a community's mitigation planners must first understand risks and ensure their capacity to manage those risks"(NRCan, 2018) .

2.1.3 Risk Evaluation and Risk Mitigation

A brief note is provided here on how risk, resilience and associated assessments can be used to benefit communities. Additional information is anticipated in Issue B-4 Flood Planning; however, some basics are provided here to give the reader context on the value of risk assessments, and also the challenges associated with developing and using them (this is further discussed in Section 2.6).

Risk Evaluation describes the process of comparing baseline risks (from a risk assessment) with generalised risk tolerance criteria, or with locally derived risk tolerances. This evaluation process can then be used to establish the gap between existing and desired risk. **Risk Mitigation,** which describes actions to reduce risk, can then be considered as a mechanism to reduce risk. Given that there are always costs associated with mitigation actions (these can be financial or societal, etc.), it is not always possible to reduce risk to a tolerable level. Sometimes, risk reduction is limited to As Low as Reasonably Possible (ALARP). In all cases, there is residual risk, which is the remaining risk that exists once mitigation activities have ben implemented.

2.1.4 Risk-Informed and Risk-Based Decisions

A further nuance in the way risk assessments are used is described here. Although, it should be noted that the distinction between these two terms is not consistently applied across the sector and reference documents. **Risk-based** decisions are prescriptive efforts to reduce risk to risk tolerance thresholds, whereas **risk-informed** decisions are more simplistic in nature and focus on reducing risk to a non-prescribed target. This may be ALARP but can be more generally a trend downwards.

2.2 Characterisations of Risk

The following section describes various characterisations of risk, and highlights the diversity and complexity of the term, especially as it relates to natural hazards.

Figure 2 shows how risk is a function of both hazard likelihood and consequence, and that risk increases radially across the diagram. A virtually certain but insignificant event can have the same risk as a catastrophic but rare event. This becomes particularly important as we look across long time-horizons. For example, a nuisance hazard, which occurs annually over several decades and accumulates losses, may in fact be more impactful than a catastrophic hazard that occurs just once. Risk provides a tool to make informed investment and land use planning decisions in the context of natural hazard, especially the dynamic hazard associated with a changing climate.

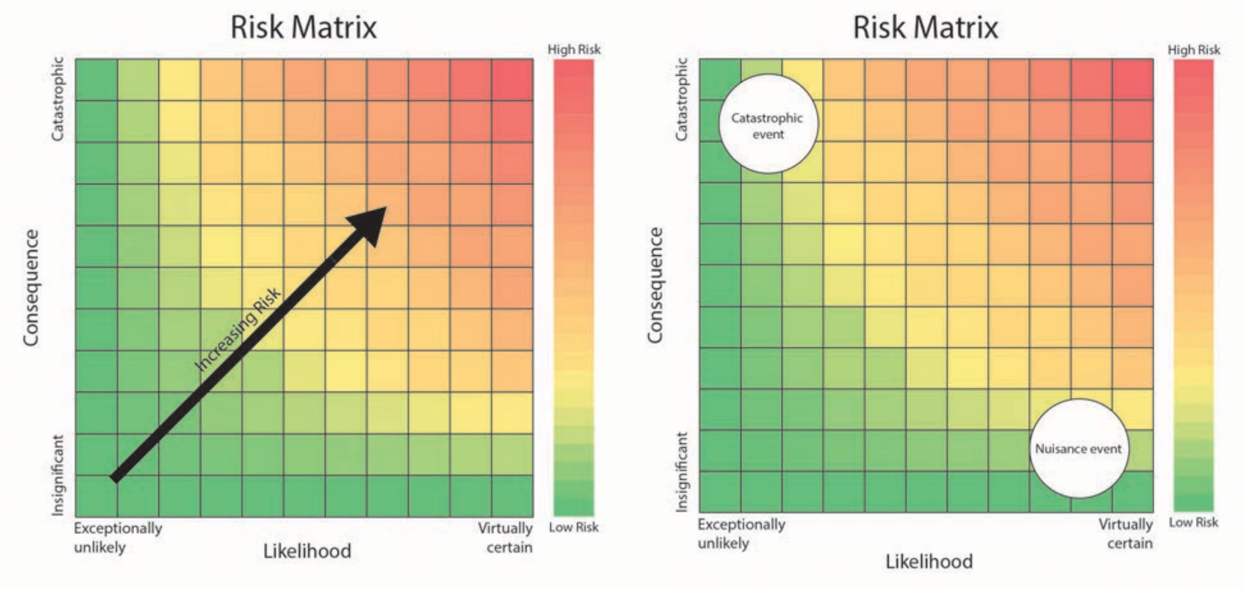

Figure 2: Risk as a function of hazard likelihood and consequence, showing both nuisance risk (i.e., high likelihood (frequent) but low consequence) and catastrophic risk (i.e., low likelihood (rare) but catastrophic consequences).

The simple definition of risk as a function of consequence and hazard likelihood is a relevant and necessary point for the identification of risks and for the prioritisation of risk reduction. However, there are other dimensions of risk that are equally important.

2.2.1 Object and System Risk and Resilience

A key concept, especially as it relates to distributed systems (e.g. a distributed critical infrastructure operation), is the difference between the risk associated with the acute damage and failure of a single piece of infrastructure (e.g. a substation getting flooded) versus the broader systemic risk (e.g. of a portion of BC's population being without power for a period of time); see Figure 3 for a conceptual model focussed on one network of critical infrastructure. The first is a relatively straightforward concept where object (or asset) risk is defined as the intersection of an individual piece of infrastructure being negatively impacted by a hazard. Systemic risk is a much more complex affair and can, at least theoretically, be expanded infinitely. For example, to include cascading effects of a single point of failure within an electrical system to the broader electrical system (network risk), and conversely potential redundancies in the system which increase systemic resilience.

This can then be considered in the context of the interdependencies with other critical infrastructures (e.g., water treatment plants, telecommunications, etc.), and then further in the context of broader societies, etc. Understanding system risk and resilience, inclusive of organisational resilience, should be aspirational. However, an understanding of object risk is required to feed into the broader systemic risk context and is a more realistic exercise to analyse.

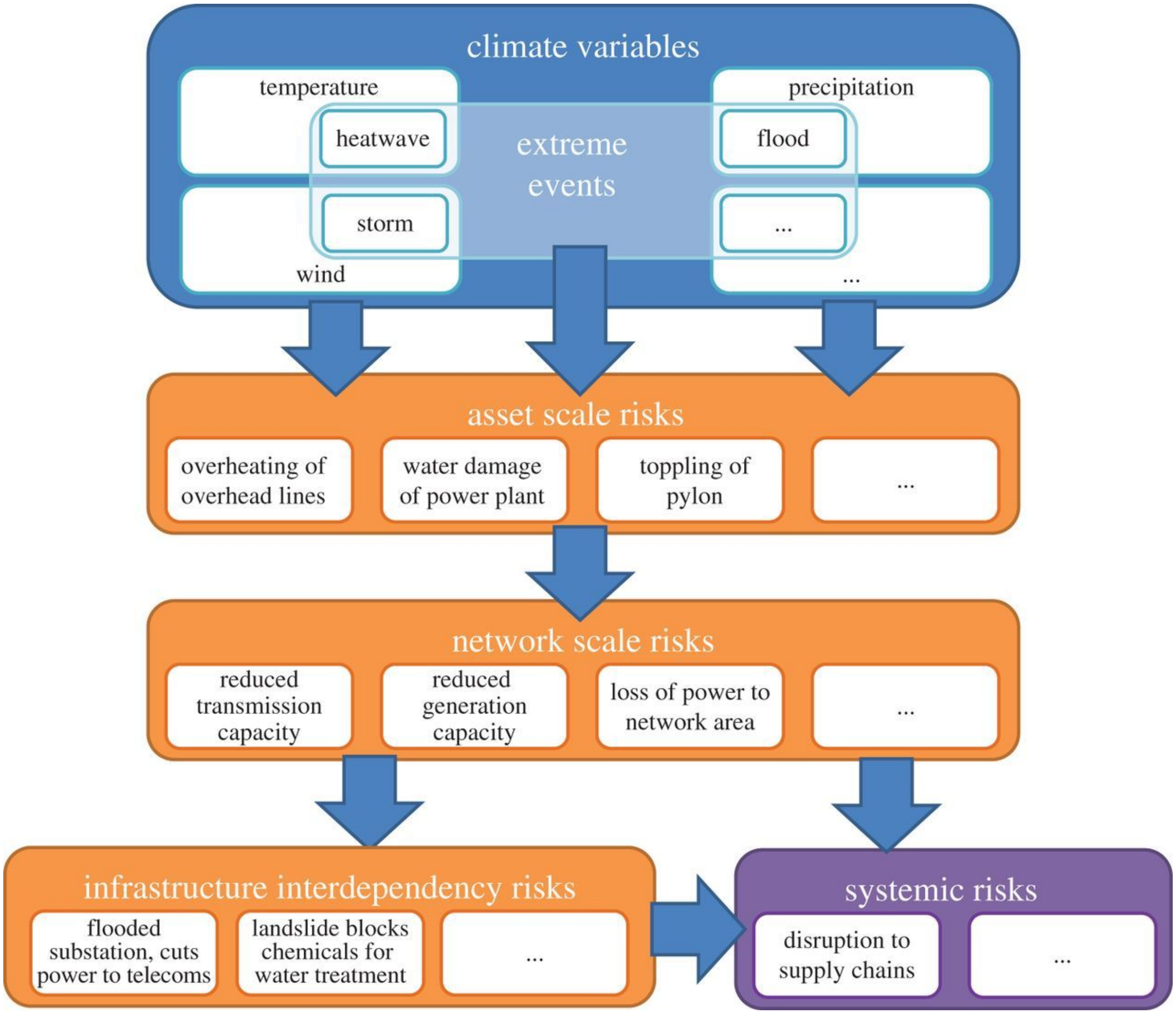

Figure 3: Different scales of risk. (Image sourced from Thompson et al. 2018)

2.2.2 Risk as a Dynamic Concept

Risk is not static. The variables that form risk (i.e., hazard likelihood and severity, exposure and vulnerability) are all prone to change over time. These changes are a result of both global scale issues – such as climate change, which can impact local hazard profiles, and local issues – such as land-use decisions, which may affect exposure and vulnerability. Figure 4 demonstrates schematically how risk can change with time. For example, for many natural hazards, it is expected that climate change will increase the likelihood of occurrence (it may also increase the severity and therefore consequences), which shifts risk from the left to the right of the diagram resulting in increased risk. Alternatively, risk can be changed by increasing the consequence of the hazard occurring, for example by allowing increased development in hazard areas. In this case the risk shifts from the bottom to the top of the graphic, resulting in increased risk. It should also be noted that these issues can be compounded, and increased likelihood combined with increased consequences will result in dramatically increased risk (as illustrated by the bubble in the top-right of the graphic). Even with increasing hazard likelihood however, it is possible to maintain or decrease risk. Primarily this can be achieved by reducing the consequences of the hazard either by changing the exposure or vulnerability of assets, and overall, making the system more resilient to the natural hazard.

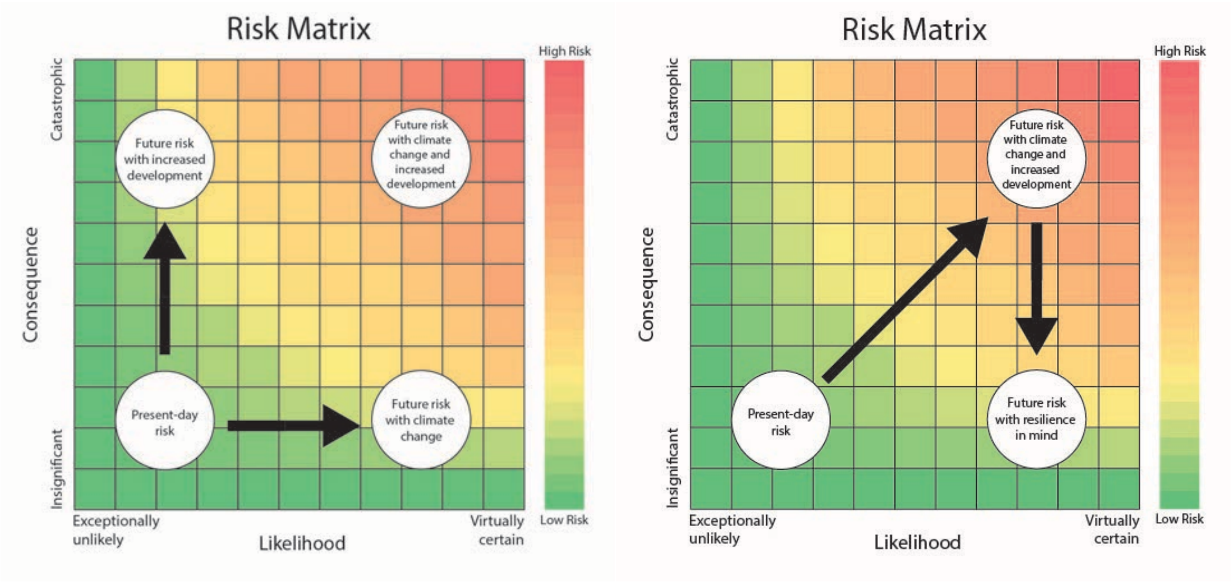

Figure 4: Dynamic risk and resilience.

2.3 Characterisations of Flood Hazard

Much like risk, hazard has many dimensions and variations. These are important to understand to fully appreciate how hazards interact with exposure to create risk:

2.3.1 Spatial and Temporal Scales of Hazard

Hazard (and therefore risk) is affected by the spatial and temporal scale of the event:

1. **Spatial Scale:** Hazards can be described on a scale of local (intensive) versus extensive. Local hazards are those that affect discrete and small areas, for example local pluvial flooding or a landslide. At the other end of the scale are extensive hazards, which affect large geographic areas (e.g., large basin riverine floods, wildfires or earthquakes).
2. **Temporal Scale:**
    a. Hazards can also be described on a range of temporal scales (duration), with some hazards that occur only for a short period of time (e.g. flash flooding), and others that can be relatively long duration (large riverine floods, wildfire). The temporal scale will affect the extent of damage, and the timelines of recovery.
    b. On an even greater range of temporal scales, hazards, especially in the climate change context, can be described as being either a shock or a stressor. Most natural hazards that are currently of concern would be considered shocks. In future, however, we will be faced with more and more stressors, for example, chronic flooding from sea level rise, or overall temperature increase which will affect worker health.

c. A third dimension of time, which is especially relevant to our ability to respond to an event, is the onset time. Some hazards are very sudden and come with little or no warning (e.g. an earthquake). Whereas other hazards have a warning time (assuming appropriate warning mechanisms are in place) of hours (flash flooding), days (storm surge flooding), or even years or months (chronic flooding from sea level rise).
d. Finally, hazards have a component related to the timing of the event. For example, there is a certain seasonality associated with many riverine floods in BC, as they occur during the spring freshet, when snowmelt adds to river flows. Whereas coastal events generally occur in the winter when large pacific storms affect water levels. Additionally, the very fine scale of time can affect outcomes. For example, for flash floods (shock events) the timing of an event being overnight or during the day, or weekday versus weekend will affect the exposure and vulnerability of elements within the flood hazard area.

2.3.2 Hazard Likelihoods

A natural hazard such as flooding is generally defined by considering a hazard profile, which is made up of the flood hazard magnitude and the likelihood (probability) of the hazard occurring. The likelihood of a particular event is tied to its severity. Minor hazard events tend to occur more frequently, and larger magnitude ones occur less frequently. Hazard likelihood forms an important input to risk and risk assessment. The following provides some brief guidance on the concept of hazard likelihood.

2.3.2.1 Annual Exceedance Probability

The likelihood of a specific flood magnitude occurring is generally represented as an Annual Exceedance Probability (AEP), where the AEP refers to the probability of a flood magnitude being equaled or exceeded in any year, with the probability typically expressed as a percentage. For example, an extreme flood that has a calculated probability of 0.2% of occurring or being exceeded in this year (or any given year) is described as the 0.2% AEP flood. In the past, flood hazard likelihood was commonly represented as a 1 in X-year return period. However, this tends to cause confusion as to the likelihood of an event with the lay public (e.g., it is commonly thought that if a 100-year flood has just occurred, it will not re-occur for another 99 years, which is incorrect), and therefore best practice dictates the use of an AEP to describe flood likelihood[2].

2.3.2.2 Flood Encounter Probability

Another way to think about flood likelihood is through the use of encounter probabilities, where it is possible to calculate the likelihood of encountering a flood of a given magnitude over a defined time period—for example, the length of an average mortgage (25 years) or the average lifespan of a human (75 years). For instance, for a 1% AEP flood, there is a 22% chance that a flood of this size or greater will occur over a 25-year period (Table 1). Over an 80-year period, there is even a 19% chance that a 1% AEP flood will occur twice. Understanding the likelihood of an event, as well as its encounter probability, can

[2] AEP in % = (1/X) x 100. (X describes the 1 in X-year return period).

support decisions related to flood management. The authors note here that encounter probability is used differently in the field of geohazard risk, where it describes the probability of a 1) a hazard occurring AND 2) that hazard reaching an element at risk.

Table 1: Encounter probabilities for various flood likelihoods.

Annual Exceedance Probability (AEP)	*Indicative Return Period*	*Encounter Probability*			
		over 25 years	*over 50 years*	*over 75 years*	*over 100 years*
100%	*Annual indicative*	*100%*	*100%*	*100%*	*100%*
33%	*1:3 years indicative return period*	*100%*	*100%*	*100%*	*100%*
10%	*1:10 years indicative return period*	*93%*	*99%*	*100%*	*100%*
3%	*1:30 years indicative return period*	*53%*	*78%*	*90%*	*95%*
2%	*1:50 years indicative return period*	40%	64%	78%	87%
1%	*1:100 years indicative return period*	*22%*	*39%*	*53%*	*63%*
0.5%	*1:200 years indicative return period*	12%	22%	31%	39%
0.2%	*1:500 years indicative return period*	5%	10%	14%	18%
0.1%	*1:1000 years indicative return period*	*2%*	*5%*	*7%*	*10%*

2.4 Characterisations of Exposure and Vulnerability

Unlike other dimensions of risk, the component of exposure is relatively simple. It is binary. An element is either exposed (e.g., in the floodplain) or not exposed (e.g., outside the floodplain). However, there is complexity in defining what should be considered at risk. This can be targeted and consider only some limited elements (e.g., people, buildings) or holistic and consider everything that would be wetted during a flood event as well as the nuances associated with these (e.g., social-economic measures of people). Further discussion, and common approaches to scoping exposure, are found in Section 2.6.5.

Vulnerability is extremely complex as it links the multiple dimensions of hazard to the multiple dimensions of exposure and consequence (see below), and it therefore has almost infinite dimensions. For the purposes of this report, it is assumed for simplicity that these are addressed either as a dimension of hazard or consequence, and no further discussion is provided.

2.5 Characterisations of Consequence

2.5.1 Direct and Indirect Consequences

Flood hazards may lead to direct and indirect consequences. Direct consequences describe all harm that is caused by the direct physical contact of water with people, infrastructure, or the environment (Figure 5) (AIDR, 2015). This includes, for example, damage to buildings and other assets through floodwaters, damage to the environment through contaminated floodwaters, or loss of human life.

It is important to also think about indirect consequences, which can be somewhat more complex. Indirect consequences will increase the spatial and temporal extent of the consequence, meaning that an area larger than where the hazard occurs can experience disruption in some form. They are typically consequences that are caused by the disruption of the physical and economic links in the region, as well as the costs associated with the emergency response to a hazard. As shown in Figure 5, when, for example, road access is affected by a natural hazard, schools or other buildings may become inaccessible and emergency services may not be able to reach certain areas or may need to travel longer distances. Another example is business losses because of interruption of normal activities. Disruption of critical infrastructure, such as electrical power lines, can lead to cascading consequences for many sectors (also referred to as systemic risk, see Section 2.2.1).

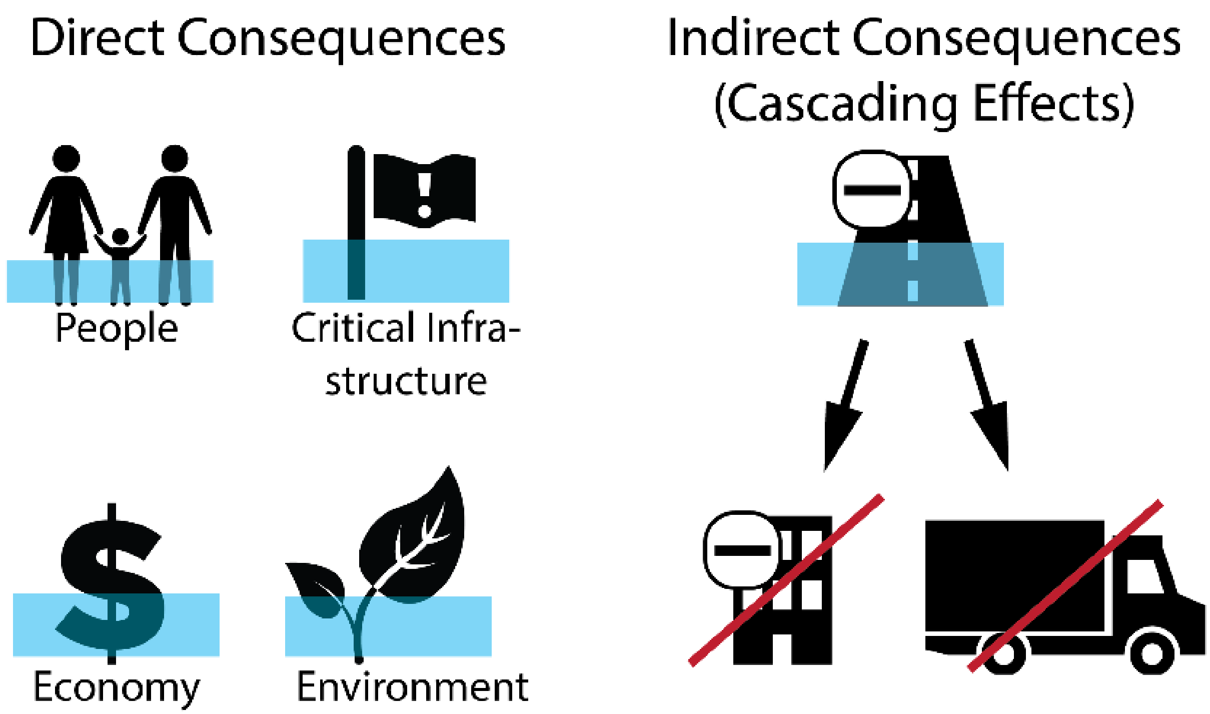

Figure 5: Direct and indirect consequences of flood hazards.

2.5.2 Tangible and Intangible Consequences

The effects of a flood hazard event on the environment, human or community health, or loss of life are difficult to quantify in terms of financial values or other quantifiable measure and are therefore considered to be *intangible* impacts. On the other hand, the *tangible* dollar losses from a damaged building or ruined infrastructure are more easily calculated. This does not mean that tangible losses are more important than the intangibles, just that they are easier to quantify and assess. The inclusion of intangible impacts is desirable for the development of a robust risk assessment (Messner *et al.*, 2006). Figure 6 provides examples of direct/indirect and tangible/intangible consequences. While not all of these consequence types are easy to estimate, they should still be considered. At a minimum, it is important to recognize what types of consequences have been included in a risk assessment and to be explicit about those that have not.

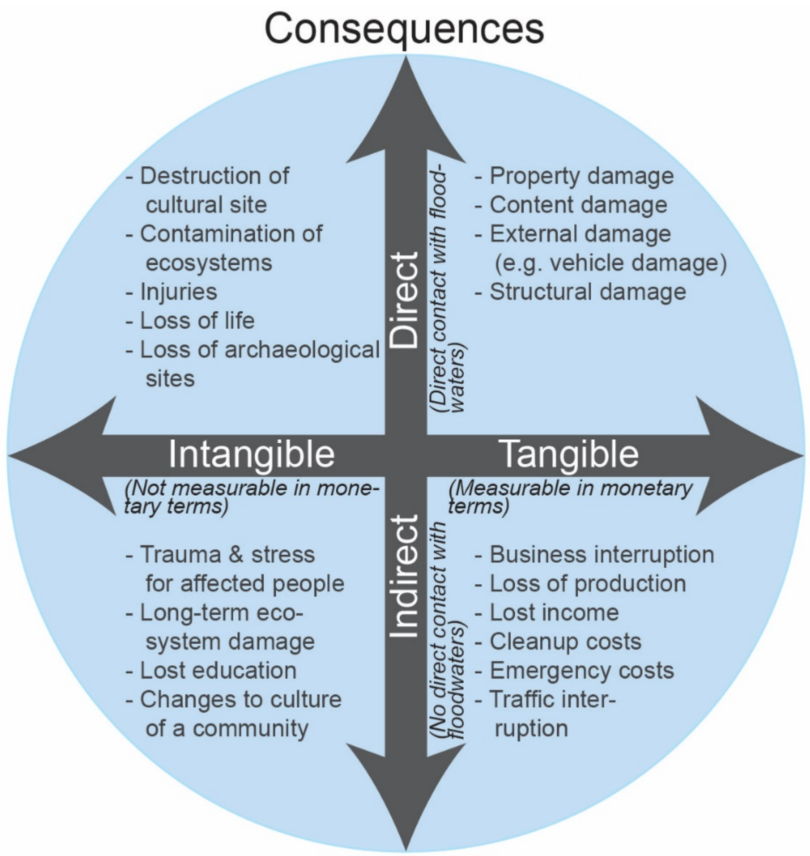

Figure 6: Types of consequences to flooding (Figure from Murphy *et al.*, 2020; adapted from UNDRR with additional input from Messner et al., 2006, and NRCan, 2017).

2.6 What is a Flood Risk Assessment?

Given that risk is the combination of the likelihood of a hazard event and its consequences, a *risk assessment* is essentially a methodology to determine the nature and extent of *risk*. This is done by analyzing potential hazards, the exposure and vulnerability to these hazards and the resulting consequences that together could potentially harm exposed people, property, services, livelihoods, and the environment on which they depend, and then combining this consequence information with likelihood of a hazard event to occur.

2.6.1 Key Steps of a Flood Risk Assessment

A comprehensive flood risk assessment has several steps (ISO 2001; UNDRR, 2017) as described below. These are generalised steps suitable for object, community, or systemic risk assessments. However, specific examples are focussed on community risk assessments, which is the focus of this project. And further, that the list is meant to be comprehensive, and that in many instances, not all steps are included in a risk assessment (e.g. vulnerability is often not considered).

1. **Consequences:**

   1.1. **Hazard Identification:** First, the type of flood hazard (e.g. coastal, riverine, etc.) and its intensity needs to be determined (e.g., flood extents, or if available, flood depth and/or flood velocities).

A range of hazard scenarios can be investigated that includes both frequent/low impact and rare/high impact scenarios. Climate change scenarios can also be included. Typically, the flood hazard identification is conducted as a separate flood hazard mapping study, as it involves a complex data analysis and modelling. The results of the flood hazard mapping are then used as input for the risk assessment. Hazard identification is sometimes called hazard analysis.

1.2. **Exposure:** Next, the exposure to a particular flood hazard is determined. Typically, this is done by analyzing what is within the flood extents, such as buildings, infrastructure, or number of people.

1.3. **Vulnerability:** Vulnerability is the capacity (or resilience) of the exposed elements to withstand the hazard. Thus, a vulnerability assessment provides information on the characteristics of exposed elements, for example, building characteristics, or age characteristics of a population (as typically children and the elderly are considered more vulnerable to flooding).

1.4. **Consequences:** Next, the consequences are determined, which are based on the hazard intensity (flood extent, flood depth) and the exposure and vulnerability of the elements (buildings, people, etc.) affected by the flood hazard. These can be quantitative or qualitative in nature (see Section 2.6.3).

2. **Likelihood:** For each hazard scenario, the likelihood of occurrence (i.e., the AEP) is determined.

3. **Risk:** Lastly, risk is calculated as the product of hazard likelihood and consequences. This can be done for a single hazard scenario, or it may be integrated over many hazard scenarios (see Section 2.6.4 for additional information). In the latter case, the relation between hazard likelihood and associated consequences is presented as a curve, and risk is calculated as the integrated area under that curve to account for the many possible hazard likelihoods (see Section 2.6.4 for details). Risk can be represented spatially on a risk map or aggregated in a risk matrix.

   In a risk matrix, hazard likelihoods and consequences are associated with standardized scores and risk is calculated as the product of likelihood scores and consequence scores. The primary purpose of risk matrices is large-scale (e.g., provincial scale) comparison and priority setting. They can also highlight changes in risk over time with climate change or changes in exposure (see also Section 2.6.6 on risk aggregation and scoring).

2.6.2 Scales of Risk Assessments – Spatial and Resources

Risk assessment can be conducted at many different scales, ranging from high-level and nation-wide to detailed and local (Figure 7), as well as other combinations of spatial scale and required resources. For example, the national All-Hazards Risk Assessment (AHRA) is a qualitative high-level tool that helps to identify, analyze, and prioritize a full range of potential threats (Public Safety Canada, 2012). This type of tool can be developed relatively quickly and inexpensively at a national scale and is invaluable for prioritization exercises. However, making decisions to reduce risk locally requires a more robust methodology—ideally a fine-scale quantitative flood risk assessment that includes some level of community engagement. The quantification of risk, although at times cumbersome, provides invaluable information for risk reduction through the provision of robust, transparent data for planning and decision-making.

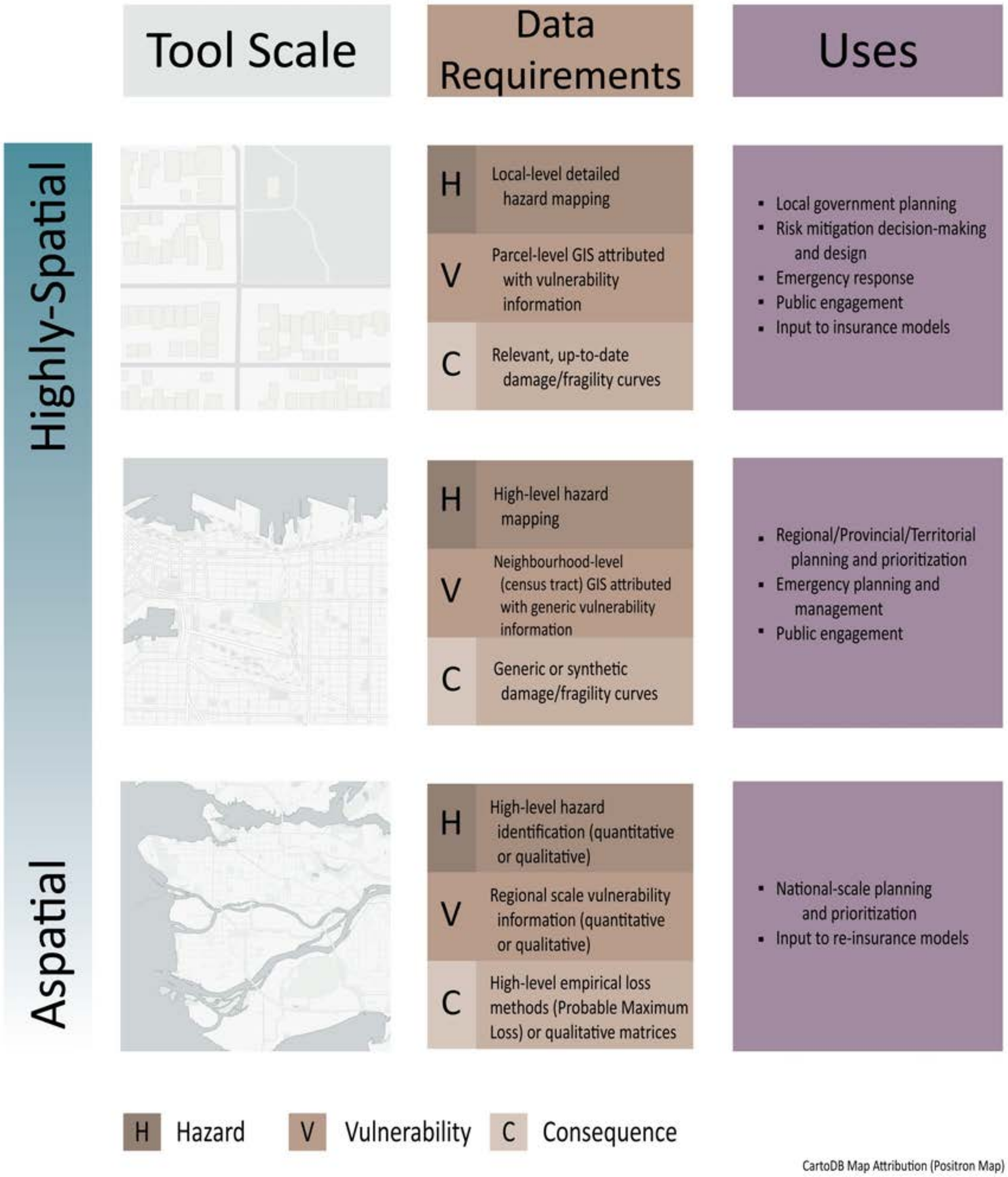

Figure 7: Scales of risk assessment (Figure from Lyle and Hund, 2017).

Note that this figure is a reproduction from an older federal document. In the context of this work, the middle column would be better described as data <u>and method</u> requirements.

The NRCan National Flood Risk Assessment guidelines, which are currently under development, suggest a tiered-system to describe the scale of flood risk assessments. A preliminary draft of these tiers is presented in Figure 8.

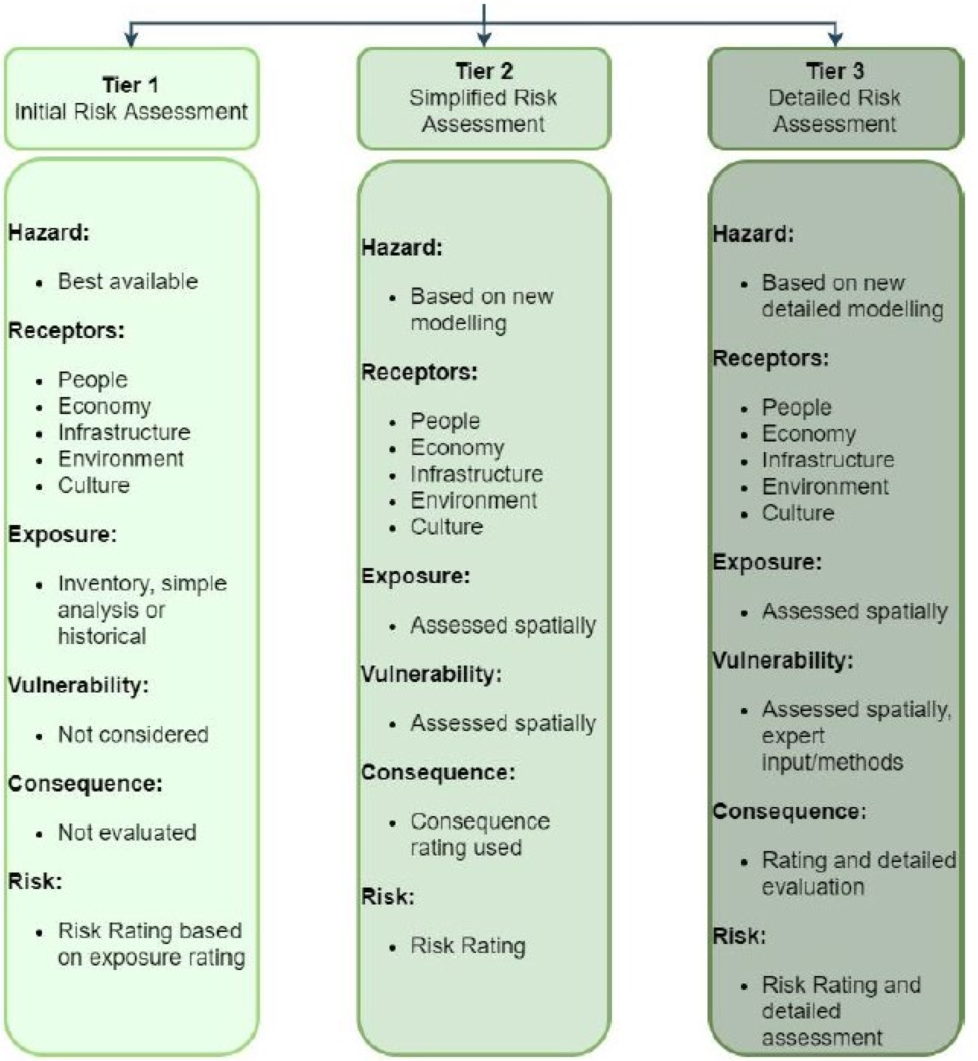

Figure 8: Preliminary draft risk assessment tier system for National Flood Risk Assessment guidelines (Figure from NRCan/NHC FRA Procedures second advisory meeting presentation from 14 April 2020).

2.6.3 Quantitative Versus Qualitative Approaches

Flood risk assessments can be quantitative (measured in numbers) or qualitative (descriptive) or fall somewhere in between. Quantitative measures are generally considered more robust; however, it is not always possible to source the appropriate hazard, exposure, and vulnerability data to support this type of assessment (see also Section 2.5.2). This may be because the data or methods simply do not exist or have not been collected, or because quantitative methods are not appropriate to measure intangible impacts of risk. In this case, rather than discounting the risk because it is too hard to calculate, qualitative measures—especially using expert elicitation—can be appropriate. Expert elicitation is commonly applied to natural hazard and climate risk assessments because of the complexity of the problem. It is also possible and useful to elicit consequence and risk information from interested and affected parties who understand the local context; this provides a particularly rich means to consider consequences and risk to natural hazard.

Alternately, a mixed approach, where initial quantitative assessments are ground-truthed and modified by experts, can be taken. This is the approach currently proposed for the Federal National Risk Profile and that is being used by the Government of BC to assess climate risks (ICF, 2018).

It should be noted that there is always uncertainty in the results regardless of whether quantitative or qualitative approaches are taken. This is sometimes managed using confidence assessments that accompany the risk assessment results. This is further discussed in Section 7.3.7.

2.6.4 Scenario-based Versus Full Statistical Accounting

Risk as a function of likelihood and consequence can be defined in different ways. Two approaches with different outcomes that serve different purposes are outlined below. These approaches should be considered as two ends of a spectrum, modified methods that include components of each are also developed and used.

2.6.4.1 Scenario-Based Risk

If a single event likelihood (e.g., an extreme event) is used to calculate consequences, this is called a risk *scenario*. This is the most common type of assessment completed in Canada, as it is relatively straightforward and requires only one hazard event to be calculated and mapped. Scenarios are commonly used for emergency response planning, where large probable maximum events are used for exercises on the assumption that a plan for a catastrophic event will also be valid for smaller events. Scenarios have also traditionally been used to support hazard mitigation decisions because this simple quasi-standards-based approach is relatively straightforward to calculate. They continue to be used as a screening tool to establish relative risks for further study.

2.6.4.2 Full Statistical Accounting of Risk

A full statistical accounting risk assessment is one that considers a range of hazard events and damage outcomes, i.e., the risk assessment is not only conducted for one single representative scenario, but for multiple likelihoods. At the most robust level, **exceedance probability curves** are developed, which relate the hazard likelihood (i.e., AEP) with an associated consequence, such as the number of affected people. This relationship can then also be used to estimate the probability for any number of people to be affected in a given year (UNDRR, 2017) (Figure 9).

In a full statistical accounting risk assessment, the **average annual loss (AAL)** can be calculated, which is the ‘long-term expected loss on an annualized basis, averaged over time’ (UNDRR, 2017). The AAL describes the average expected loss over a long period, which considers frequent events with potentially little loss, as well as infrequent events with potentially larger losses. In terms of dollar values, the AAL could represent the ‘amounts of funds that need to be put aside annually in order to cumulatively cover the average disaster loss over time’ (UNDRR, 2017). The AAL refers to the total risk (as a product of likelihood and consequence for each of the scenarios) and is calculated as the total area under the exceedance probability curve (Figure 9). See also Section 3.6.1 for an illustrative example of a full-statistical accounting of risk.

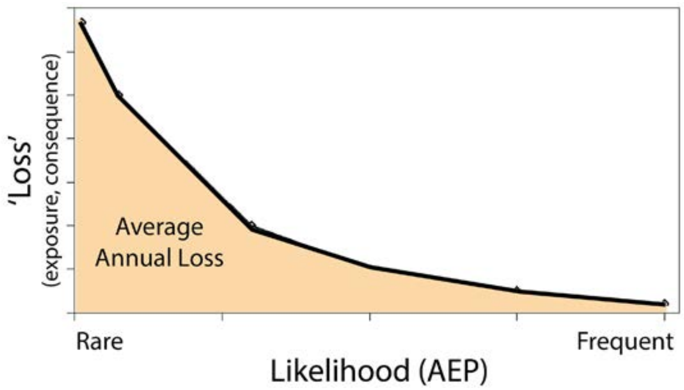

Figure 9: Total risk (or average annual loss), calculated as area under the exceedance probability curve. (Figure adapted from (UNDRR, 2017)**.**

2.6.4.3 Trade-offs between Scenario and Full Statistical Accounting Approaches

Scenario approaches are the most commonly used—primarily because of the smaller effort relative to full statistical accounting approaches, which can be resource intense (and require hazard data for many likelihoods). However, updates in technology and methods are slowly reducing the relative effort to conduct full statistical accounting approaches, and they are becoming more common. Full statistical accounting approaches assessments are generally considered best practice as they provide an understanding of the impacts of frequent small events, as well as infrequent large events (i.e., a full picture of risk). This is especially true with climate change, as some smaller and medium events become more common. Decisions can be affected by the approach taken (Lyle, 2016), and it is therefore important to choose an appropriate approach given the availability and quality of resources, data, and time.

2.6.5 Indicators, Measures and Proxies for Flood Risk Assessments

Risk assessment is shaped by the types of exposed elements that are considered, and more importantly by those that are excluded. Given that the impacts of hazards are often diverse, best practice suggests that a broad spectrum of impacts should be considered in risk assessments.

To summarize diverse consequences in a consistent way, **indicators** are typically used. The United Nations document on indicators for disaster risk reduction (United Nations, 2016) suggests inclusion of a wide range of indicators, which include mortality, affected people, economic loss, damage to critical infrastructure, and disruption of basic services (see Table 2). These indicators were each based on the targets for disaster risk reduction as formulated in the Sendai Framework (UNISDR, 2015). The Australian risk assessment guidelines also recommend inclusion of consequences to the environment and to the cultural identity of a community (AIDR, 2015). Similarly, the BC climate risk assessment includes a holistic approach to risk management, where health, environment, and economic consequences are considered (ICF, 2018). While there is a movement towards a more holistic approach, many of these indicators remain difficult to quantify (see also above section on direct/indirect and tangible/intangible consequences), and in practice, many risk assessments still tend to focus on assessing economic/financial values alone.

Table 2: Descriptions of indicators for flood hazard consequences. Based on (AIDR, 2015; UNDRR, 2016; Stantec Consulting Ltd. and Ebbwater Consulting Inc., 2017).

Indicators for Flood Consequences	Generalised Description
1. Mortality	The number of deaths and missing persons due to a hazard event.
2. Affected People	The number of people who are directly or indirectly affected by a flood hazard. **Directly affected people** are people who are injured or suffer other health effects, are evacuated or displaced, or suffer direct damages to their livelihoods (e.g., their house is damaged). **Indirectly affected people** suffer from the cascading effects of a disaster, such as disruption to basic services, economy, and critical infrastructure.
3. Economy	An indicator used to represent economic losses that result from a flood hazard. This primarily includes direct damage and financial reconstruction costs to public and private buildings. It can also include indirect economic losses, such as emergency response costs and economic losses due to disruption of business operations. This indicator is generally considered to apply to broader economic impacts, but is sometimes limited to financial losses.
4. Damages to critical infrastructure and disruption of basic services	This is an indicator that describes consequences that can potentially have more widely spread cascading effects on society, such as damage to critical infrastructure and disruption of basic services. This can include damages to health facilities, emergency response facilities, governmental facilities, educational facilities, transportation infrastructure, roads, electrical systems, etc.
5. Environment	This indicator is used to describe environmental consequences resulting from flood hazard and is often considered to include both environmentally sensitive areas that are directly exposed (e.g., are within the flood hazard area), and the effects of contaminants that are released into the hazard area when industrial or other hazardous sites are affected.
6. Culture	This indicator is used to describe consequences to the culture of a community, and includes both Indigenous and non-Indigenous aspects.

The above is not a complete list of impacts but provides a good starting point for review and discussion. For example, it does not fully cover indirect impacts (e.g., long-term health) or intangible impacts (e.g., human stress). However, given that most indirect and intangible impacts are difficult to quantify and to monetize, the above provides a good foundation for a risk assessment.

Beyond the gross indicators for risk mentioned above, there are many ways to categorize and consider impacts. As described below, not all these impact types are easy to estimate, but that does not mean they should not be considered. At a minimum, it is important to recognize what types of impacts have been considered in a risk assessment and to be explicit about those that have not.

The measurement of indicators is dependent on the quality and availability of data, methods and resources. In some cases, full quantitative measures are used (i.e. the absolute number of expected deaths). However, in other cases, qualitative or quasi-quantitative methods are used (e.g. a 3 or 5 part scale). Further, in some cases, where suitable data or methods are unavailable, proxies are used to present a representative picture of consequences. For example, it is rarely possible to model and quantify the damage associated with a toxic leak resulting from a flood, as this would require hydraulic models that consider toxicology and contaminant movement, and therefore as a stand-in, the mere presence of toxic materials on the floodplain is used to assess risk.

2.6.6 Risk Aggregation and Risk Scoring

An important goal of a risk assessment is to provide a means to compare risks (UNDRR, 2017) across spatial and temporal scales, as well as hazard types and indicator categories. Comparing risk can help to prioritize funding and disaster prevention strategies to target locations, hazards, and indicators with the highest risk. To achieve this, typically, a spatially distributed risk assessment (e.g., multiple risk assessments of different locations) is conducted. Next, the outputs of the risk assessment are aggregated, which, considering the complexity of risk indicators, is not a straightforward process (UNDRR, 2017). Different techniques exist for risk aggregation (UNDRR, 2017):

- When conducting a full statistical accounting risk assessment, one of the main outputs is the exceedance probability curve. This curve allows the calculation of the total risk or average annual loss (i.e., the integrated area under the curve) for different hazards or time periods.
- When conducting a scenario-based risk analysis, risk can be calculated as the product of the two dimensions of risk: consequence and likelihood. Here, it is important to select scenarios as broadly as possible (i.e., to consider both frequent and rare events) and to consider the implications of using different scenario types to compare risks over time or space,
- Lastly, in the index-based approach (see below), likelihood and consequence are each represented by an index score, and actual risk is then calculated as the product of the two scores. Scoring is applied to each indicator, following a set of pre-determined rules that are ideally consistent across a country or region. A benefit of scoring is its simplicity for comparing relative risk between different indicators, hazards, and regions. Risk indices can incorporate a variety of input types, from fully quantitative through fully qualitative and anything between. The AIDR has developed scoring tables where each index score has a quantitative measure (e.g., number of deaths) as well as a qualitative description that can be scored by an individual or expert group. Typically, the results are provided in a risk matrix of likelihood and consequence, which helps to visualize and prioritize risks.

Index-based risk scoring approaches are intended to create consistency to more easily compare results of several risk assessments (e.g., across a country) to inform priority setting of resources. However, Canada does not currently have a framework to create such consistency. This might change with the development of the NRCan Federal Risk Guidelines. In the absence of a consistent framework, it is important to highlight that risk score results are strongly dependent on the method that has been used.

Further aggregation across indicators is sometimes conducted. Where total risk scores are developed by adding up individual indicator risks. This generally involves some weighting of indicators, which can be challenging. Weighting of indicators effectively creates value judgements, e.g., is a life worth 10 times the loss of a cultural asset? Weighting of indicators must be carefully considered to ensure that they reflect the values of the affected parties and decision-makers who develop and use the risk assessment. There is a danger in applying generic weightings, as values will vary from location to location, person to person, etc.

2.7 Limitations to Risk Assessment Methods

Although widely accepted as best practice for natural hazards management, risk-informed or risk-based planning and the requisite risk assessments are a relatively new concept in Canada. Traditionally, natural hazards have been managed based on specific hazard standards (e.g., a 0.5% AEP flood event or a factor-of-safety on engineered designs in coastal hazard areas) (see also Section 3). As we transition from a factor-of-safety approach for flood hazards to more holistic quantitative risk assessment methods, there is a need to develop new methods to understand the interactions between the hazards and the assets at risk. For the most part, methods for this type of detailed assessment are in their infancy, even though currently several guideline and strategy developments are under way.

Further, the impacts of flood hazards are widespread, and affect people, infrastructure, the economy, culture, and the environment. Damage estimation, however, has traditionally been the domain of engineers, and, as such, has focused on economic valuation of infrastructure and building losses, leaving a large gap in knowledge regarding intangible impacts (Messner and Meyer 2006). This gap has increasingly been acknowledged, but there is still limited validated research available, and tools to look at intangible impacts are largely undeveloped. It is known that when damages are monetized, buildings become priorities for hazard mitigation, whereas when damage is expressed as the number of people affected by an event (through stress or inconvenience), road damage and associated disruption become a mitigation priority (Veldhuis, 2011). The metrics chosen for assessing damage can deeply affect subsequent planning decisions. In effect, the non-inclusion of intangible impacts can affect priorities.

A further limitation is the focus on ‘risk’ and not on ‘resilience’. Arguably, risk (and especially resilience) assessments should consider the nature of actions that are already in place to reduce risk. For example, existing flood protection infrastructure (e.g., dikes) provide a measure of defense that is generally not included in assessments.

Simply, no risk assessment will manage to comprehensively assess all risks, and it is important to ensure that as much as possible that the controlling risks (the risks that drive the overall risk and should therefore be prioritised) are included and robustly considered within an assessment.

2.8 Existing Risk Assessment Frameworks

Risk assessment, assuming a consistent definition of being the product of hazard likelihood and consequence, is applied in many existing frameworks. A brief review of existing frameworks is provided here.

2.8.1 International Standards Organization (ISO) Standard 31000 – Risk Management[3]

The ISO Standard 31000 is a simple overarching framework that effectively defines risk as the product of hazard likelihood and risk. It provides broad information, as it is meant to be applicable to all types of risk, inclusive of business risks for example.

2.8.2 All-Hazards Risk Assessment (AHRA) – Public Safety Canada[4]

This is a protocol for identifying, analyzing and prioritizing threats and mitigating risks in a standardized way (Public Safety Canada, 2012). It includes natural hazards (earthquakes, floods), as well as chemical, biological, radiological, nuclear and explosive hazards, both non-malicious and malicious threats. Includes a scenario-based risk assessment approach (high-level perspective).

The AHRA tool prototype aims to help users define and score potential hazards or threats across different categories of impacts (people, economy, environment, territorial security, Canada's Reputation and Influence, Society & Psycho-Social, and Critical Infrastructure), and determine the likelihood of the event occurring within a 5-year timeframe.

2.8.3 EconoMe – Federal Office for the Environment, Switzerland[5]

This tool looks at natural hazards in mountains (avalanches, rockfalls) and is an obligatory tool in Switzerland (since 2008) for evaluating protection projects by comparing costs (economy) and benefits (i.e., reducing risks) of protective measures (Bründl, 2012). It employs standardized scenarios and calculation factors (not editable). The tool also includes EconoMe-Railway & RoadRisk, for addressing rail and road safety. Access to EconoMe is restricted to authorized personnel and institutions.

2.8.4 Hazard, Risk and Vulnerability Analysis (HRVA) Tool – British Columbia[6]

This is a toolkit with a range of methods and tools, with participatory components, geared towards municipalities. It is a screening tool for assessing hazard, vulnerability and risk, and identifying priority areas for emergency programs. It is currently being updated and upgraded. This tool, although relevant to the BC context, is designed for municipal users and is not suited for provincial-scale use.

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[3] International Standards Organization (ISO) Standard 31000 – Risk Management: https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-1:v1:en

[4] All-Hazards Risk Assessment (AHRA), Public Safety Canada: https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/mrgnc-prprdnss/ll-hzrds-rsk-ssssmnt-en.aspx

[5] EconoMe, Federal Office for the Environment (Bundesamt für Umwelt: https://econome.ch/eco_work/index.php?PHPSESSID=pjv9oeqfcokfah2kv81lqc1ia0

[6] Hazard, Risk and Vulnerability Analysis (HRVA), British Columbia https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/local-emergency-programs/hazard-risk-and-vulnerability-analysis

2.8.5 Public Infrastructure Engineering Vulnerability Committee (PIEVC) – Engineers Canada[7]

This is a protocol developed by Engineers Canada to assess the engineering vulnerability of individual infrastructure. It was developed over a decade ago, and at the time was a leading-edge tool for climate vulnerability (not risk) assessment.

The tool has not been markedly updated recently and relies on subject matter expertise and qualitative judgements as opposed to being robustly quantitative. The proprietary nature of this program (i.e. only some engineers are considered qualified to deliver this program and the results become the property of Engineers Canada) has meant that this tool has fallen out of favour with users in recent years (e.g. Indigenous Services Canada have decided to not use the tool in future). The authors note that as of the final draft of this report, that the Institute for Catastrophic Loss Reduction (ICLR) has recently taken ownership and responsibility for the tool.

2.9 Resilience Assessment Methods, Frameworks and Limitations

Resilience assessments are briefly discussed here as an aspirational consideration. As described in Section 2.1.2, resilience refers to the flipside of risk, and is “the ability of a system to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner” (UNDRR, 2015). The assessment of resilience is a very involved exercise as it requires a robust understanding of risk in addition to an understanding the mechanisms of recovery.

Quantitative assessment of resilience is generally defined in the literature in two ways (Murdock, de Bruijn and Gersonius, 2018). One approach is to quantify resilience by looking at the response of systems to disturbances (Bristow and Hay, 2016), while a second approach assesses the presence of resilient properties that would enable a system to cope with disturbances. In the latter, resilience characteristics can be defined as (1) flexibility, (2) redundancy and (3) robustness/hardening (ARUP, 2015).

At an asset-level, this requires understanding of how systems might fail and what resources (human and physical) are required to recover the system coupled with an understanding of how likely it is that these resources will be available (i.e. will access be disturbed, will operators be otherwise occupied with the hazard, will materials be scarce). At a system-level, resilience assessments further require an understanding of all system-wide interdependencies.

Given the complexity of a true resilience assessment, there are few example frameworks to consider or follow. The European Union (EU) is currently embarking on the development of a program to explore and develop such a framework through the EU-CIRCLE project[8], which aims to “prevent, withstand, recover and adapt from the effects of natural hazards and climate change” for critical infrastructure. Their approach is to follow a four-step process, wherein the first three steps establish risk (Figure 10). The final

[7] Public Infrastructure Engineering Vulnerability Committee (PIEVC), Engineers Canada: https://pievc.ca/

[8] EU-CIRCLE, European Union (acronym not defined): https://www.eu-circle.eu/

step establishes capacity (i.e. the ability to withstand shocks and stressors). All of these elements together help inform system resilience.

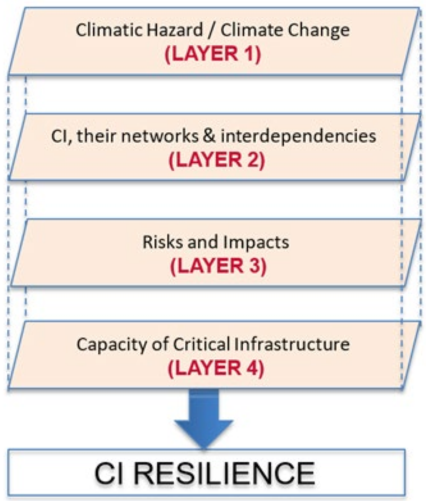

Figure 10: EU-CIRCLE Resilience Framework.

At this time, only the first steps of the framework have been fully developed. However, of relevance here is the overall framework itself, which was developed after an extensive literature review. This highlights the benefits of understanding risk as a steppingstone for ultimately understanding resilience, and finally to increase resilience.

2.10 Summary

Risk and resilience are complex concepts, with many different dimensions. However, understanding risk and baseline resilience are key steps in reducing risk and improving resilience. The complexity of the issue does not need however be overwhelming, there is immense value in first understanding the basics of risk (i.e., a simple risk analysis of hazard and consequence). This can support initial prioritisation and becomes the basis of future more detailed risk and resilience studies. This is well summarised in Australia's Critical Infrastructure Resilience Strategy, which states:

> *"Traditional approaches to risk management require a good understanding of likelihood and consequence. However, because of the growing complexity of critical infrastructure systems and networks…it is difficult to fully comprehend all relevant vulnerabilities and threats. As complexity increases, owners and operators are forced to make decisions on increasingly imperfect information. An approach that builds organic capacity in organizations to unforeseen risks and threats is therefore necessary to expand the way all hazards are managed by critical infrastructure owners and operators".* (Council of Australian Governments, 2011)

3 Investigation B-3.1 Risk-based versus Standards-based Approach to Flood Management

3.1 Introduction

International best practice, in the form of the United Nations Office for Disaster Reduction (UNDRR) Sendai Framework, provides guidance on how to mitigate the impacts of natural hazards, including flood. Canada and British Columbia are signatories to this framework.

A major tenet of this framework is a risk-based approach where hazard, likelihood, exposure, vulnerability, and consequence all play a role in decision-making and planning. This is a shift away from how floods have historically been managed in Canada, where the norm is to plan for and aim to protect from a single hazard scenario (i.e., the 0.5% AEP) without consideration of the potential consequences of flood. A risk-based approach is by its nature focussed on the reduction of flood damages rather than attempting to stop or divert floodwaters. Given that flood damages – financial, social, ecological and others – in Canada are on the rise, mitigation tools or plans that are focussed on reducing damages will, over time, have a positive return on investment.

A risk-based approach is particularly relevant to the context of flood management in the face of climate uncertainty, as it enables practitioners to consider the problem of natural hazard management more holistically. It requires an understanding of what is at stake (exposure and consequence) under multiple hazard scenarios (e.g., small and large floods). This information can be used to plan for a range of possible climate futures, and ultimately support the building of community-resilience.

However, there are many obstacles to developing complete and useful flood risk assessments (as discussed in the latter investigations), and there is a certain momentum to the current standards-based approach that has created a clear and understandable management pathway to make decisions. There are therefore trade-offs that should be considered if a risk-based approach to flood management is considered.

3.1.1 Research Objectives

The primary objective of this investigation was to **evaluate and compare the benefits and costs/limitations of taking a risk-based approach to flood management as opposed to a standards-based approach.**

3.1.2 General Approach

The project was primarily a desktop research and analysis exercise and was conducted based on the following five steps:

1. Scanning international academic and grey literature to learn how others jurisdictions are defining and using/considering risk or standards-based approaches;
2. Developing an overview on international best practice for managing floods;
3. Summarizing of obstacles to risk-based approaches given BC regulatory context;

4. Desktop research and targeted interview questions to attempt to determine costs and benefits of different approaches; and
5. Provision of recommendations and next steps based on earlier findings.

This investigation is presented first to provide a base of understanding as well as to provide justification for the latter investigations. However, there is relevant information, analysis, and results in latter investigations that inform this one (e.g., the costs associated with developing various scales of risk assessment).

3.2 Definitions

In the first instance, the two approaches – standards-based and risk-based – must be defined. Like all terminology in hazard management, their definitions are not entirely straightforward, and exist on more of a spectrum – especially with regards to "risk-based" approaches, which can have many variations. Descriptions of the terms as they are used in this report are provided below.

3.2.1 Standards-Based Approaches

Standards-based approaches generally imply flood management systems where specific guidance and/or **hazards** focussed targets are provided by senior governments or professional bodies. This is status quo in BC at this time. Examples of implementation include:

1. The use of the 0.5% AEP design flood to mandate dike crest elevations or Flood Construction Levels (FCLs) for nearly all situations.
2. The focus on dikes, training works and landfill as *standard* implementation measures to mitigate flood damages within the *Flood Hazard Area Land Use Management Guidelines* (FHALUMG).

In this case, management actions tend to be focussed on limited options. As, the choice of response ("doing the right project") is often, although not necessarily, limited to well understood past practices (e.g., dikes, FCLs). And the nuance of the design ("doing the project right") is pre-determined (e.g., the dike crest elevation will be the 0.5% AEP design flood profile plus a freeboard of 0.6 m). Although, the current provincial guidance allows for some variances to these standards, the general definition for the purposes of this report is to assume that a standards-based approach is a rigid, but well-understood **hazards**-based target and approach.

3.2.2 Risk-Based Approaches

Risk-based practices are those that consider some or all the components of **risk** (e.g., hazard severity and likelihood, exposure, consequences, vulnerability). For example, by considering priorities and actions based on total risk as combination of hazard likelihood and consequence. This explicitly considers all drivers of risk (e.g., likelihood or consequence, or implicitly exposure) and therefore opens up mitigation options to include those that have a focus on exposure and vulnerability reduction.

This is not a new idea, at least in concept. It has been around for 1000s of years (Sugden, 2016), and in western flood management since the 1940s, when Gilbert White wrote his seminal dissertation on "Human adjustments to floods" (White, 1942). This concept however is not often implemented consistently or strategically by governments. The reasons for this are explored later in this section.

Risk-based concepts are however *de facto* practiced in some parts of the existing BC flood management regime. For example, the consequences of flooding for agricultural fields (assumed low consequence) and residential areas (assumed high consequence) are considered differently within the Dike Design Guidelines (2011), which outline a lower standard of a 2% AEP design flood for agricultural dikes. Another unfortunate example is the different protection standards afforded to First Nation communities, whose lands were often left unprotected, while neighbouring settler communities were diked (e.g., under the Fraser River Flood Control Program (Watt 2005)).

3.2.3 Evolution of Approaches

To better understand how hazards-based and risk-based approaches both differ but lie on the same spectrum, it is useful to think about how flood management has evolved in recent history. Sayers et al. (2013) describes this evolution in terms of six generalized stages (see Figure 11).

Historical practice in Canada for the last half century has focussed on controlling and defending against flow (Stage 3; standards-based). Whereas an evolved approach involves considering damages and risks and making decisions to get the best return-on-investment for flood mitigation activities. This evolved approach (Stages 5 and 6; risk-based) requires a good understanding of risk.

Icon	Stage / Description of Actions
	**1. A willingness to live with floods** • Individual and small communities adapt to nature's rhythm.
	**2. A desire to use the floodplain** • Fertile land in the floodplain is drained. • Permanent communities are established. • Local uncoordinated dikes are constructed.
	**3. A desire to control flood flows and defend against flooding** • Large-scale structural approaches (dikes, dams and other controls) are planned and implemented.
	**4. A desire to reduce flood damages** • A recognition that engineering alone has limitations. • Effort is devoted to increasing resilience of communities.
	**5. A desire to manage risks effectively** • A recognition that budgets are limited and not all problems are equal. • Risk management is seen as a means to target limited resources.
	**6. A desire to promote opportunities and manage risks adaptively** • Adaptive management used to work with uncertainties in future climate change, demographics and funding.

Figure 11: Evolution of Flood Management (Sayers et al 2013). Graphic © Ebbwater Consulting Inc.

3.3 International Jurisdictional Summary

To support future policy and decisions, a review of international literature was conducted to establish how others, who are facing the same challenges, are addressing the issue of increasingly damaging and expensive flood events. Six Countries were selected for inclusion in the jurisdictional scan, including: Australia, New Zealand, USA, England, Germany, and the Netherlands. These were selected based on factors such as the degree of similarity with Canada's governance arrangements and flood hazards; the level of innovation in federal, regional, and local flood management approaches; and the accessibility of information regarding management approaches online[9].

The following were investgated:

- The policy and regulatory flood management context – what is the governance model and what are the key federal statutes and policies?
- Management approaches within the context of a changing climate -- what policy/planning/engineering options are being proposed to manage changes in the hazard?

The result of this work is summarized in Table 3. It was found, that in general, comparable jurisdictions are moving towards risk-based approaches to flood management and planning. The exception is the United States, where the generalized approach continues to be standards-based. However, like BC, there are many examples of how risk-based practices exist implicitly within the broader management regime. For example, the Community Rating System (a Federal Emergency Management Agency (FEMA) program) grants points to community activities that are inherently risk-based such as buyouts for repeatedly flooded properties (exposure reduction), and the US Army Corps of Engineers (USACE) Levee Safety Program applies different design standards defendant on what is behind the levee. Further, the now repealed Executive Order 13690, which was originally promulgated in 2015, under the Obama administration, sets different targets dependent on the criticality of exposed assets (e.g., federal prisons are deemed an activity for "which even a slight chance of flooding would be unacceptable") through the Federal Flood Risk Management Standard (FFRMS); this is risk-based.

It should also be noted that many of the reviewed jurisdictions do still have standards-based approaches on the "regulatory books" and continue to rely on specific design floods for example. This highlights that the pace of transition from standards-based to a risk-based approach is slow, and that existing entrenched approaches continue to be applied either *de facto* or as a back-stop minimum standard.

[9] This work was originally completed for the Ontario Ministry of Natural Resources and Forestry (OMNRF) and has been adapted and summarized for the current project. A much more extensive and fully referenced report is available from OMNRF.

Table 3: Summary of results from scan of flood management literature in various countries and British Columbia with respect to defining a flood hazard, overall approach to flood management and inclusion of climate change in policy documentation

	Hazard /Risk Statutory Regulation	Overall Approach to management	Tools used in management	Explicitly addresses climate change
EU	'Significant' risk as identified in mandated flood risk assessments.	RISK MANAGEMENT - Reduction of risk to people and property through catchment-based, locally planned and implemented portfolio of management options.	Portfolio (suite of multiple measures) within protection, prevention, preparedness, emergency response and recovery planning.	Yes - currently in EU guidance documents for consideration at local level.
England	Development regulation based on 1% AEP; exceptions may be permitted.	RISK MANAGEMENT - Sustainable flood risk management that adapts over time, is consistent and transparent and meets identified social, economic and environmental outcomes.	Flood risk management plan (FRMP) identifies all possibilities for risk reduction within the disaster cycle using a portfolio approach.	Yes - current guidance from EU and national policy to consider at local level based on hydrology and hydraulics
Germany	Flood protection designed to 1% AEP; multiple AEP for land use planning and development.	RISK MANAGEMENT - Managing risk through limiting development of new risk and reducing existing risk using all possibilities in the disaster cycle.	Flood risk management plan (FRMP) identifies all possibilities for risk reduction within the disaster cycle using a portfolio approach.	Not currently. Planned incorporation as of 2021.
Netherlands	Annual risk of death cannot exceed 1:100,000 persons annually.	RISK MANAGEMENT - 3 layers: (1) manage probability (stringent protection standards), (2a&b) manage consequences with land use planning and emergency management.	Portfolio approach; however, protection is driver. Consequence management occurs only when structures comply with standards.	Yes - currently in national level policy documents.
USA	1% AEP defines the flood hazard area.	HAZARD MANAGEMENT - Protection from flood hazard (1% AEP) and flood insurance for development.	Structural protection measures, insurance, zoning, building codes etc. tied to flood hazard mapping.	Currently limited at national level. Some local examples.
New Zealand	Varies - structural protection tends to be 2% AEP for urban, smaller urban is 1-2% and rural 2-5% AEP.	RISK MANAGEMENT - with 4 R's: (1) risk reduction, (2) readiness, (3) response and recovery and (4) building resilience at all levels.	Portfolio approach -- tools vary by location and context.	Yes - national guidance documents for adaptation.
Australia	Probable maximum flood is ideal; protection design (often 1% AEP).	RISK MANAGEMENT – Organizational and community resilience building through a model of shared responsibility and comprehensive flood management (i.e. prevention through to recovery).	Variable across States and Territories. Flood hazard mapping and risk assessments used to inform a variety of structural and non-structural flood management approaches.	Yes - guidance options are provided by national policy.
British Columbia	Flood protection generally designed to 0.5% AEP.	HAZARD MANAGEMENT – Protection from flood hazard (0.5% AEP), and policies that promote hazard-based (structural) controls.	Portfolio approach – Integrated Flood Hazard Management is aspirational goal, however *de facto* practice focusses on structural responses.	In part. Province has made significant efforts to consider climate change for some flood types (e.g. coastal) and locations (Lower Fraser River).

3.4 Best Practice

A key finding of the jurisdictional scan was that most jurisdictions are in the process of transitioning toward a risk-based approach to flood management. This finding is congruent with the consensus in global peer-reviewed literature: implementing a holistic, risk-based approach to flood management reduces negative impacts while promoting other aspects of societal well-being over the long-term. The following sections summarize some of the seminal frameworks and ideas in this space.

3.4.1 Sendai Framework for Disaster Risk Reduction

The Sendai Framework for Disaster Risk Reduction (Sendai) [x] is the global blueprint for reducing disaster risk and increasing community resilience. The goal of Sendai is to "prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures… to strengthen resilience". The framework is thus multi-disciplinary and follows four priorities (Figure 12).

Figure 12: Four priorities of the Sendai Framework for Disaster Risk Reduction.

Sendai recognizes that humans are at the centre of disasters. I.e., not only are humans responsible for increasing hazards, hazards themselves are not problematic unless they interact with humans. The framework thus places human decisions at the centre of disaster risk reduction, and advocates for a risk-based approach to managing multiple hazards (i.e., all-hazards approach). Sendai also encourages whole-of-society engagement actions, such as "To empower local authorities, as appropriate, through regulatory and financial means to work and coordinate with civil society, communities and Indigenous peoples and migrants in disaster risk management at the local level."

Canada, and more recently BC, are signatories to Sendai. The BC Government is actively taking steps to incorporate Sendai into its activities. For example, the *BC Government Action Plan* (Emergency Management BC, 2018), developed to answer the *Abbott/Chapman Report* following the 2017-2018 floods and wildfires in BC, outlines a

[x] Sendai Framework for Disaster Risk Reduction 2015-2030. United Nations. Weblink: https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf, accessed May 24, 2019.

plan for an Integrated Disaster Recovery Framework. The multi-disciplinary framework is currently under development by various agencies and is focused on activities related to Sendai Priority 4 (Figure 12). The authors also note that anecdotally several BC communities have been challenged to scale the Sendai Framework and Priorities to actions on the ground, especially as they relate to land use planning.

Importantly, according to the *BC Government Action Plan*, the framework for BC will "reflect the important roles of First Nations and other recovery partners". This aligns with other initiatives at the International, Federal and Provincial levels (e.g., United Nations Declaration on the Rights of Indigenous Peoples, Tsilqot-in decision, Truth and Reconciliation Commission Calls to Action and BC draft principles). This is relevant in the context of this project, not only because inclusion of Indigenous values should be part of any flood management and risk work going forward, but also because many of these values inherently recognise the many dimensions of risk (see for example Okanagan Nation Alliance Flood Risk Assessment).

Recently, the BC Government also announced that it will be modernizing the *Emergency Program Act* (EPA) [1996][xi]. The goal of the process is to legislate a new Act in 2020[xii] that formally recognizes Sendai and works toward making the province more resilient by recognizing that the environment is changing in ways that will challenge everyone.

3.4.2 Strategic Flood Risk Management in Literature and Practice

In addition to international directives, the consensus in global peer-reviewed literature is that implementing a holistic, risk-based approach to flood management reduces negative impacts while promoting other aspects of societal well-being over the long-term. In this section the authors draw on an internationally recognised paper by Sayers et al. (2014), which captures guiding approaches and rules for sound strategic flood management. This paper and framework have been cited upwards of 50 times in peer-reviewed journals in the five plus years since publication. Further, this paper and the 'golden rules' also map well with Sendai.

3.4.2.1 10 Golden Rules for Strategic Flood Management

The Sayers et al. (2014) paper was co-authored by representatives of diverse perspectives (academic and government officials, engineers and planners) as well as recognized leaders in the field of flood risk management. The authors suggest that strategic flood risk management provides a means of working towards sustainable development, and associated social, environmental and economic goals. However, they also acknowledge that resources to achieve this are limited, and that pragmatic trade-offs must be made between reducing flood risk and investing resources towards achieving other societal goals. In this respect, they emphasise the importance of investing resources effectively and efficiently.

Therefore, the primary goals of strategic flood management are to efficiently use limited resources to:

- Reduce risk to people and communities from flood sources;

[xi] Modernizing BC's Emergency Management Legislation. Weblink: https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/modernizing_bcs_emergencymanagement_legislation.pdf. Accessed October 28, 2019.

[xii] Note that this process has been delayed due to the COVID-19 pandemic.

- Promote ecosystem goods and services; and
- Reduce risk to, and promote, economies;
- Promote social well-being.

The authors note that these are lofty goals; however, programs aren't expected to reach these goals at the outset. Rather, the goals are intended to guide an iterative, adaptive strategic planning process. The authors go on to outline several common characteristics of successful, strategic plans including:

- They will be based on understanding of the whole-system behaviour and societal goals (i.e., consideration of cumulative pressures and associated values);
- Decision-making will be informed by knowledge of risk and uncertainty over time;
- A portfolio of measures and instruments will be used to manage risk; and

In addition to these characteristics, the authors present ten 'golden rules' for sound strategic flood management. The authors state that these 'golden rules' are necessary, but not necessarily sufficient, components of successful flood management.

Table 4: 10 Golden Rules of Strategic Flood Management (Sayers et al. 2014).

Rule	Description
1. Accept that absolute protection is not possible and plan for exceedance.	There will always be a bigger flood. Residual risk always exists and resilience to future, inevitable, flood events can be built through the planning process.
2. Promote some flooding as desirable.	The natural connection between land and water is critical. Flood plains provide fertile land and other ecosystem services in addition to accommodating flood waters.
3. Base decisions on understanding risk and uncertainty.	Managers should not delay decision-making and action on the basis of uncertainty. Rather, managers should draw on the available knowledge, explicitly account for uncertainty, and then monitor and adapt management plans with time.
4. Recognize that the future will be different from the past.	Climate and flood risk are changing. Managers need to move beyond planning processes that focus on historic flood records and information, and account for future changes in flood risk.
5. Do not rely on a single measure; implement a portfolio of responses.	Flood risk has multiple components. Management tools can be used to reduce hazard, exposure, and consequence while also working towards other environmental, economic, and social goals.
6. Utilize limited resources efficiently and fairly to reduce risk.	A management plan should be tailored to the specific context, with consideration of not only the cost-efficiency of risk reduction outcomes, but also the fairness of these outcomes and the associated ecosystem enhancement opportunities.

Rule	Description
7. Be clear on responsibilities for governance and action.	Funding and decision-making should reflect shared responsibility. Collaboration on a watershed scale is critical to achieve shared outcomes and to avoid conflicts.
8. Communicate risk and uncertainty effectively and widely.	The public does not often understand the degree of flood risk they face. Significant and targeted awareness programs are required to obtain greater public and political support for progressive management initiatives.
9. Promote stakeholder participation in the decision-making process.	All interested and affected people play an important role in developing and delivering management activities. This should be done in a way that promotes "living with floods" rather than "fighting against them".
10. Reflect local context and integrate with other planning processes.	There is a need for locally relevant and specific management planning, as opposed to focusing on compliance with a one-size-fits-all engineering standard.

3.4.3 Evaluation of the International and British Columbia Approaches

The purpose of this aspect of the project is to evaluate the strengths and weaknesses of the flood risk management approaches presented in the jurisdictional scan, which can then be leveraged to support recommendations on strategic directions for flood management in BC. To provide a framework for this evaluation, the authors draw on these "10 Golden Rules".

While the Sayer's paper provides a simple and effective framework, it is important to note the limitations of this task. A thorough review of the international literature regarding evolving flood risk management approaches is outside of the scope of this project. So too is a comprehensive evaluation of the flood risk management approaches in multiple jurisdictions using best practice criteria.

The table below (Table 5) presents a rough summary of how each of the jurisdictions in the scan performs relative to these rules. It is important to note that these results relate only to the literature reviewed for the scan and as such may not be an exhaustive characterization of all local initiatives. BC has been added to this scan, but note that the ratings are based on experience and knowledge of the authors, rather than an explicit review of policy documents. It is therefore subjective.

Overall, each of the jurisdictions that are proactively working toward management of flood risk fared favorably based on the 'golden rules'. The exception here is the US, which is currently using a standards-based approach to manage floods, although there is some early evidence of progression towards a risk-based approach.

As outlined in the previous section, Sayers et al. (2014) state that several additional characteristics are necessary to sound strategic flood management. Two of these characteristics include understanding whole-of-system behaviour over time and continuing to monitor and adapt to new information. While all the jurisdictions (other than the US) address these components as part of their flood management programs, the means by which they achieve this varies. Among European Nations, these components of flood management are mandated by the overarching EU Directives. In comparison, Australian and New Zealand flood management approaches are founded on the concept of the natural disaster cycle and, therefore, also integrate existing Emergency Management and Planning initiatives.

Table 6 presents general strengths and weaknesses of the approach taken in each jurisdiction above and beyond the specific characteristics and golden rules of strategic flood management described by Sayers et al. (2014).

Table 5: Summary of international best management approaches for '10 golden rules'

This table provides a summary of the extent to which the federal policy of several jurisdictions, including BC, meet the 'golden rules' of strategic flood management presented in Sayers et al (2014). A cell is labelled "yes" and coloured green when the examples considered clearly meet the rule. "Transitioning" or yellow coloured cells indicate there is some evidence that the jurisdiction is taking steps to move towards this approach. An example for this case is Germany, which has a goal to integrate climate change considerations into Flood Risk Management Plans by 2021. Cells labelled "no" and coloured red indicates the jurisdiction does not meet the rule.

Sayers et al., 2014	Australia	NZ	USA	England	NL	Germany	BC
Absolute protection is not possible; plan for exceedance	Yes	Yes	No	Yes	Transitioning	Yes	No
Promote some flooding as desirable	Yes	Yes	Transitioning	Yes	Yes	Yes	No
Decisions based on risk and uncertainty	Yes	Yes	Transitioning	Yes	Yes	Yes	No
Future will not be the same as the past	Yes	Yes	Transitioning	Yes	Yes	Transitioning	Transitioning
Not single measure, rather portfolio of measures	Yes	Yes	Transitioning	Yes	Transitioning	Yes	Transitioning
Efficient use of limited resources	Yes	Yes	No	Yes	No	Yes	No
Clear lines of responsibility	Yes	Yes	Yes	Yes	Yes	Yes	No
Communicate effectively and widely	Yes	Transitioning	Transitioning	Yes	Yes	Yes	Transitioning
Stakeholder participation	Transitioning	Transitioning	No	Transitioning	Transitioning	Transitioning	Transitioning
Local context is reflected	Yes	Yes	No	Yes	Yes	Yes	Yes

Table 6: Strengths and weaknesses of flood management approach for each international jurisdiction

Note that the table does not include an evaluation of the relative merit of the risk-based approach.

Jurisdiction	Strengths	Weaknesses
Netherlands	• Flood management is part of the Dutch culture and identity and has significant capacity and resources available (financial, human, etc.) • Flood management is being integrated with larger societal concerns such as water scarcity and land-use as part of a holistic approach • Management approach offer equity for all citizens	• Approach is highly technical and driven by central government expertise rather than being locally defined • Approach is highly reliant on technical expertise and it is unclear if trust in engineered solutions is sufficiently warranted
Germany	• Emphasis on planning for residual risk and not relying exclusively on engineered solutions • Emphasis on the importance of shared responsibility for flood management and encourages property-level protection measures	• Approach is highly reactionary rather than proactive
England	• Emphasis on limited resources by senior government - forces shared responsibility for flood management and innovation • Consideration of all types of flooding (not just riverine) through the use of the Source, Pathways, Receptors and Consequences model	• Separation of management authority by size of water course creates issues for transferability of learning
Australia	• Strong National focus on building resilience to natural hazard events through shared responsibility and risk-based management • Examples of innovative models to prioritise flood risk management and investment at State level • Devolved management approach gives Local Government's flexibility to manage flood risk based on their local context	• Federal government over-invests in disaster recovery and under-invests disaster mitigation • Inadequate financial and technical support available to Local Governments, resulting in inadequate flood risk mapping and management
New Zealand	• National risk framework for management founded on the components of risk reduction, readiness, response and recovery • Strong National focus on climate change with guidance materials for regional- and local-levels of Government	• Under-utilization of federal policy mechanisms to provide direction and set national standards regarding flood risk management. • Local Governments fund mitigation, leading to affordability issues in low income communities
USA	• Clear, well-communicated federal flood hazard regulations and mapping guidelines with links to on-ground flood management decision-making and operations. • Evidence of some federal departments, as well as regional and local Governments taking steps to exceed minimum hazard standards based on innovative initiatives.	• While there is some evidence of a move towards a risk-based approach at the National level, the approach remains hazard-based due to a recent legislative repeal.

Jurisdiction	Strengths	Weaknesses
BC	• The devolution of flood management primarily to local governments makes the local-context an inherent component of most projects. • The Province has explicitly started considering climate change in some projects, for example through the updated Flood Profile for the Fraser River (2014), and through design considerations in Highway Technical Guidelines. • Further, the nascent UNDRIP/DRIPA informed flood management processes mean that stakeholder engagement and communications are generally trending in a good direction.	• BC, and its citizens, continue for the most part, to consider dikes (designed to a singular standard) as the primary response to flood. This affects most measures of effective flood management (e.g., not risk-based, does not promote some flooding as desirable, does not consider dike failure explicitly, etc.). • Flood management is generally considered to be the responsibility of government, as opposed to all-society (inclusive of the public and private sector).

3.4.4 Concluding Remarks and Observations

It is clear from the analysis presented above that many international jurisdictions are adopting new approaches to flood management. This has been driven by the recognition that existing flood management frameworks (primarily standards-based approaches developed in a stationary climate, that are also reliant on large-scale structural solutions) have proved ineffective over the last few decades.

The authors did not conduct a detailed analysis of the primary drivers associated with this shift. However, anecdotal information suggests three main catalysts for change:

1. The occurrence of devasting or catastrophic floods in the jurisdiction (e.g. extensive flooding in the UK in 2007 affected policy (Stevens, Clarke and Nicholls, 2016) from which a line can be drawn to the 2009 National Flood Risk Assessment and consequential policy shifts)
2. International frameworks and policy direction for disaster risk reduction, such as the 2011 Hyogo Framework and the subsequent Sendai Framework (2015). These give strong signals that risk should be the basis of planning for natural hazard.
3. A general recognition that historic methods for flood management (large scale structural responses for example) may not work in future given existing and future pressures (e.g. existing development in the flood plain and future development pressures) and given climate change, which for the most part is increasing flood hazard.

While there remain many obstacles to adopting these new best management approaches in BC and Canada, it is clear that leading nations in flood management see risk-based planning as the way forward, especially in light of climate change and climate uncertainty.

3.5 Challenges to Implementation of a Risk-Based Approach in BC

The following outlines some challenges to the implementation of risk-based approaches in Canada and BC. The authors encourage readers to explore other Flood Strategy Issue reports to learn more about the current and historic regulatory regimes in BC.

3.5.1 Historic Challenges

The concept of risk-based planning as a robust tool for flood risk reduction is not new in Canada. This was a major tenet of the Flood Damage Reduction Program (FDRP), which ran from 1975 to the late 1990s. The program intent was to reduce risk by "defining flood-risk areas, by discouraging continuing investments in those areas, and by following up with appropriate measures to limit damage to existing development" (Bruce, 1976).

The FDRP grew out of the realization of the Federal government that past Federal contributions to disaster assistance payments were high and continued to rise (for instance, flooding in 1974 had caused more than $70 Million in damage, of which the Federal government's share was about $31.2 million), and that development in the flood plain continued to put more and more Canadians at risk of flooding (Bruce, 1976).

It was realized that development on the floodplain would continue if no actions are taken, as often, it is 1) the last remaining or most easily developed land in a municipality, 2) developers, municipal governments, and house buyers are not aware of the flood hazard, 3) even if the hazard is known, developers may put pressure on local government for development permits in the floodplain, and 4) the mobility of Canadians likely means that many people are not familiar with local flood possibilities (Bruce, 1976). Apart from high disaster assistance payments, federal government also paid high contributions to costly structural flood protection works. Again, the same conditions largely exist to this day.

To the authors' knowledge, no audit of the FDRP program is available, and as such there is no clear understanding of the success of the program in reducing risk to Canadians from flood. Arguably, the program was successful in identifying hazard areas across the country, but not in reducing exposure, vulnerability and risk (as evidenced by increasing Disaster Financial Assistance (DFA) payouts over the program period (Office of the Parliamentary Budget Officer, 2016)). Despite the identification of flood hazard areas in the form of flood maps, communities continued to develop and build in flood hazard areas. It is likely that the pressures outlined in the previous paragraph were the main obstacles to success and will continue to be obstacles to land-use based approaches to flood risk reduction.

With DFA payments continuing to rise there is a need to learn from the past failures of the FDRP, and work to develop policies, regulations and tools that will support communities to overcome the obstacles outlined above and the additional obstacles described below.

3.5.2 Existing Built Environment

Floodplains are desirable places to live, work and play. And, even with knowledge that these are hazardous zones, have been built on. Further, given that floodplains are dynamic, and in many cases will grow with climate change, even areas that have been successful at limiting development in high hazard areas may find that the fringes of the flood plains are currently developed.

Clearly, it is harder to reduce exposure than to avoid creating it in the first place. However, the existing state of the flood plain should not be seen as a reason why land use planning approaches should not be considered. This is especially true when looking at flood risk reduction through a long-term lens. Redevelopment does occur on a natural cycle and can be spurred after a flood event if the necessary pre-planning is in place. Managed retreat out of flood hazard areas is an acknowledged option in Canada and BC specifically (e.g. City of Vancouver Coastal Flood Risk Assessment, City of Surrey Coastal Flood Adaptation Strategy), and therefore should not be considered an insurmountable obstacle.

3.5.3 Current Regimes and Entrenched Pathways

Humans are generally entrenched in how things are done; this is no different for how floods are managed. For the most part, despite the signals that the current system is not working, we continue to be bound by our existing regimes.

For example, many regulatory regimes and financial mechanisms promote the use of structural measures (i.e., dikes) for flood control. Prior to the National Disaster Mitigation Program (NDMP), anecdotal research suggests that the majority of senior government funds were spent on structural measures.

Further, and related to the issue of current development on the floodplain, is the messy and wicked issue of "serial engineering" or "safe-development-paradox". Where, in a case that a dike was constructed and development allowed behind it, it seems imperative that the dike continue to be maintained (and possibly raised or improved) in order to protect the assets and land values that have been created because it was built in the first instance (Hunt, 1999; Lyle, 2001; Haer, Husby and Botzen, 2020).

Adopting a new pathway (in this instance and risk-based approach) will require, in many instances, that we first break out of our existing pathway.

3.5.4 Data and Resource Needs for Risk Assessment (see also latter tasks)

A risk-based planning regime requires that risk information is available or created to support planning and other flood management decisions. Comprehensive risk assessment is in its infancy in Canada (Tamsin S. Lyle and Hund, 2017). This is especially true of holistic risk (i.e. with consideration of intangible impacts such as to health, culture and environment) and quantitative risk. Holistic, quantitative risk assessment is a resource intensive exercise, requiring both significant and diverse spatial data and methods/expertise. Significant effort has been made in the last few years to improve the state of risk assessment for natural hazard management in Canada. This includes programs to develop guides for flood risk assessment (e.g. Natural Resources Canada Flood Mapping Guideline Series), and programs to support the development of data sets of hazard and exposure (through the Geological Survey of Canada). However, risk assessments are a minority tool when it comes to flood management in favour of traditional hazard mapping and standards-based approaches.

3.5.5 Lack of Risk-Based Targets

In addition to a paucity of risk assessments being available to support risk-based planning and decision-making, BC and Canada (and the world generally) lack good guidance on how to effectively use risk assessments to reduce risk. Note that this is also further explored in Section 8. First, there are no current targets for risk in BC (or Canada). Although, the Sendai Framework and supporting documents provide high level guidance to:

- Reduce:
  - Mortality
  - Affected People
  - Economic Loss
  - Damage to Critical Infrastructure and Disruption of Basic Services
- Increase:
  - Disaster Risk Reduction (DRR) Strategies
  - International Co-operation
  - Availability and access to multi-hazard early warning systems, disaster risk information and assessments.

Further, there are some broad concepts of the use of flood risk tolerance as a mechanism to prioritize risk reduction activities within professional guidance documents (e.g. EGBC Flood Risk Assessment Guidelines). However, these are not yet widely used either *de facto* or *de jure*. There is however at least once example of using risk assessment and risk tolerances as a mechanism for a flood management process in the City of Vancouver. Regardless, there remains a large gap in knowledge and practice with regards to actual on-the-ground implementation of risk-based planning in the province.

3.5.6 Lack of Risk-Based Planning Templates

Unsurprisingly, given the lack of risk assessments and risk-based targets, there are few examples of planning processes (e.g., the process of identifying a need to plan for flood, scoping the project, acquiring data, engaging interested and affected parties, identifying and comparing flood mitigation options, and preparing a strategic plan to implement and monitor success and/or failure) that are truly risk-based. More commonly, the same or similar steps are conducted with an eye to deliver a mitigation option that meets the current design target for the least cost. Without templates to follow, it is challenging (especially for local governments) to launch into risk-based planning processes. This is further explored in Issue B-4: Flood Planning.

3.5.7 Perceived Risk in Knowledge

Although anecdotal, there is a concern, especially amongst local governments, that completing natural hazard and risk-based projects, will create increased liability for the government. For example, that by identifying and disclosing hazard and risk on a floodplain, and then not being able to address the risk, opens the door to legal contests. This effectively creates a disincentive to conduct risk assessments, even though best practice clearly dictates that understanding risk (e.g. Sendai priority 1) enables good decisions to reduce risk. Whereas, ignoring the risk only exacerbates the problem.

3.6 Summary Trade-offs

The following summarizes the key differences and trade-offs between a standards-based and risk-based approach to flood management. Given the limited scope of this investigation, the objectives and measures used to compare approaches are drawn from research and the authors' experience and should be considered subjective.

To provide a framework to compare the different approaches, three ideas are explored. First, as recognised and described in Section 2.3, flood risk has many characterisations, dimensions, and scales. Each of the approaches is compared to the components of flood hazard and risk with regards to how well these are considered. Second, implementation, as it relates to governance, systems, resources (non-monetary), capacity, etc. is considered. Finally, relative order of magnitude up-front and long-term costs are presented. Comments are provided, and a relative three-part scale of "Yes, the approach can manage this component, or is preferred", "Partial, the approach can manage this component with significant resources", "No, the approach cannot manage this component, or is least preferred". It is noted that this exercise is presented at a high-level to quickly summarize findings for two ends of a spectrum; it provides a general overview and does not, for example, explicitly note how modifications to an approach might make it more preferred.

Table 7: Summary of tradeoffs between generalized standards-based and risk-based approaches to flood management.

	Standards-Based	Risk-Based
Flood Components		
Object vs. System	Approach works easily for object risk, and if applied consistently could be used to manage larger systems.	Approach can be scaled from object risk through systemic risk; cost for systemic risk is significantly higher.

	Standards-Based	Risk-Based
Dynamic (e.g. Climate)	Generally, not suited to managing uncertainty and changes to flood hazard.	Approach can be adapted to explicitly include changes to hazard, as well as other elements of risk.
Spatial Scale	Can be applied at most spatial scales.	Can be applied at most spatial scales.
Temporal Scale		
Duration	No. Only one standard scenario considered.	Yes, if detailed vulnerability/susceptibility of elements is considered.
Onset	No. Only one standard scenario considered.	Yes, if elements of resilience (such as capacity) are considered.
Shock vs. Chronic Stressor	No. Only one standard scenario considered.	Yes, if time horizons are considered.
Hazard Likelihood Variance	No, by definition only one likelihood is used	Yes
Direct vs. Indirect Consequences	No, does not explicitly consider this	Yes, if appropriate methods and data are used.
Tangible vs. Intangible Consequences	No, does not explicitly consider this	Yes, if appropriate methods and data are used.
Implementation		
Overall complexity	We know how to do this, and it is straightforward: • Makes structural design straightforward • Makes some property/asset-focussed structural adjustments straightforward (e.g. FCLs) • Can be applied to land use planning but creates a binary response (e.g. assets are either allowed or disallowed in the floodplain) and does not enable best use of land.	The complexity of true risk assessment echoes the complexity of flood itself and therefore is a challenging exercise. However, it is possible to develop and use flood risk assessments.

	Standards-Based	Risk-Based
Governance	We have systems, albeit imperfect, in place (e.g., supporting legislation, EGBC Guidance) to make this approach function.	This would require a paradigm shift in how flood is publicly understood, governed, regulated, funded, etc. Note that this report does NOT provide recommendations related to this. However, current commitments (e.g., Sendai) suggest that there is in fact a **reputational risk associated with not shifting to this new paradigm**. Further, some local governments (e.g., District of North Vancouver) have already promulgated risk-based regulations.
Resourcing (practitioners)	The current system falls primarily in the domain of engineers. Arguably, there is plenty of capacity in the engineering community to continue to use a standards-based approach.	As discussed elsewhere in this report (see Sections 4 through 7) there is currently a paucity of practitioners able to conduct full, holistic, full statistical accounting, etc. FRAs and to then implement them through risk-based plans. It is also noted that these types of projects require multi-disciplinary teams, taking the onus away from the engineering and geoscience community, both increasing the number of available practitioners and greatly increasing the complexity of risk assessment and risk-based planning processes. However, it is expected that the capacity will grow to meet the need, should FRAs and risk-based planning become the norm.
Resourcing (time)	Timelines for standard focussed works are generally well understand and short (in the order of months-years dependent on the spatial scale and other variables).	FRAs require time to conduct properly. This is in the order of 2-3 times the schedules required for straightforward hazard/standards-based assessments.
Costs ($)		

	Standards-Based	Risk-Based
Implementation (of risk assessments, not actions to reduce risk)	Flood modelling and mapping in support of standards-based approach are estimated to cost between $10,000 and $15,000 per kilometre (Issue B-2,(Northwest Hydraulic Consultants Ltd., 2021a)), and a total to map the province in the order of $30M. This is approximately a third the cost of risk-modelling and mapping (which also requires hazard modelling/mapping as an input).	As discussed elsewhere in this report, costs for FRAs are significant, ranging from $4.5M for a provincial-scale prioritization FRA to $65M to conduct local, fine-scale FRAs across the province; note that these costs exclude the cost of hazard mapping. See also Section 5.3.3.
Long-term	We have no substantive mechanism to look at long-term costs associated with a standards-based approach and the subsequent preference for structural responses. However, especially given climate change, it is expected that existing damage costs (which are in the $100Ms annually in the province (Abbott and Chapman, 2018)) will increase. As an example, recently completed damage calculations for the Lower Fraser River show an increase in dollar costs associated with floods of 43% between the present day and the year 2100 (Fraser Basin Council, 2016)	An inherent benefit of the risk-based approach is the use of long-term, comprehensive targets for risk reduction (and therefore long-term cumulative damage costs), which enables and encourages a broader diversity of flood mitigation actions (e.g., exposure reduction). Although we have no substantive mechanism to look at long-term costs, we can assume that they would less than standards-based approaches.
Externalities	Something that is rarely considered in standards-based approaches that result in structural defenses are the externalities associated with the action itself. This can be great (e.g. loss of fisheries values, loss of recreational incomes, etc.)	Risk-based approaches lend themselves much better to understanding and quantifying externalities. And further, generally result in outcomes that consider co-benefits, as well as actions that have a smaller footprint on related economic sectors (e.g. agriculture, tourism, fisheries, etc.)

In summary, the standards-based approach is “easy, but prone-to-failure”, as it does not recognize the complex, wicked nature of flood. Whereas the risk-based approach is “way harder, but worth it”.

3.6.1 Illustrative Example of Total Risk Reduction Using Standards-Based and Risk-Based Approaches

The following provides a visual illustrative example of how risk reduction is achieved through both standards-based and risk-based approaches. This work was originally conducted as part of a submission to Infrastructure Canada in 2016 (Ebbwater Consulting and West Coast Environmental Law, 2016).

First, consider the standard risk matrix (as presented in the introduction as Figure 2, and below in Figure 13, 1. Risk), with axes of likelihood and consequence. Note that in this instance, the x-axis has been reversed such that high likelihood events are on the left and low likelihood events are on the right. The intensity of the colour across the graphic describes risk, where the pale pink areas represent low risk and the dark pink, high risk.

Next consider real experienced flood risk (2. Flood Risk). For the most part, humans acknowledge that it is not appropriate to build on or live in areas with frequent and damaging floods (e.g. the river channel), and therefore the effective existing flood risk is represented by only half the original graphic. Again, the risk associated with different parts of the graphic are represented by the intensity of the colour. The pale pink in the bottom right-hand corner is the area with the least risk (i.e. risk associated with low likelihood, low consequence events). Whereas, the greatest risk (and most intense colour) is associated with low consequence, high likelihood events and equally high consequence, low likelihood events. There is significant risk along the whole edge of the diagonal line created by a combination of likelihood and consequence. Total flood risk (calculated as the integration of the intensity of the area under the curve) is summarised in the bar on the right-hand side of the graphic.

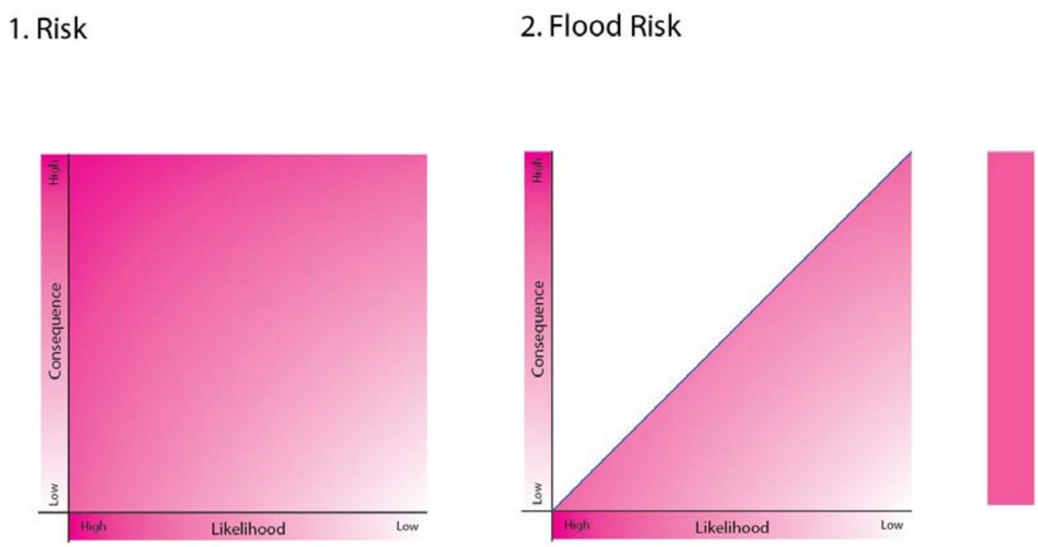

Figure 13: Illustrative example of risk reduction using standards-based and risk-based approaches. Part 1.

Using the above as a base for existing risk, next we can consider risk reduction using standards-based and risk-based approaches. First consider standards-based approaches (see Figure 14, 3. Flood Risk – Protect), where the 'standard' is represented by the vertical dotted line in the middle of the graphic. For example, the BC standard of a 0.5% AEP flood event falls on the likelihood axis and is drawn as a straight line. Then, theoretically if all designed actions related to this standard do not fail, then all the risk to the left of the line, shown in green, is effectively removed. The remaining (i.e., residual) risk is shown as the area to the right of the line and continues to be represented in pink. As before, the intensity of colour represents the level of risk. The relative reduction in total risk is presented in the bar chart – where the majority of risk is 'removed', but there is still considerable residual risk (see the top part of the bar). This is because there is significant risk associated with the low likelihood, high consequence events that is not managed through a standards-based approach. Effectively, this illustrates the idea that design standards can be exceeded, and the impacts of this will be significant.

Whereas, if we take a risk-based approach, where the aim is to work to reduce risk (with consideration of the full-statistical accounting of risk), then the flood mitigation actions will tend to focus on concepts that will work across all risk scenarios (e.g., both frequent and rare) such as managed retreat, or certain resilient building practices. Some ecosystem-based practices (e.g., mangrove or equivalent shorelines) can also be used to 'take the edge off' hazard magnitude and therefore consequences. These examples are represented by the diagonal dotted line in Figure 14, 4. Flood Risk – Adapt. In this case, targeting risk reduction actions to remove the highest areas of risk is represented by the diagonal green area (e.g., the eliminated risk). The residual risk, represented by the remaining pink triangle, is considerable, and is comparable in area to the residual risk in the standards-based example (shown here as 3. Flood Risk – Protect). However, when we consider the total risk (as illustrated by the colour intensity), we can see that there is significantly less total residual risk (see smaller portion of bar left in pink).

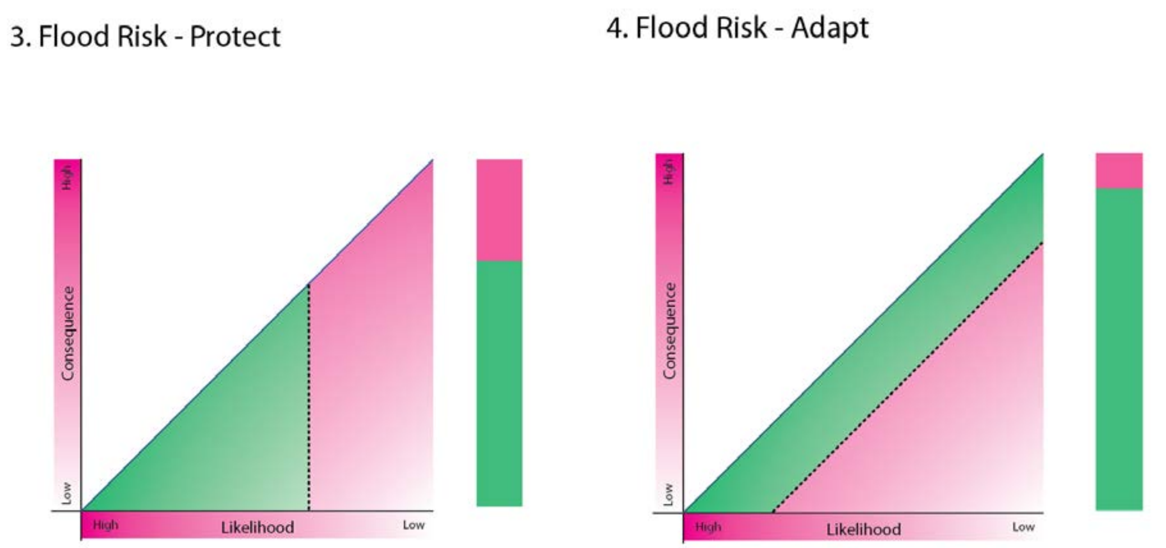

Figure 14: Illustrative example of risk reduction using standards-based and risk-based approaches. Part 2.

The above is purely illustrative, and obviously the calculations that underpin it are dependant on the assumptions made regarding the 'location' of the standard and the risk reduction from the 'shift' in consequences. Further, the above assumes a static and linear representation of risk. However, the overall intent is to show that standards-based approach, albeit effective up to the standard, leaves significant residual risk associated with events greater than the standard. Whereas risk-based approaches are designed to consider and reduce overall risk and therefore managed a broader spectrum of hazard events resulting in less residual risk.

3.7 Recommendations

In summary, **it is recommended that the Province and others with authority in BC adopt a comprehensive, risk-based approach to flood management, in line with international best practice** (e.g. UNISDR 2015). Because the Province does not act alone (the Federal, Local and First Nations governments all have some measure of authority and responsibility) it will ideally enable and encourage other orders of government to do the same. This is further explored in Issue A-1: Flood Risk Governance (Ebbwater Consulting Inc. and Pinna Sustainability, 2021).

While a necessary step forward, developing and successfully rolling-out a risk-based planning framework will be a complex and resource-intensive task. Provincial policy direction will be required on various issues. Some of these were described in an independent review commissioned by the New Zealand federal Government (Tonkin & Taylor Ltd., 2016). While the review was intended to support the development of a National policy Statement in New Zealand, many of these issues are directly transferrable to the BC context for risk-based flood management, including:

- Setting thresholds for risk tolerances;
- Defining what constitutes a significant risk;
- Selecting planning responses to reduce risk;
- Managing multiple natural hazards and cascading effects (e.g. flooding due to seismic activity);
- Dealing with low probability events;
- Dealing with uncertainty;
- Communicating flood risk and science; and
- Raising awareness about flood risks and engaging communities in decision-making processes.

3.7.1 Specific Actions

This section captures actions to move-towards a risk-based approach in BC. It includes High-level estimates of priority and cost (primarily dollar cost, but also in some instances human resources and skills) are provided in this table as High (red, 10s of $M), Medium (yellow, $Ms) and Low (green, $1000s to <$M). These costs will be further refined and aggregated in Issue D-1: Resources and Funding (AECOM Canada Ltd., 2021). A note to whom the recommendation is targeted at in the Recommendation/Option Column.

Table 8: Recommendations related to movement towards risk-based planning framework.

No.	Recommendation/Option	Description	Priority	Cost
1.	Develop a multiscale, risk-based planning framework for adaptive flood management within BC. (Province)	A new planning framework is required to support the adoption of an adaptive, risk-based approach to flood management. This will establish the building blocks for a continuous cycle of planning, acting, monitoring, reviewing and adapting, as described by Sayers et al. (2014). The building blocks of the framework include: • Setting objectives for management	H	M

No.	Recommendation/Option	Description	Priority	Cost
		• Identifying and assessing risks • Developing and evaluating strategies to reduce risk • Implementing preferred strategies to reduce risk • Monitoring, evaluating and reporting management activities and changing flood risk • Continuously improving management activities as part of an adaptive management framework The framework should support long-term, multi-scale planning – from the provincial to local level. This will enable information sharing and prioritization of risk reduction activities across the relevant agencies. The planning framework should also incorporate mechanisms to enable updates to planning approaches as new research and technology becomes available. Finally, the framework should focus on applying flexible adaptation strategies that can change over time and preserve other flood risk management options.		
2.	Develop base risk tolerances and/or risk targets. (Province with input from Local and First Nations Governments)	As a component of the risk-based planning framework (recommendation #1), and leveraging a provincial-scale risk assessment (see recommendation in Section 5.6), the Province should set targets to support decisions and action on risk reduction. This might follow a model of specific quantitative targets (e.g., like is partly practiced in the Netherlands), or be less prescriptive and focus on trends and ALARP.	M	M
3.	Develop guidance materials, templates and decision-support tools to support the uptake of the framework, including a BC-specific flood risk assessment guideline. (Province)	Resources will be required to support the uptake of the framework. These resources should be flexible in nature, supporting both simple and more complex risk analysis and planning processes. This will enable application of the planning framework by the broad range of jurisdictions and First Nations across the province (who vary greatly in resourcing and capabilities).	M	M
4.	Enhance capacity and capability amongst provincial, regional and local flood management	To enable the successful roll out of the risk-based planning framework, a capability and capacity building program will be required across all levels of	H	M

No.	Recommendation/Option	Description	Priority	Cost
	agencies to undertake risk-based planning. (Province, Local Governments and First Nations, Professional Associations (UBCM, PIBC))	Government. Potential program initiatives could include: • Promotion of robust risk assessment (e.g. holistic, quantitative and qualitative) through the showcasing of best practice. • Development of online and in-person courses on flood risk reduction and planning • Support of in-person networking opportunities for risk assessment professionals • Development of an online portal to facilitate information and resource-sharing		

3.8 Concluding Remarks and Observations

Risk-based flood management planning is preferred around the world. There are clear advantages to this type of approach, especially in the face of climate change. A risk-based approach can manage the complexity of flood problems better than a standards-based approach, for example by recognising and considering the diversity of flood experiences and flood impacts. Further, it is posited that over time a risk-based approach will reduce losses and impacts from flood events more effectively than a standards-based approach.

However, there are many entrenched obstacles to the shift towards this type of approach in Canada and BC. Many of these are related to the novelty of a risk-based approach, and our current lack of data, resources and people to support these types of assessment as well as the existing governance structures. Further, risk assessments and risk-based planning will always be more expensive and difficult that standards-based approaches. However, the risk-based planning approaches will result in long-term reduction in risk and financial losses and should therefore have a positive return on investment.

Despite the many obstacles in play, there is opportunity to have a paradigm shift in the province – more data is available to support risk assessment, there is clear direction from senior government that this is a preferred approach. Further, the Province itself promotes risk-based through the adoption of a Sendai approach to emergency management. The authors strongly encourage the Province to make a shift towards a risk-based approach.

4 Investigation B-3.2 Province-wide Exposure and Vulnerability Database

Risk is calculated as the combination of hazard likelihood and consequences. And therefore, flood hazard data and consequence data, which itself is developed through an understanding of exposure and vulnerability (see Section 2 for definitions and further information) are the two principal inputs to an FRA. Flood hazard data requirements are addressed in part in issue B-2 Flood Hazard Information (Northwest Hydraulic Consultants Ltd., 2021a) and are discussed more in Section 5. This chapter focuses on the current availability of exposure and vulnerability datasets in BC and explores the possibility of a future province-wide exposure/vulnerability database.

4.1.1 Research Objectives

As identified in Section 3, one of the current obstacles to consistently applying risk-based approaches to flood management in the province is a lack of data to support risk assessments. The Province (and other governments) have traditionally supported the development of hazard assessments, and although there are certainly gaps, there is relatively strong inertia to continue to develop hazard mapping. Whereas risk mapping and the underlying data need to develop risk assessments is relatively novel, and in many cases the data to support full quantitative and holistic assessments is unavailable or inconsistent/incomprehensive. This investigation focusses on understanding the **effort required to develop and maintain a province-wide asset inventory (e.g. elements at risk) and/or exposure data set covering flood-prone areas.** The authors note that they have looked at the exploration of data sets to support both a provincial scale risk assessment (see also Section 5) as well as provincially-supported data sets that would also inform local risk assessments (see also Section 7)

4.1.2 General Approach

This investigation was primarily a desktop research and analysis exercise supplemented with interviews and targeted questions to colleagues and collaborators (see also general methods, Section 1.4). In this Section, first, background information on best practice approaches on exposure/consequence indicators – i.e., what type of information is needed and should be captured as input to an FRA (Section 4.2) is provided. Next, existing exposure/vulnerability datasets that might serve as input to FRAs (Section 4.3) are reviewed and includes considerations for First Nation exposure/vulnerability data (Section 4.5). Then general challenges and opportunities with current exposure/vulnerability data availability (Section 4.6) are discussed, as well as steps forward (Section 4.7), data security concerns (Section 4.7.1.1), cost estimates (Section 4.8) and recommendations (Section 4.9).

4.2 Summary of Best Practice and Challenges

The Risk & Resilience Primer (Section 2) provides important guidance on the complex nature of flood consequences that is in part due to the incredible diversity and interconnectedness of elements exposed to flood hazards.

Risk assessment is shaped by exposed elements that are considered; simply, what is measured matters. An idealized risk assessment (e.g. one with endless resources), would consider a full complement of holistic indicators to encompass tangible and intangible impacts, and be conducted with high-quality spatially-fine data.

However, data availability is a major limitation even when developing risk assessments. This becomes particularly challenging when conducting a spatially detailed risk assessment where often the data needed for such an assessment is not available at that spatial resolution (e.g., census population is typically reported in dissemination areas, which are relatively small for city centres, but large for rural areas), or is not spatial at all (e.g. much information on First Nations reserves is aspatial). Therefore, assumptions need to be made, and thus, each dataset typically comes with different levels of confidence in data quality. To display this information and highlight potential uncertainties in datasets, it is best practice to assign confidence levels to each dataset (AIDR, 2015).

4.3 Currently Available Exposure and Vulnerability Datasets

A range of different datasets are currently available in BC, which can be used as input to FRAs. These datasets are discussed below, with reporting on their level of detail and accuracy. The focus below is on spatial datasets, as these are best practice. However, the authors note there is value in using aspatial information if nothing else is available or for high-level preliminary assessments.

4.3.1 Local Datasets

4.3.1.1 Local Cadastral Data

The best data for local FRAs is typically obtained directly from the jurisdiction for which the FRA is being done. This data typically has the highest accuracy in portraying local assets. However, the availability of such data varies greatly between jurisdictions. While bigger cities typically have many, detailed and high-quality datasets, smaller rural communities often do not have the resources and capacity for developing and maintaining such datasets. For instance, cities typically have building footprint data, while such data is limited for smaller communities. Another challenge with jurisdictional data is that it is not consistent throughout a larger region (e.g. local governments within a regional district may follow different practices). Thus, if the FRA is conducted for a regional district, or province-wide, this data could not be used, as there is no consistency between the availability and quality of data for different jurisdictions – and unincorporated settlements and First Nation communities would also typically not be covered by local government data.

4.3.2 Provincial Datasets

4.3.2.1 GeoBC/BC Data Catalogue

The BC Data Catalogue[13] provides open and consistent data for a range of datasets, which can be used as measures or proxies for different indicators. For instance, data for critical infrastructure (such as, locations of first responders (ambulance, RCMP, fire halls, etc.), local government offices, hospitals, airports, port terminals, food banks, etc.), basic/critical services (roads, railway tracks), environment (species and ecosystems at risk distribution, parks, ecological reserves, protected areas, conservation lands,

[13] Province of BC - BC Data Catalogue. Province of British Columbia. Downloaded from https://catalogue.data.gov.bc.ca/dataset?download_audience=Public

contamination sources, etc.), or culture (civic facilities (museums, community halls, recreation centres, pools, arena), childcare, education centres, etc.) can be obtained. An advantage of the BC Data Catalogue is the consistency of data availability throughout the province, enabling its use in particular for regional and province-wide FRAs, where consistency in data across the study area is key. The datasets also come with well-documented metadata and are regularly updated.

However, as they are provincial datasets, they may not capture all local assets of importance. Further, most assets are reported as point data (in contrast to actual building footprints etc.). Another downside is that considerable time is needed to download, pre-process and compile each dataset, though this can be sped up by the use of automated web scraping/downloading and processing code via a programming language.

4.3.2.2 Integrated Cadastral Information (ICI) Society

The ICI Society[14] brings together a variety of geospatial datasets from both public and private sectors in BC, with the goal of allowing data sharing and collaboration across sectors. The ICI Society is set-up with a membership model, where members pay membership fees for access to data. Membership for local government and First Nations is free, and there are different pricing models for associate members. These are the most diverse group, including the private sector, RCMP, port authorities, forest products companies, and other private sector companies, and are often mostly consumers of data. BC Assessment, utility companies, telecommunication companies are both providers and consumers of the data. The ICI Society has existed since 2001 and has built relationships with both government (local/provincial) and utilities who assemble and share data with the ICI Society. The ICI Society then compiles the data and makes it accessible for other members. The data is refreshed weekly, and automatically uploaded from servers of their members in case there have been any updates. The ICI Society datasets are also constantly being updated to include new data types.

Data access for FRAs is typically obtained via the jurisdiction for which the FRA is conducted. ICI Society data, which is relevant for FRAs, typically include data on electrical power infrastructure (substations, distribution poles, transmission infrastructure, etc.), telecommunication facilities, etc. The datasets are typically high-quality with local accuracy and are being regularly updated. However, some post-processing is also needed to prepare the data for direct input to an FRA (e.g., compile information from different electricity or telecommunications providers).

4.3.2.3 BC Assessment Data

BC Assessment[15] data contains valuable information on building and land value, building use, and more. It is thus an essential dataset for FRAs. However, it should be noted that the dataset is not itself spatial and needs to be joined to spatial cadastral information.

[14] Integrated Cadastral Information (ICI) Society. https://www.icisociety.ca/

[15] BC Assessment: https://www.bcassessment.ca/

Data is typically obtained from BC Assessment via the jurisdiction for whom the analysis is conducted, as a datafile, and related to a spatial file by parcel identifiers. BC Assessment data provides relatively high-quality information at a local scale for each parcel. It is also mostly available consistently throughout BC – however, with the limitation that no BC Assessment data (or similar) is available for First Nation reserve lands. Furthermore, there are sometimes issues where multiple parcel information overlay. For instance, mobile home parks are not spatially resolved into several properties, but properties presented as overlaying polygons of the same extent. Similarly, apartment and strata buildings with multiple units are treated differently because the original intent of the dataset is to support tax assessments, and therefore individual rolls are grouped by 'owner' rather than 'user'. Typically, BC Assessment data is used for financial damage assessments, however, it also provides information on building use descriptions, and can thus be also used to identify potential environmental contamination sources.

4.3.2.4 Archeology and Heritage Sites

An important dataset for consideration of potential cultural impacts is the Archaeological and Heritage Sites[16] dataset, compiled and provided by the Archaeology Branch of MFLNRORD. This dataset includes registered heritage sites, Indigenous archaeological sites, Indigenous traditional use sites, and non-Indigenous archaeological sites. While it is an important dataset, it only includes reported archaeological sites. There are many additional unrecorded sites that sit within flood hazard areas. There are, of course, many sensitivities around archaeological sites, especially Indigenous archaeological sites, which have important cultural meaning and the location for which should not be shared. When using the archaeological datasets in risk assessments, it is important to only report on the total number of affected sites, but to not show site locations on a map.

4.3.3 Federal Datasets

4.3.3.1 NRCan Patterns of Human Settlement in Canada Dataset Model

NRCan has been developing a database on 'Patterns of Human Settlement in Canada' (Journeay and Yip, 2020). This dataset provides information on both exposure (physical assets and people at risk) as well as physical and social vulnerability information.

For the dataset, the spatial extents of human settlement are determined via remote sensing and satellite imagery, and census 2016 information is then distributed from dissemination areas to settlement areas (Figure 13). This reduces the major challenge of census data discussed in the preceding section, where dissemination areas are too large in rural areas to use as input to an FRA. The dataset also includes spatial social vulnerability indicators, based on demographic information from census data, for housing conditions, family structure, individual autonomy, and financial agency (Journeay and Yip, 2020). Further, the dataset includes additional neighbourhood scale information on vulnerability, where neighbourhoods

[16] MFLNRORD. Archaeology and Heritage Sites. Obtained from the Archaeology Branch | Ministry of Forests, Lands, Natural Resource Operations and Rural Development.

are assigned to one of eight vulnerability archetypes. This provides a very valuable dataset to FRAs, as it allows capturing the vulnerability of people within the flood hazard area in a consistent way for risk assessments of natural hazards.

The dataset further includes a land use classification, with information on form and character of built environment (e.g., rural, urban-low density, urban-medium density, commercial-industrial, etc.), and details on the built environment with allocation of buildings by construction type and design level (Journeay and Yip, 2020). Lastly, the dataset also assesses changes in physical and social vulnerabilities over time.

It should also be noted that the dataset has an all-hazards approach, and provides exposure/vulnerability data for natural hazards, including earthquakes, floods, wildfire, debris flow, and cyclones. NRCan used Canada-wide/global datasets on these natural hazards to interface these with the physical and social vulnerability layers.

The NRCan 'Patterns of Human Settlement in Canada' dataset provides an important input to FRAs, with a much higher spatial resolution of demographic information, especially for rural areas, than is available via census data. Further, the social and physical vulnerability information provides much needed information for FRAs. Nevertheless, it is a Canada-wide data layer, and thus, sometimes shows issues at the local scale – especially when looking at very rural communities with only a few buildings. The dataset is slightly coarser than the parcel level information that is found in other datasets, which limits its use for high local risk assessments. However, nevertheless, the dataset is invaluable to FRAs. It is also currently undergoing an update and development of new features. The dataset will be provided as open data in the future.

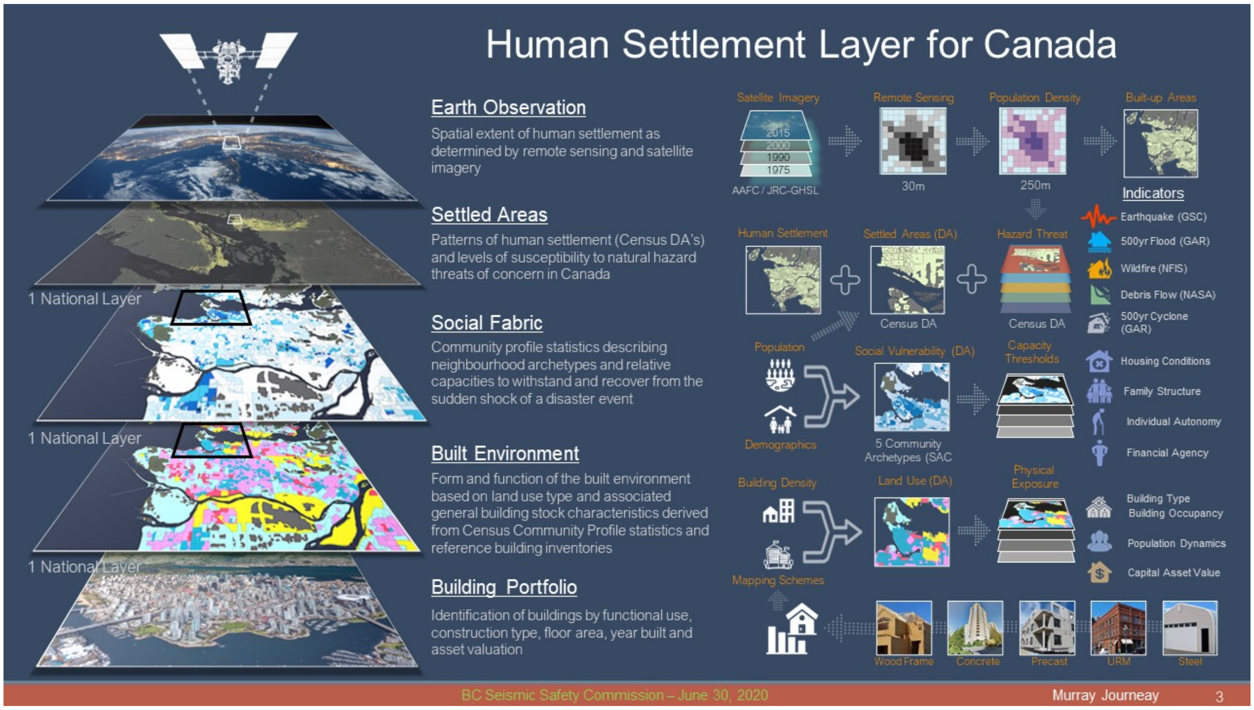

Figure 15: Human Settlement Layer for Canada data compilation. Figure from presentation by Murray Journeay and Jackie Yip, NRCan, on 2020-06-19.

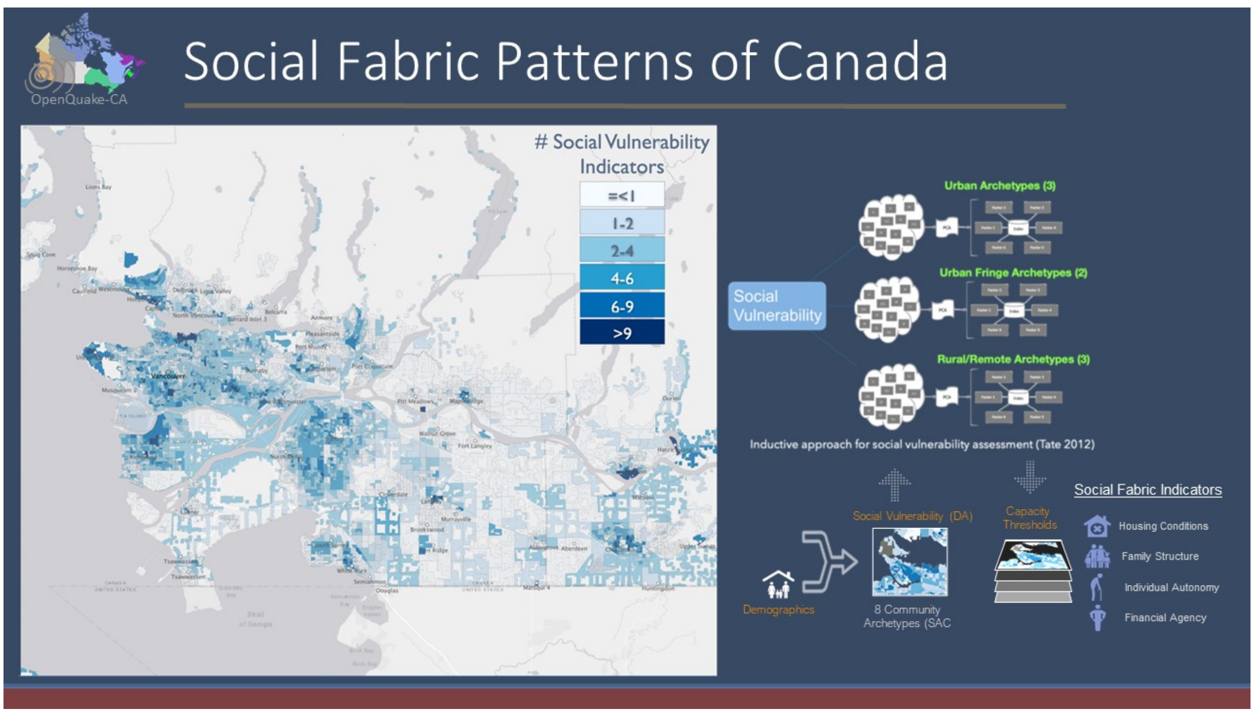

Figure 16: Social Vulnerability Indicator – Human Settlement Layer for Canada. Figure from presentation by Murray Journeay and Jackie Yip, NRCan, on 2020-06-19.

4.3.3.2 Statistics Canada Census

The 2016 census from Statistics Canada[17] provides the latest available information on demographics. Spatial census data can be accessed for instance via the Census Mapper[18], where spatial datasets for different spatial disaggregation can be downloaded (e.g., information at the dissemination area level). While census data has a good spatial resolution within population centres, where dissemination areas are small, it is challenging to use census data in more rural locations, where often, a dissemination area is large and can cover both settled and unsettled areas.

4.3.3.3 Agriculture and Agri-Food Canada - Annual Crop Inventory

A Canada-wide dataset on land cover and agricultural crop varieties is the Agriculture and Agri-Food Canada Annual Crop Inventory[19], which is updated each year. This dataset is developed based on satellite observations from multiple sensors during key crop phenological stages (reproduction, seed development and senescence), and trained and validated using provincial crop insurance information and collected field information (AAFC, 2019). It provides a consistent dataset for most of BC with detailed information on crop types, and other land use/land cover. However, the dataset is missing parts of the Central Coast around Bella Coola (as they might have assumed that agricultural production is low in that region). Further, the spatial resolution of the data are 30 m grid cells, and as it is developed as a Canada-wide dataset, there are some uncertainties when looking at the local scale.

4.4 International Open-Source Datasets

4.4.1.1 Microsoft Building Footprints

The relatively new Microsoft Building Footprints[20] dataset provides building footprints across Canada (as well as the U.S., and Uganda and Tanzania). The dataset is based on Bing Satellite Imagery, using artificial intelligence algorithms to identify buildings, and then polygonising them (with detection of building edges and angles) to create building footprints. The purpose of the dataset is to support OpenStreetMap (see next section) and humanitarian efforts. For Canada specifically, Microsoft collaborated with Statistics Canada for this project. Data is published open on GitHub[21]. It is a consistent dataset available for all of BC; however, as it is based on remote sensing imagery and image classification (identification) algorithm, there are uncertainties at the local scale. Overall, it provides a valuable dataset however, as building footprints are typically not available outside the bigger population centres.

[17] Statistics Canada – 2016 Census: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/index-eng.cfm
[18] Cenus Mapper: https://censusmapper.ca/
[19] AAFC (2019). Annual Crop Inventory 2018. Agriculture and Agri-Food Canada. https://open.canada.ca/data/en/dataset/ba2645d5-4458-414d-b196-6303ac06c1c9
[20] Microsoft Building Footprints. https://www.microsoft.com/en-us/maps/building-footprints
[21] GitHub: GitHub is a development platform, which is open-source and open-access, i.e., programming codes are openly posted and updated there throughout a programming project. https://github.com/

4.4.1.2 OpenStreetMap

OpenStreetMap[22] is an open map initiative where people around the world can contribute to mapping (according to strict quality assurance rules), supplemented by other open data which is integrated in the OpenStreetMap platform. Data is open and can be downloaded. Data quality is typically high; however, data availability varies from location to location. For instance, for one town, building footprints may be available, as someone has digitized them, or a jurisdiction has provided them as open data and it was loaded into OpenStreetMap. But for other places, this data might not be available.

4.5 Considerations for First Nation Exposure and Vulnerability Data

Many of the datasets described above, such as census and BC Assessment data, do not include First Nation reserve lands. Thus, if that information cannot be captured adequately by other means (e.g., via the First Nation) it will be missed in an FRA, biasing the results and reducing the quality of the work.

There are efforts underway to compile data for First Nation reserve lands. For instance, the ICI Society has been engaging with its First Nation members to compile such data, often in relation to emergency response and address data, where the availability of such data would benefit the First Nation.

Further, there are some Indigenous communities who are currently seeking to capture culturally-sensitive information as well as develop data sharing agreements that reflect the sensitivity of the information so that it can be used, with respect, in FRAs (e.g., the Scw'exmx Tribal Council who have developed an agreement to support a current flood project funded under the First Nation Adapt program (authors' own knowledge).

As discussed in the preceding archaeology data section, there are also data sensitivities to be considered when dealing with First Nation data. Archaeological and traditional sites are important parts of First Nation culture and identity, and First Nations might for instance be hesitant to share information outside their Nation, especially if a risk assessment is not conducted by the Nation themselves but by a neighbouring jurisdiction.

Finally, in the authors' experience working with First Nations across the province on flood risk assessments, the authors note that the data and used in projects rarely reflects Indigenous worldviews. For example, the linear approach to considering risk to individual elements does not reflect the interconnectedness of everything.

Simply, there is much work to be done to ensure that First Nation lands are treated equally in traditional datasets (e.g., census). And secondly, there will be even more challenges to collect appropriate information and data to support culturally relevant risk assessments.

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[22] OpenStreetMap: https://www.openstreetmap.org/#map=2/71.3/-96.8

4.6 Challenges and Opportunities with Current Exposure Data

A number of challenges, and a few opportunities related to the use of existing data sets were identified through this investigation. These are described below.

4.6.1 Data Access and Sharing Protocols

A challenge that was noted by interviewees and by the authors' themselves is the initial challenge of connecting with an appropriate and responsible person at a given authority to inquire about data and eventually gain access. Getting appropriate agreements in place and acquiring data is a hugely intensive exercise, which must be repeated for each dataset and for each project. For example, obtaining critical infrastructure information for a project (i.e. to address one indicator) would require communications and agreements with multiple asset owners (e.g. hydro, gas, etc.).

4.6.2 Data Processing and Consistency

All flood risk practitioners to whom the authors spoke throughout this project highlighted the challenges in compiling the exposure and vulnerability data for an FRA. It is typically one of the most challenging and time-consuming tasks for FRAs. Even if data is accessible online, there is substantial time spent organizing and pre-processing different datasets to prepare them for input into an FRA analysis. Currently, most qualified professionals are working in silos, pre-processing the same kind of data, and delivering results to separate branches of governments. This leads to a loss in efficiency and increase in cost for FRAs, where, with a more consolidated province-wide exposure/vulnerability database, data pre-processing efforts could be substantially reduced, and spent instead on other project aspects, such as more engagement. It needs to be recognized that the data processing and data delivery are substantial work tasks in themselves. They also require diligent work with good metadata documentation, to ensure that data quality is preserved, and it can clearly be communicated to stakeholders, on which datasets (and therein data issues) the risk results are based.

4.6.3 Data/Methods Availability for Structural Damages and Financial Losses

Further, for more comprehensive FRAs where for instance detailed building information is needed, such information is typically not available. For instance, the Lower Mainland Flood Risk Assessment used insurance and restoration software (Xactimate) to estimate building damage functions, a residential survey of household content values, crowd-sourced building surveys based on Google Streetview for estimating main floor height and outsourced a 10,000 businesses survey to BC Stats to provide more info on potential flood damages to businesses. Such comprehensive building data is typically not available, and while it might not be feasible to integrate such detail into a province-wide exposure/vulnerability database, it could be used as example for other studies. As part of the NRCan dataset, a detailed building dataset is also being developed, which could help fulfill some of the shortcomings of currently available building data.

4.6.4 Data Quality and Consistency

Interviewees and the authors' own experience highlighted that even when data was available and seemingly promising for use in an FRA, often, as the project progressed and quality control was conducted, it was established that there were gaps and/or errors in the data. It is important that all users of the data understand that it may include errors or not be appropriate for use at fine scales. This can be addressed through the use of confidence scores on the various datasets.

4.6.5 Data Gaps for Intangible Elements

Another current data challenge for FRAs is the limited quantitative data availability and methods approaches for cultural and environmental impacts. For example, there is a lack of geospatial data to more holistically represent vulnerable population groups; this includes for example those with mental and chronic health issues, seasonal migrants and homeless populations. Further, environmental datasets either as a source of damage (e.g. contaminants) or a receptor (e.g. ecologically sensitive area) are limited and inconsistent across the province. Culturally appropriate datasets are limited at best.

4.6.6 Opportunities and Emerging Directions

Despite the many current data challenges in BC, there are also many opportunities. Many diverse data sources already exist, and most of them are openly accessible. New datasets are being developed, such as the NRCan exposure/vulnerability dataset. And overall, capacity for processing exposure/vulnerability data and conducting FRAs is growing in BC.

4.7 A Proposal for a New Exposure Database for BC - Discussion

To reduce efforts in pre-processing exposure/vulnerability data, a compiled province-wide database is essential; this will significantly reduce effort and cost over time.

Overall requirements for an exposure/vulnerability database include good and consistent metadata documentation, and a mechanism to automatically upload data from data providers. Further, if new datasets become available (e.g., the new Microsoft Building Footprints data), the database needs to be able to acknowledge and accept this data.

It also needs to be ensured that the database provides exposure/vulnerability datasets in a way that are easily and consistently integrated into risk assessments. Thus, a consistent data schema needs to be developed. A schema is a formal description of data, data types, and data file structures. In a database, the schema describes the structure in terms of table names, column names, constraints, etc. to maintain the integrity of the data.

Lastly, engagement with the risk assessment community, inclusive of Indigenous communities, should be included in development of an exposure/vulnerability database, to ensure that the database fulfills all needs for risk assessors, e.g., includes all types of datasets and indicators which are typically used for a quantitative FRA.

As exposure/vulnerability data is generally similar across all natural hazards, an all-hazards approach should also be adopted, which allows use of the database for different natural hazard risk assessment (i.e., not solely focused on flood risk). This will allow better efficiencies and returns on investment for the database.

Importantly, the longevity of such a database is imperative to consider at the outset of database development. This would most be ensured by incorporating the maintenance and operation costs in provincial government budgets and locating the top-down responsibility of ensuring database operationality at the provincial level. However, it is important that risk assessment practitioners continue to have an advisory role in the exposure/vulnerability database, to ensure it continues to fulfill the need for (likely more and more evolving, risk assessments).

There are different ways forward to such a database, and potentially, a combination of different approaches could be used.

4.7.1 Build on Private Sector Initiatives

BGC has been developing their Cambio Communities dataset, which contains provincial datasets that are already specifically pre-processed as input for FRAs. At the moment, this dataset is restricted, and access is left to clients, who can determine who will obtain access to the datasets. It currently covers about half the Province. In the future, it could potentially become a subscription-/license-based model and provide compiled exposure/vulnerability data to risk assessors.

There are of course advantages and disadvantages associated with a private sector enabled approach. Arguably, this would be efficient, but could limit growth of the sector and of the dataset to subsume new ideas and concepts. At this time, the Cambio Communities dataset although consistent, is not holistic; it is focussed on the readily available tangible elements of exposure. No vulnerability elements are currently included. Further, a pay-per-use model will exacerbate issues of equity (see Issue A-1: Flood Risk Governance (Ebbwater Consulting Inc. and Pinna Sustainability, 2021) for additional discussions related to equity).

4.7.2 Build on Quasi-Public Sector Initiatives

The ICI Society also already provides a geospatial data sharing model, which includes both the public and private sector.

The advantage of this approach is the existing infrastructure and networks. ICI is also good at maintaining the information; it is constantly adding new datasets.

Some challenges with this approach are that the dataset doesn't currently include the full suite of holistic datasets that should be used for FRAs, and therefore considerable effort would be required to bring it up to an appropriate standard. Further, the metadata standards would have to be improved. Currently, the metadata is very inconsistent, as it is provided by diverse data owners.

4.7.3 Enable Open-Source Community Database

Another approach would be to develop a set of open-source programming codes (e.g., R language), which are shared openly via GitHub, continuously evolved by the risk assessment community, and which can be used to automatically download and pre-process any exposure/vulnerability data which is available openly online. This would allow access to the newest data, but would involve some prior code development, continuous time investments to keep codes up-to-date, and programming might also not be accessible to all members of the risk assessment community.

4.7.4 Intergovernmental Collaboration

There is already important work going on both at the provincial and federal government level. At the provincial level, GeoBC has geospatial expertise and infrastructure in place at the government level. The BC Data Catalogue already provides a province-wide database with consistent metadata. While currently, it is relatively cumbersome to download individual datasets for a risk assessment, the necessary infrastructure is already in place.

The NRCan exposure/vulnerability work and ongoing database development provides a valuable compiled exposure/vulnerability database for social and economic impacts to natural hazards, and thus should continue to be supported for further development. Continuing development and updating of that dataset will provide high-quality input data for FRAs.

Further, NRCan is also in the process of starting a BC Disaster Risk Reduction Hub (BC DRR Hub), which will serve as a mechanism to strengthen the governance of disaster and climate risk management. As part of the BC DRR Hub, the goal is also to enable top-down sharing of data, with ethical agreements for data sharing. Thus, some of the development of a province-wide exposure/vulnerability database could be set up in cooperation with the BC DRR Hub.

4.7.5 Build a New Bespoke Database

There is also the option of opening a request for proposal to develop a new database and model. However, given that existing systems exist, this is not an efficient option, and has not been pursued further.

4.7.6 Data Security Concerns

An important consideration for a province-wide exposure/vulnerability database are data security and data sensitivity concerns. However, most of the datasets discussed above are either already openly available (BC Data Catalogue, Annual Crop Inventory, Microsoft Building Footprints, OpenStreetMap, Census), will be openly available in the future (NRCan exposure data), or are based on open data (BC Assessment data). Exceptions to this are the ICI Society, which also compiles private data for instance from utility and telecommunication companies, and some jurisdictional data which may not be publicly available (though most jurisdiction provide access to their data through web maps). Further, archaeological data is also highly sensitive, as discussed in Section 4.2, and should not be publicly available.

Therefore, for province-wide exposure/vulnerability database, there would be need for different data security protocols. Ideally, most of the data would be openly accessible (though this might depend on the cost sharing model that would be chosen), while other data would be restricted based on data sharing agreements with the data holders. This can be set up relatively straight-forward in database development, where different datasets are tagged with different data sharing requirements. Local and sensitive data, such as information provided by First Nations for a local FRA, would however not be included in such a province-wide database.

4.8 Class D Cost and Capacity Estimates

The authors contacted several database providers in BC (ICI Society, BC Assessment, etc.), but did not receive information on the costs of operation at the time of report writing. Some database providers might be hesitant to share such sensitive and confidential information, or not calculating it in a way that can be used for comparison. For instance, as a research team, NRCan does not calculate the cost of developing and operating the NRCan exposure/vulnerability model as it has been developed mostly using salaried staff scientists. The authors also reached out to an artificial intelligence company who specializes in geospatial data management, and obtained some very rough cost estimates from them, as well as from BGC. As there is limited information, the authors recommend working with costing experts to improve potential cost estimates for developing and operating a province-wide exposure/vulnerability database.

As discussed in Section 4.7, there are several ways forward towards an exposure/vulnerability database. It could occur via a private operator (e.g., the Cambio Communities platform of BGC, the ICI Society, or another provider), or via internal government approaches (e.g., GeoBC). In any case, collaboration with federal initiatives (NRCan exposure/vulnerability model and BC DRR Hub) should be ensured.

Class D cost estimates[23] for development and operation/maintenance of an exposure/vulnerability database are provided in Table 9. It should be noted that these are very rough estimates and should be refined with costing experts. The range in costs depends on the complexity of the database (e.g., how many different datasets are included, how accessible is the data download, how much development of a common data schema, and data alignment of existing data to that schema, has been conducted, etc.), and if new datasets being developed to be integrated into the database. Further, importantly, for a database, annual maintenance and operation costs need to be considered. Again, the costs for this depend on how simple or complex the operation design is (e.g., how often are datasets refreshed, is customer support service provided, are continuously/actively new datasets being incorporated, etc.).

Table 9: Class D cost estimates for development and operation of an exposure/vulnerability database.

No.	Task	Class D cost estimate range	
1	**Development of database based on existing data (all sources)**	**$500,000**	**$1,500,000**
	Cost for developing data delivery system (software platform)	$300,000	$1,000,000
	Cost for developing data schema	$50,000	$100,000
	Cost for obtaining and aligning data	$250,000	$400,000
2	**Generate multiple new exposure/vulnerability datasets**	**$200,000**	**$1,500,000**
	(e.g., detailed building vulnerability data, new cultural/environmental datasets, …)		
3	**Annual maintenance and operations costs**	**$120,000**	**$600,000**
	(estimated at $10,000 to $50,000 monthly)		
	Total	$820,000	$3,100,000
	Total (without generation of new datasets)	$620,000	$2,100,000

[23] A class D estimate (± 50%) is a "preliminary estimate which, due to little or no site information, indicates the approximate magnitude of cost of the proposed project, based on the client's broad requirements. This overall cost estimate may be derived from lump sum or unit costs for a similar project. It may be used in developing long term capital plans and for preliminary discussion of proposed capital projects." (EGBC, 2009).

Capacity and resourcing for the development of a provincial database would be highly dependant on the path taken (i.e. private sector, public sector, open source), and no specific numbers are provided. The authors do however note that the these sectors should be consulted in the development of an exposure database.

4.9 Recommendations

Table 10 lists recommendations based on the above analysis. It includes high-level estimates of priority and cost (primarily dollar cost, but also in some instances human resources and skills) are provided in this table as High (red, 10s of $M), Medium (yellow, $Ms) and Low (green, $1000s to <$M). These costs will be further refined and aggregated in Issue D-1: Resources and Funding (AECOM Canada Ltd., 2021). A note to whom the recommendation is targeted at in the Recommendation/Option Column.

Table 10: Recommendations based on Investigation B-3.2

No.	Recommendation	Rationale	Priority	Cost
1.	Implement a province-wide exposure/vulnerability database. (Province)	There is clearly a need for such a database, and it would increase the efficiency of risk assessments substantially, thus freeing up FRA budget to include other components (e.g., include more engagement with stakeholders and First Nations), or potentially reduce FRA budgets. It will also support more consistency between FRAs.	**H**	**M**
2.	Develop a consistent data schema . (Province in collaboration with Canada)	A consistent data schema, which is targeted at integration into risk assessments, will be a key component of a database. NRCan has recently contracted the development of a Schema for hazard, which could possibly be leveraged.	**H**	**M**
3.	Conduct additional engagement with risk assessment practitioners. (Province)	To ensure that the database will fulfill the need of risk practitioners, appropriate engagement will need to be conducted. This must include engagement with Indigenous Peoples. Risk practitioners should also continue to play an advisory role, so that the database stays up-to-date.	**M**	**M**
4.	Ensure that database captures best practice for FRAs and includes a wide range of datasets. This will initially require engagement with practitioners and research (see above), and ultimately	To capture the full picture of risk, diverse indicators (people, economy, critical infrastructure, environment, and culture) need to be included in an FRA – and thus,	**H**	**M**

	require the development of new datasets. (Province, Canada, Post-Secondary, Private Sector, Practitioners)	data for these indicators need to be included.		
5.	Ensure availability of consistent metadata through the development of a guideline. (Province in collaboration with Canada)	Metadata is key for ensuring data quality and documentation and should be part of any database.	**H**	**L**
6.	Respect data sensitivities and develop protocols for data sharing. (Province in collaboration with First Nation Governments)	While most exposure/vulnerability data is open access, some contain sensitive information (e.g., archaeological sites) and data security needs to be preserved.	**H**	**L**
7.	Ensure longevity and currency of database. (Province)	From the beginning, the longevity of the database needs to be considered. Thus, oversight by government and integration into government operational budgets would be important.	**M**	**M**
8.	Continue to support NRCan 'Human Settlement in Canada' database development. (Province)	The NRCan dataset provides a valuable resource of social and physical exposure and vulnerability data, and maintenance and development of new features of that dataset should continue to be supported.	**M**	**L**
9.	Apply an all-hazards approach to collecting data. (Province, working with multiple ministries)	Some exposure and vulnerability data is similar across all natural hazards, and thus, efficiencies (and consistencies) can be obtained. Consultation with other specialists will be required (e.g. EMBC).	**M**	**L**

4.10 Concluding Remarks and Observations

Risk is calculated as the combination of hazard likelihood and consequences. And therefore, flood hazard data and consequence data, which itself is developed through an understanding of exposure and vulnerability are all need to support risk assessments. **One of the current obstacles to consistently applying risk-based approaches to flood management in the province is a lack of comprehensive, consistent, and high-quality exposure and vulnerability data to support risk assessments. This data gap has created enormous costs in the development of robust risk assessments in the province as each project required significant resources to acquire, create and process appropriate datasets. The creation of a provincially consistent and comprehensive database would significantly reduce the costs associated**

with individual assessments and lay the groundwork for more consistent and higher-quality flood risk assessments.

There are many existing datasets, databases and agencies that support risk assessment data. However, no one group has consistent, comprehensive, and high-quality data in an easily accessible format. It is recommended that the Province work with the risk assessment and geospatial data communities to leverage existing resources to develop a 'one-stop shop' for risk assessment data.

5 Investigation B-3.3 Provincial Flood Risk Assessment

In Section 2, various scales and uses for flood risk assessments were discussed (see Section 2.6). A provincial scale risk-assessment is at the upper end of the scale (see Figure 7), and would cover the jurisdictional extents of the Province and be used to build a provincial-scale understanding of overall risk, as well as some understanding of the spatial variations in risk, and potentially the main drivers of risk (e.g. are dense areas with high potential consequences overall more risky than dispersed rural areas). This information could then be used to resource, prioritize, and efficiently spend effort to reduce risk at the provincial level.

5.1.1 Research Objective

Given the usefulness of a provincial scale risk assessment to pursue a risk-based approach to flood management (see Section 3), and to prioritise resources under the current management regime and the current lack of such an assessment, this investigation focusses on establishing recommended approaches to developing a provincial scale FRA.

The specific objective for this work was to **investigate approaches to complete a province-wide FRA, addressing effort required, level of detail, types of flood risk, current and future scenarios, scale, and any information required and data gaps**.

5.1.2 General Approach

The project was primarily a desktop research and analysis exercise supplemented with interviews and targeted questions to colleagues and collaborators (see also general methods, Section 1.4). To cover all of BC with FRAs, two generalised approaches were considered.

In a **bottom-up approach**, local FRAs conducted for multiple communities across the province would be aggregated to create a single picture of flood risk across the province.

In contrast, a **top-down approach** is one where one consistent FRA is conducted for all of BC; essentially starting from scratch.

For both approaches, a key first step is to assess where FRAs have so far been conducted throughout BC, which is discussed in Section 5.2. Next, the bottom-up approach is discussed (Section 5.3), followed by the top-down approach (Section 5.4), a discussion of the trade-offs between the two approaches (Section 5.4.2.5), and recommendations specific to the B-3.3 investigation (Section 5.5).

5.2 Assessment of Flood Risk Assessments in BC

5.2.1 Overview of Available Studies

Based on information from public funding programs (NDMP, CEPF and FNA) and other FRAs that the authors were aware of (non-comprehensive list), an initial list of 107 studies were compiled (Table 11). Upon closer examination however, only 60 of these studies included an FRA component. Another 16 studies were identified as related, which included climate risk assessments, non-structural mitigation assessments, and dam-break risk assessments.

Of the 60 studies with FRA components, a total of 24 reports could be obtained. Most of these were from the NDMP/CEPF funded projects; it was more difficult to obtain reports from FNA funded projects. Two reports for related studies could be obtained, notably one of which was for an FNA funded project.

Table 11: Summary of number of studies listed for the NDMP/CEPF and FNA funding programs, as well as other projects (non-comprehensive).

Description	NDMP/ CEPF # of Studies	FNA # of Studies	Other (non-comprehensive) # of Studies	Total # of Studies
Overview				
All studies initially listed	73	32	2	107
Studies with FRA	43	15	2	60
Related Studies	11	5	0	16
Other Studies (flood hazard, other natural hazard, strategy, etc.)	19	12	19	50
Reports Obtained				
Obtained Reports for studies with FRA	17	4	3	24
Obtained Reports for related studies	1	1	0	2

Note that some studies may have received funding from both NDMP and FNA but were only counted once in one of the funding programs.

The 60 studies with an FRA component were further sorted into three categories:

- **Regional, quantitative:** Regional FRA; typically done at a screening-level (similar to NRCan Tier 1), but in some cases, a more detailed (Tier 2 or 3) study might also be included. The key criteria was that the study was conducted at regional scale (e.g., a regional district, or a larger region). All studies were quantitative studies.
- **Local, qualitative:** Typically, the FRA was part of a larger study (for instance, for many studies, flood hazard mapping was the main focus of the project, but a small qualitative FRA component was included as well). The qualitative FRA typically consisted of listing assets within the flood hazard extents, without a quantification of risk as the product of consequence and likelihood.
- **Local, quantitative:** This includes any FRA study that concentrated on a local jurisdiction and where a quantitative FRA was conducted. In some cases, the focus might be on exposure assessment, in other studies vulnerability and damages were assessed for multiple scenarios. But in all cases, a quantitative risk assessment (for several indicators) was conducted. In some cases, where no detailed information was available, but where the study name included FRA (i.e., indicating a study focus on flood risk) and where the study was done for a local jurisdiction, this category was assumed.

There were also other studies, which potentially had an FRA component, or were considered relevant:

- **Climate Change Adaptation Study:** A climate risk assessment was conducted, which potentially contains a part of an FRA; typically, however, it is not specifically mentioned that flood risk was investigated. The FRA might also only be a small component of the overall study, and if assessed, it was likely done qualitatively.
- **Dam Risk Assessment**: Risk assessment focused on dam failure; in some cases, this was done quantitatively, in some qualitatively, but typically different methods were used than in FRAs.
- **Non-structural Mitigation Plan:** These studies might have an FRA component, but in many cases, it could not be more clearly assessed if an FRA was conducted (as not many reports were available). If, however, a report was available, and it was clear that an FRA was conducted as part of the study, the respective FRA category (1,2 or 3) was assigned.

Lastly, studies that clearly focused on flood hazard instead of flood risk, assessed risk for another natural hazard (e.g., avalanche risk), or focused on provincial strategy development were removed from further analysis.

Table 12 provides the number of studies for each of the above-mentioned categories. A total of 9 regional/quantitative, 24 local/qualitative and 27 local/quantitative FRAs were identified. Under the FNA program, a further 5 climate risk assessments with potential FRA component were conducted. Under the NDMP/CEPF funding programs, 8 non-structural mitigation (with no clear identification of FRA) and 3 dam-break risk assessments were conducted. More details on different methodologies are discussed in Section 5.4.1 for regional FRA studies, and in Section 7.2 for local quantitative FRA studies.

Table 12: Studies with FRA and related studies,

Description	NDMP/ CEPF # of Studies	FNA # of Studies	Other (non-comprehensive) # of Studies	Total # of Studies
Studies with FRA - Details				
Regional, quantitative	8	1	0	9
Local, qualitative	15	9	0	24
Local, quantitative	20	5	2	27
Related Studies - Details				
Climate Risk Assessment	0	5	0	5
Non-structural Mitigation	8	0	0	8
Dam Risk Assessment	3	0	0	3

Throughout BC, available FRAs are concentrated within Southern BC, where most of the large population centres are located, and while overall, many FRAs have been conducted throughout BC (to varying degrees of detail), there remain many areas without FRA (Figure 15). The authors also estimated the approximate population covered by these FRAs as 3.3 million, based on 2016 census data (i.e., about 70% of the total population has already been covered). However, this number comes with many caveats: populations figures are considered highly approximate as census areas do not necessarily match FRA boundaries; the populations given are the total based on the administrative area not the potential flood hazard area. This is particularly important for the big regional studies (in particular the Lower Mainland FRA) where the figures are highly dependent on the areas mapped; the Lower Mainland FRA included over 1.5 M people alone, so pulls a large weight on the estimate; populations for First Nation communities are likely to be particularly inaccurate; and there is also element of double counting, where studies are included in both local and regional studies. This makes the total estimate particularly unreliable. While the regional FRA population percentage is relatively high (50%), it is much lower for local, quantitative FRAs (17%).

Table 13: Estimate for population covered currently by an FRA.

FRA Category	Population	Percentage BC
Regional, quantitative	2,337,724	50%
Local, qualitative	177,052	4%
Local, quantitative	772,399	17%
Total	3,287,175	71%

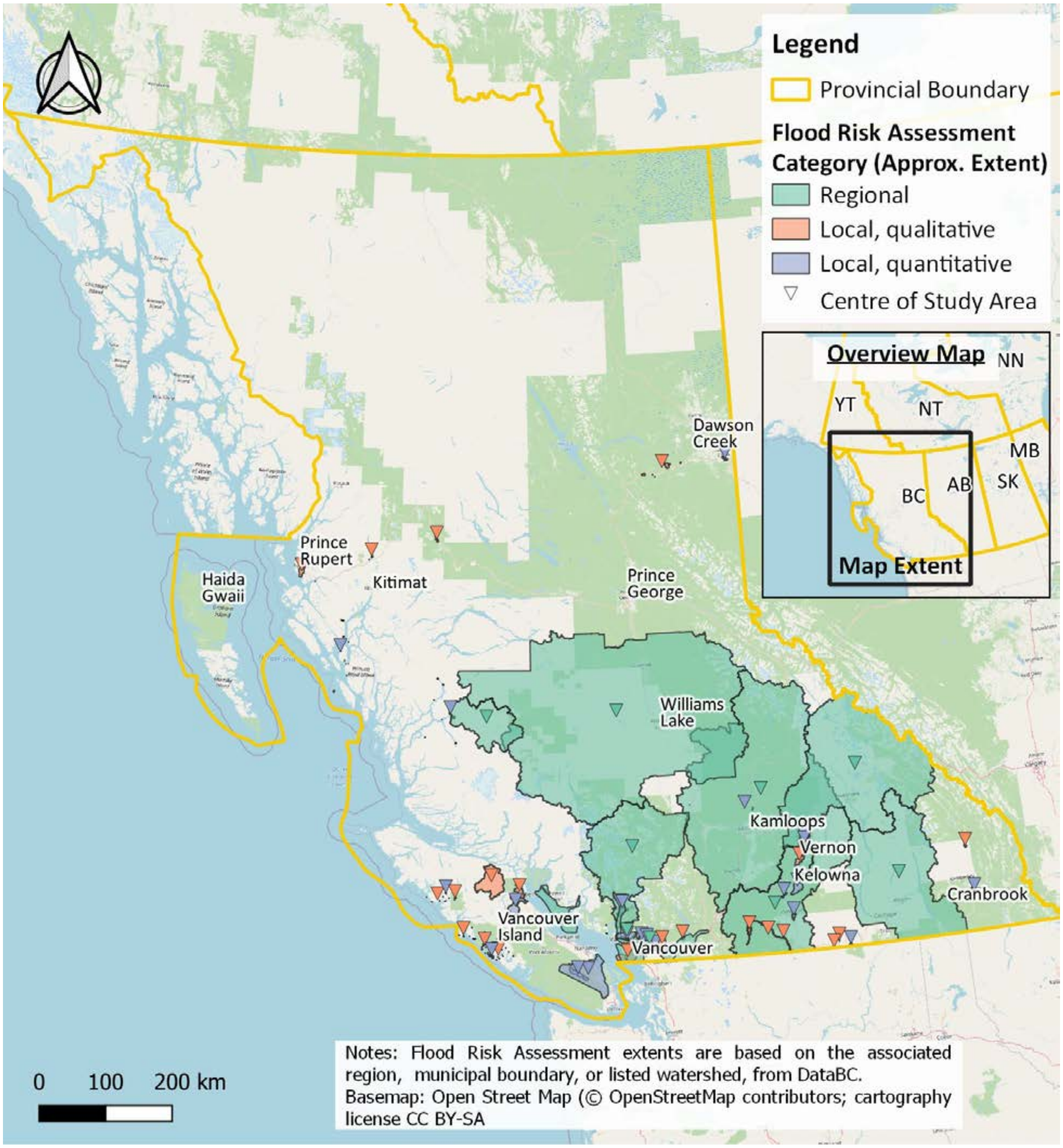


Figure 17: Identified FRAs in BC. Note that further FRAs may exist, and that FRA extents and categories were assumed based on available information.

Details on regional/quantitative, local/qualitative and local/quantitative FRAs, their spatial distributions and project budgets are provided in the following sections.

5.2.2 Regional, Quantitative Studies - Overview & Budgets

Much of southern and interior BC (excluding Vancouver Island) has been covered in regional FRAs (Figure 15, Figure 16). This includes the Squamish-Lillooet Regional District (RD), the Lower Mainland, the qathet (formerly Powell River) RD, the Okanagan River and Similkameen River watersheds (Okanagan Nation Alliance (ONA) territory), the RD Central Kootenay, the Thompson River watershed, the Columbia-Shuswap RD (in progress), the Cariboo RD, and the Bella Coola Valley. Not covered by regional FRAs are Vancouver Island, most of the South to North Coast, North and Northeast BC, the East Kootenay RD, and parts of the Fraser Valley RD.

It should be noted that FRAs were included in this category only if the FRA covered a large regional area and was done quantitatively. In contrast, if a regional district led the analysis, but the analysis focused only on smaller, specific regions within the regional district (as for instance for the Cowichan Valley RD and the Peace River RD FRAs), these FRAs were included in category 2 or 3 (depending on the methodology used).

Total project budgets varied widely between different regional FRAs (Figure 16; Table 14; Figure 17), with an average project budget of approximately $450,000 per regional study (the average budget per capita was $0.2; however, see caveats on population estimates in preceding section). The average budget per assessed area was 55 $/km^2. All the regional FRAs included a hazard assessment component (note that no information is available on the Columbia Shuswap RD, and inclusion of flood hazard modelling is assumed for the Bella Coola Valley based on project title), and some included a small effort related to mitigation planning. For the Lower Mainland FRA (LMFRA), flood hazard data based on a hydraulic model was available, but still included a flood hazard component (additional scenarios, assessing dike fragility, etc.).

The most expensive regional study per area was the LMFRA, which had an estimated cost of 238 $/km^2. This study differed in their methodology from other regional FRAs, as it for instance considered building vulnerability (through the use of flood damage curves), in contrast to focusing on exposure alone as was done for most other regional studies (the different methods are discussed in more detail in Section 5.4). Therefore, it could also be argued, that this study has some components of a local/quantitative study. If the LMFRA is excluded from the regional budget analysis, the average budget per area (for a regional/quantitative study) is 32 $/km^2 (Table 14).

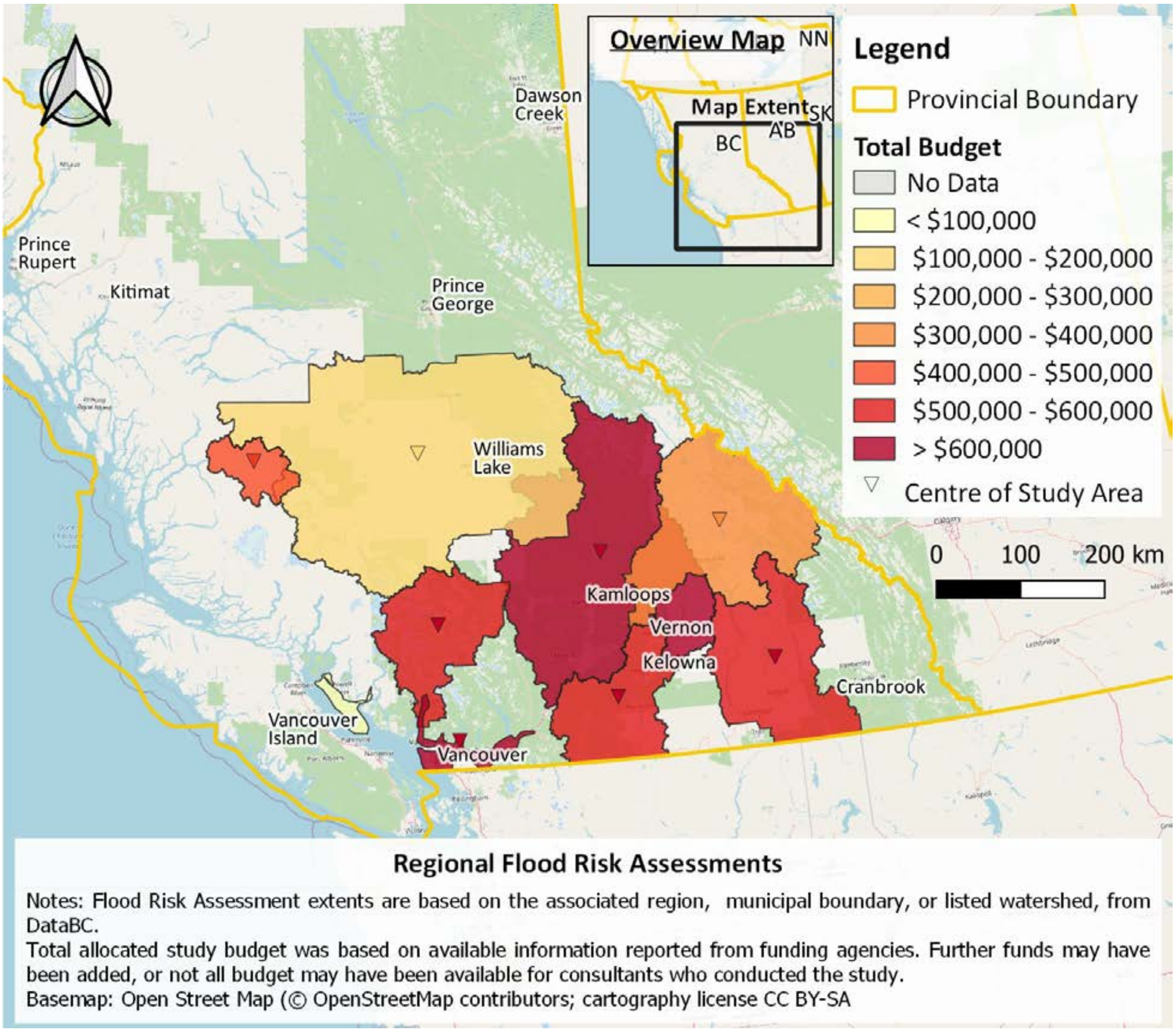


Figure 18: Total project budget (as allocated by funding agencies) for regional flood risk assessments.

Table 14: Total project budget overview for regional/quantitative FRAs. LMFRA = Lower Mainland Flood Risk Assessment.

Regional/Quantitative FRA	Total Budget ($)	Total Budget per Area ($/km²)	Total Budget per Area excl. the LMFRA ($/km²)
Minimum	67,725	2	2
Maximum	725,000	238	94
Average	453,803	55	32
Total	4,084,225		

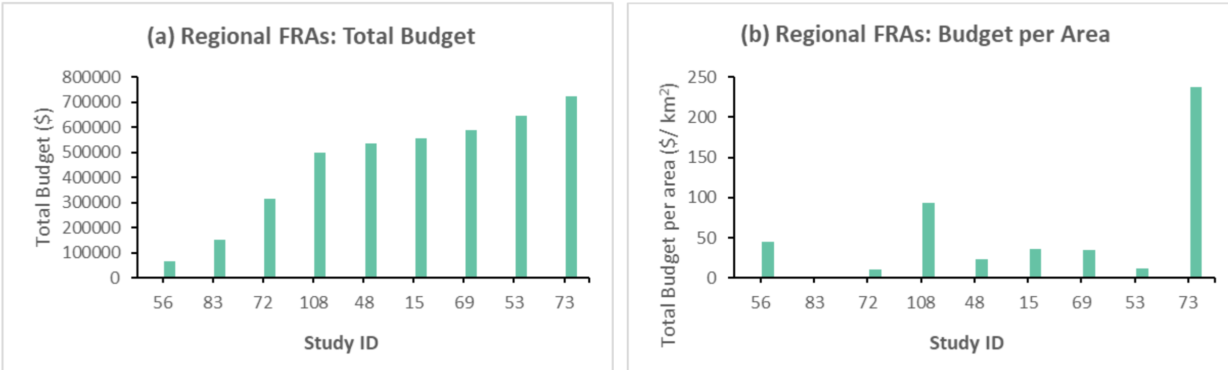


Figure 19: (a) the total budget, as reported by funding agencies and (b) the total budget per area for regional/quantitative FRAs.

5.2.3 Local, Qualitative Studies – Overview & Budgets

Local qualitative FRAs have been conducted throughout BC, for example along the North Coast, on Vancouver Island, as well as the southern interior (Figure 18).

Many projects funded by FNA were included in this category; for many of these projects, only the project title, budget and a brief project description was available, and category allocation had to be based on this limited information. Most of the projects focused on flood hazard mapping, but also indicated a flood risk component: for instance, the Kitsumkalum study, floodplain mapping for the Upper Nicola Band, several studies conducted as part of the Coastal Vulnerability Study[24] (for the Ahousat First Nation, Tla-o-qui-aht First Nation, Kyoquot First Nation, Hesquiaht First Nation, Ehattesaht First Nation), and flood assessment for the Sts'ailes Band. Other studies focused on an adaptation plan, as part of which flood impacts were considered, e.g., the Toquaht Nation Adaptation plan.

NDMP/CEPF-funded projects included Prince Rupert, Delta, the Peace River RD (as the focus of the analysis was on local communities, not the entire RD), the Salmon and White River on Vancouver Island, the Ebenezer Flats near Smithers, Campbell River, Thasis, Canal Flats, Greenwood, the Similkameen River, Midway, Mission, and Vernon. Reports and more detailed information were only available for a few of these studies, and assumptions were therefore made for the other studies. However, most of the study descriptions mentioned of flood hazard mapping as study focus, and the FRA was therefore assumed as a smaller component of the study. For FRA studies with available reports, often only a qualitative description of for instance infrastructure within the flood hazard area was included, but no quantitative assessment of several indicators was described.

[24] Coastal Vulnerability Study projects were here only included if project title and description clearly identified that impacts were considered. If the project title and description focused on flood hazard mapping alone, the study was not included in the FRA studies (and counted as "Other Study", as given in Table 2).

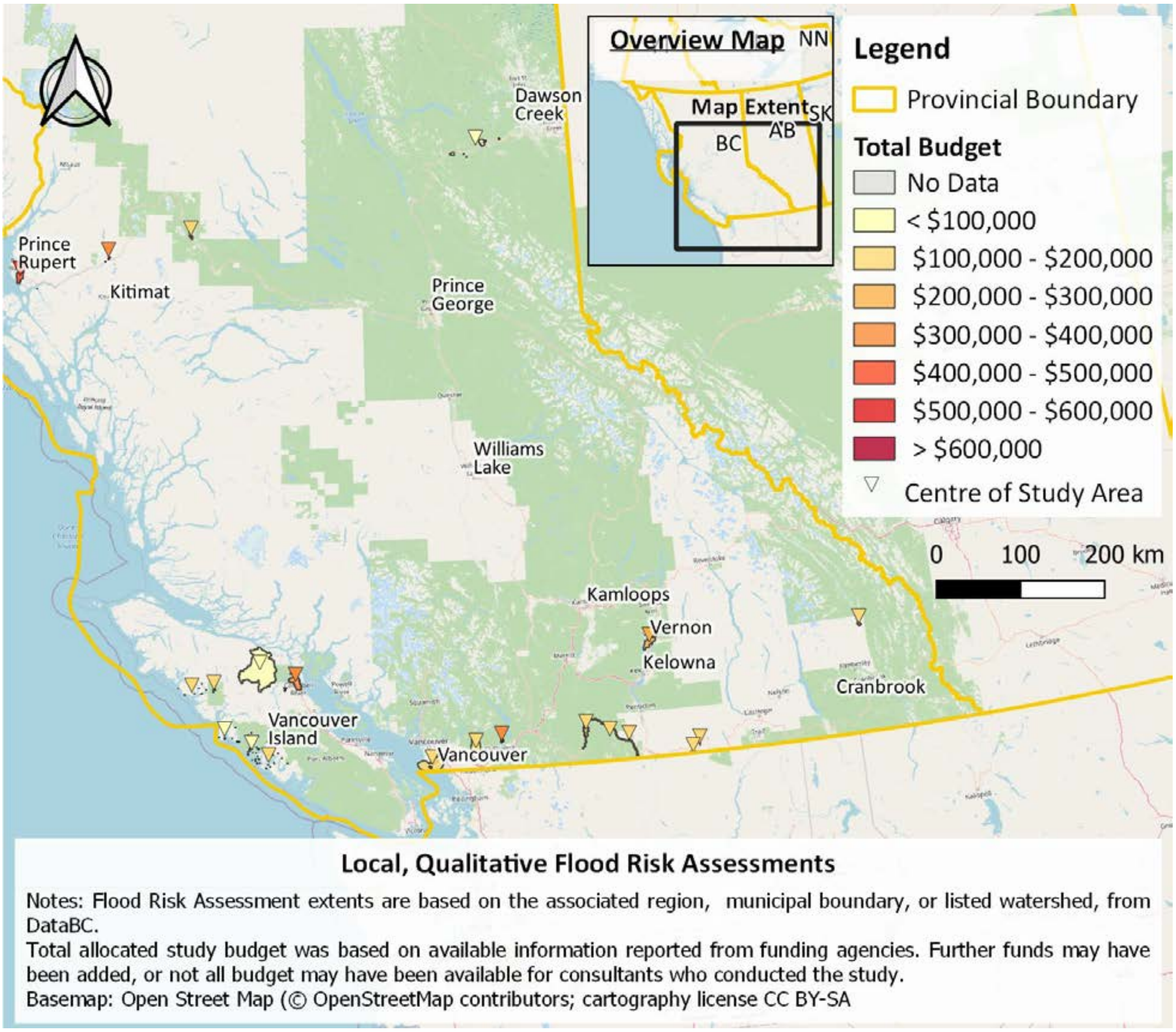


Figure 20: Total project budget (as allocated by funding agencies) for local/qualitative flood risk assessments.

Total project budgets for local/qualitative FRAs varied from \$60,000 to \$480,000 (Figure 18,Table 15, Figure 19), and the average budget per capita was approximately \$1 (albeit this estimate comes with many caveats). The average budget per area was 20,420 $\$/\text{km}^2$, which is substantially higher than for the regional/quantitative FRAs with an average budget of 55 $\$/\text{km}^2$. However, it is assumed that all these studies included flood hazard mapping based on project title or reporting where available (apart from the Toquaht Nation Adaptation Plan). Therefore, likely, most budget was used for flood hazard mapping and only a small portion of the total budget to conduct the qualitative FRA. Thus, the budget reported in Table 15 cannot serve as an indication of budget for conducting local FRAs. However, it should be noted that the FRA component in these studies was typically very high-level/coarse, and therefore cannot be used as an indication of best practice FRA (e.g., in most cases, risk as the product of consequence and likelihood was not determined).

Table 15: Total project budget overview for local/qualitative FRAs.

Local/qualitative FRA	Total Budget ($)	Total Budget per Area ($/km²)
Minimum	60,000	56
Maximum	480,000	80,753
Average	174,774	20,420
Total	3,670,260	

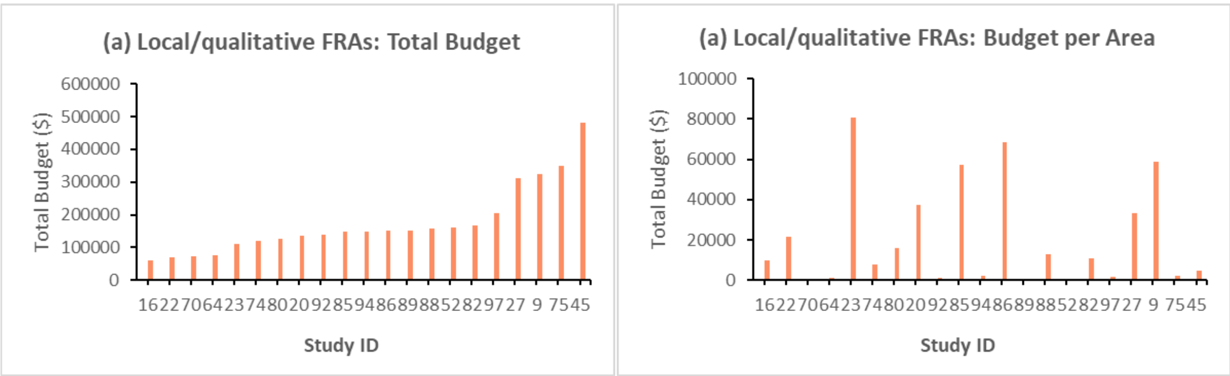


Figure 21: (a) the total budget, as reported by funding agencies and (b) the total budget per area for local/qualitative FRAs.

5.2.4 Local, Quantitative Studies – Overview & Budgets

Local quantitative FRAs have been mostly conducted in Southern BC, as well as some studies along the North Coast (Figure 20). NDMP/CEPF-funded projects have been conducted in the Lower Mainland (North Shore, City of Vancouver, Pitt Meadows, Squamish, Coquitlam, North Vancouver), the Southern Interior (Armstrong, Cranbrook, Kelowna, Spallumcheen, Grand Forks, Penticton, Peachland), Vancouver Island (Oyster River, Lake Cowichan, Cowichan Valley RD (focus was on specific locations, not the entire RD), Tofino, Zeballos), as well as one study in the Northeast (Dawson Creek).

There have also been several local studies done by First Nations along the North and Central Coast (Nuxalk First Nation, Gitga'at First Nation), which focused (according to the funding description) on comprehensive flood risk assessments for the local communities. Other FRAs by First Nations were conducted in the Interior (Whispering Pines/Clinton Indian Band, and Splatsin First Nation) and the Lower Mainland (Kwantlen First Nation, and Squamish Indian Band).

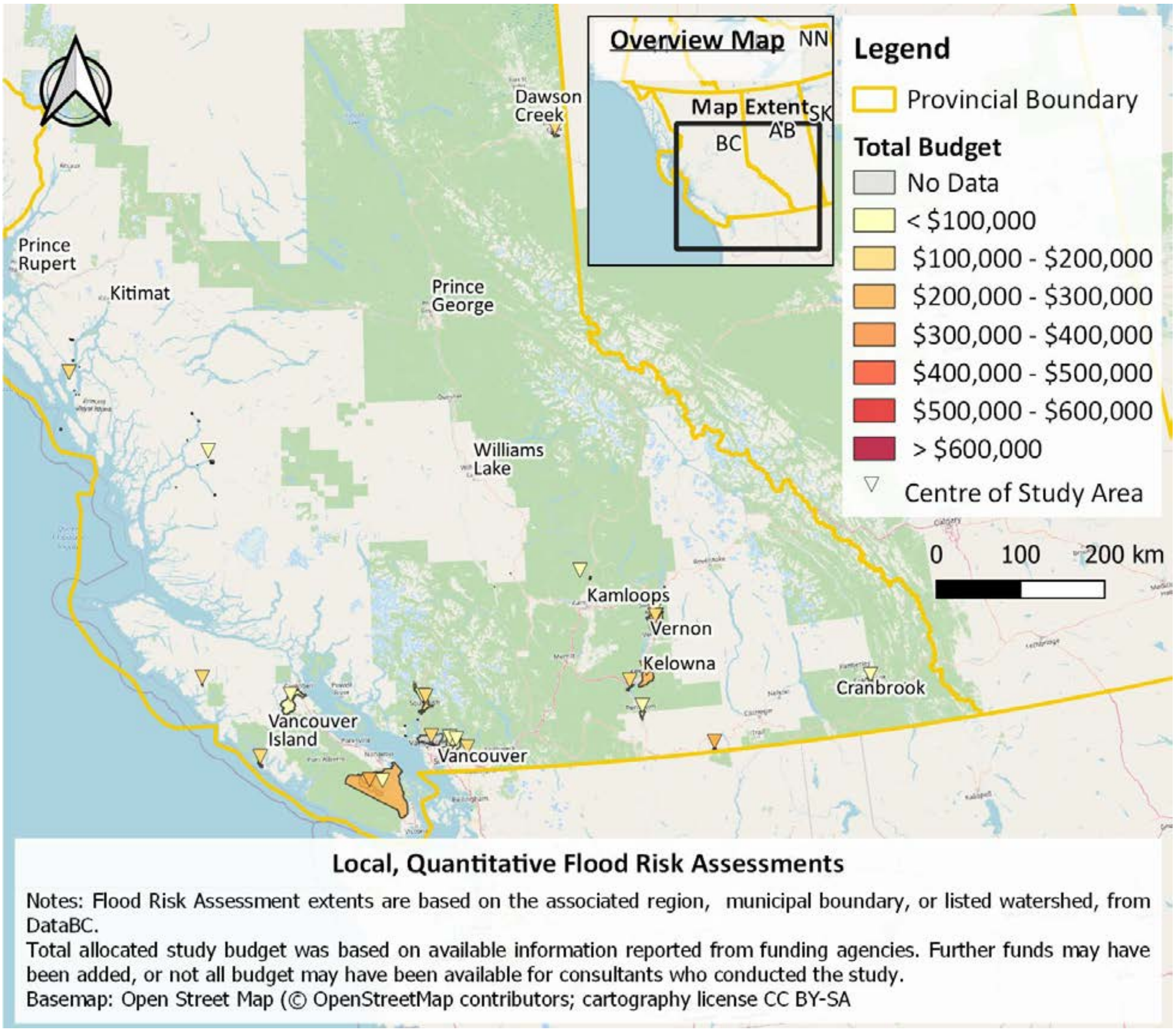


Figure 22: Total project budget (as allocated by funding agencies) for local/quantitative flood risk assessments.

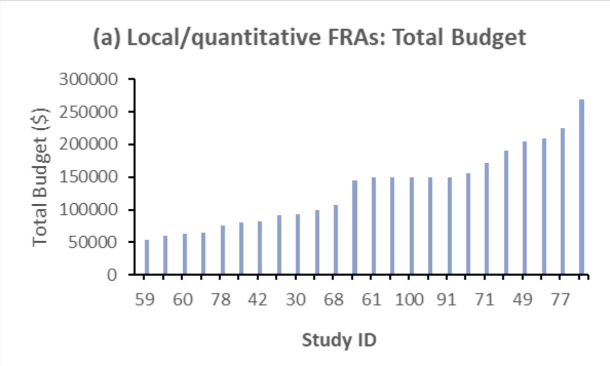
The total budget for local/quantitative studies ranged from $53,000 to $268,700, with an average of $132,905 (Table 16; Figure 21). The average budget per area was 8,642 $/km^2, which is much lower than the average budget of 20,420 $/km^2 for local/qualitative studies. This difference in price likely reflects that the focus of some of the local/qualitative FRA studies was flood hazard mapping, for which the majority of the budget was likely used (see note related to this limitation also in Section 3.1.3). The budget per area for local/quantitative studies was however substantially higher than for regional/quantitative studies (55 $/km^2), which reflects the different scale of approach.

The range of budget for local/quantitative FRAs likely reflects how comprehensive the FRAs were, as the depth of analysis likely varied substantially from study to study. The lowest budget ($53,000) was related with an industrial park risk assessment (i.e., a very small area), which resulted in 409 $/km^2. Further studies in the range of $53,000 to $100,000 included typically more high-level FRAs (noting however that reports are not available for all studies). For instance, the Oyster River/Saratoga Beach FRA falls into this category, which was a high-level (but quantitative) FRA, conducted as part of the NDMP Stream 1, which was then used to apply for funding for more detailed flood hazard mapping. Budget in the range of $100,000 to $150,000 typically included more detailed FRAs, some of which conducted as part of the NDMP Stream 1 however where limited flood hazard information was available, and thus additional (screening-level) flood hazard mapping was conducted as part of the study (e.g. City of Dawson Creek Non-structural Flood Mitigation). It also included FRAs, such as for the Village of Zeballos, for which detailed hazard analysis and risk assessment were conducted, but the overall study area was relatively small, resulting in the highest costs per area with 51,300 $/km^2. Project budgets between $150,000 and $210,000 included more detailed comprehensive FRAs (e.g., the District of Tofino Coastal Flood Risk Assessment, the Quantitative Risk Assessment for the Squamish River Floodplain). The reports for the two projects with the highest budget ($225,000, $269,000) were not available, but they presumably also included a more detailed FRA.

The FRAs and their methods will be discussed in more detail in Section 7.2, for the FRAs where reports were available.

Table 16: Total project budget overview for local/quantitative FRAs.

Local/quantitative FRA	Total Budget ($)	Total Budget per Area ($/km^2)
Minimum	53,000	92
Maximum	268,700	51,230
Average	132,905	8,642
Total	3,189,709	



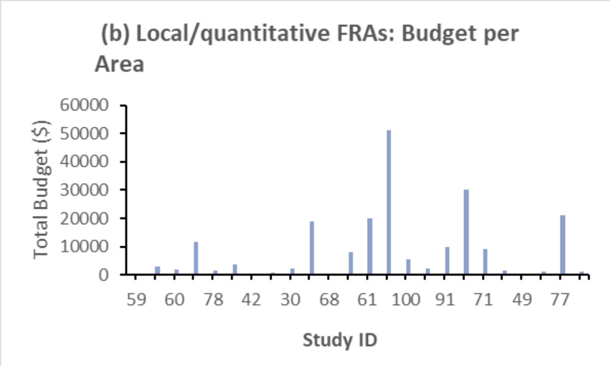


Figure 23: (a) the total budget, as reported by funding agencies and (b) the total budget per area for local/quantitative FRAs.

5.2.5 Limitations

It is important to recognize that the above assessment of FRAs in BC, and the associated budgets, was based on available data only, i.e., taking only publicly funded FRA projects into consideration. This included FRAs that have been conducted in recent years primarily under the NDMP, CEPF and FNA programs. FRAs conducted outside of these funding programs have only been added, where the authors had knowledge of the projects, which is therefore a non-comprehensive list, and other FRAs might be available throughout BC. Further, older FRAs might also not be represented well in the analysis. However, it can be assumed that much has changed since an older FRA was conducted, considering climate change (changes of hazard and likelihood), population growth, development and land use change (exposure and vulnerability change). The short time frame of this project did not allow for a more in-depth analysis and search of FRAs.

Another challenge was the categorization, as often not enough information was available, and judgement had to be made, based on title, brief project description and other material available online. The geographic extents of the study were also not always clear, and typically, the extents of the jurisdiction or First Nation conducting the study have been assumed as FRA extents.

Lastly, while budgets were reported by funding agencies for all studies, these budgets may not reflect the actual budget available to conduct the study. Where information was available, the total reported budget included contributions by municipalities or private entities, however, this was not available for all studies. Further, the allocated budget may also not reflect the amount that was available to the consultants to conduct the work, nor if the actual work was more expensive and the consultants went over budget.

5.2.6 Conclusions

The review of existing flood risk assessments in the province, although not completely rigorous or comprehensive allows for some insight on the quality and value of the work completed to date:

- For the most part, risk assessment is treated as a cursory addition to flood hazard assessment projects.
- There is great diversity in approaches, and arguably many, if not most, projects would not be considered robust.
- There are however some examples of both robust and novel approaches to risk assessment that have been completed in the province and could be used as templates going forward.

5.3 Bottom-up Approach to Develop a Provincial Flood Risk Assessment

The bottom-up approach to develop a provincial flood risk assessment would be based on leveraging existing local FRAs, and then filling in gaps, and aggregating information (see also Section 2.6.6 on aggregation of risk assessments).

This section first provides information on available and missing FRAs throughout BC, building on the FRA assessment from Section 5.2 above, next, aggregation of local FRAs is discussed, and lastly, Class D (high-level) cost estimates are provided for the development of a provincial FRA using the bottom-up approach.

5.3.1 Current Availability of Local Flood Risk Assessments in BC

The analysis of available FRAs in BC revealed that 27 local/quantitative FRAs have been identified (Section 5.2). While some further FRAs may exist, which were not identified as part of the publicly funded projects, the total number of local and quantitative FRAs will still be relatively low. Note that local/qualitative FRAs are not considered to inform a provincial FRA, as these FRAs were typically done as a small component of a flood hazard study, and do not provide enough in-depth information on flood risk.

Throughout BC, there are 162 municipalities[25] and 209 First Nations[25], thus, a total of 371 local jurisdictions. In addition, there are another approximately 889 unincorporated settlements, which are typically administered under the jurisdiction of a regional district. However, not all these local jurisdictions are near the coast or a watercourse. For a very high-level estimate of the number of jurisdictions potentially within a flood hazard zone, provincial coastline and watercourse layers (using only named rivers) were buffered by 200 m. If the extents of a local jurisdiction intersected with the buffer, it was counted as potentially being within a flood hazard zone. It should be noted that this is a very rough estimate, as the only a small area of a jurisdiction extent may be within the 200 m buffer, the settlement area of the municipality or First Nation may not be within the flood hazard zone, and further, obviously, many other factors such as topography, climate, and watershed characteristics influence flood hazard extents. However, within the scope of this study, it was not possible to assess the flood hazard in more detail. Results of this analysis showed that a total of 349 local jurisdictions (160 municipalities and 189 First Nations) are within 200 m of the coast or a watercourse, and thus, potentially at risk of flooding.

Given that so far, to the authors' knowledge, 27 local/quantitative FRAs have been conducted (8% of all local jurisdictions nearby a potential flood hazard), 322 more local/quantitative FRAs would be needed. These estimates will likely be slightly lower in reality, as some further FRAs might be available, which were not identified in this study, and some local jurisdictions might not be exposed to flood hazards (considering the authors' rough estimate). It might also be possible to conduct local and quantitative FRAs for several smaller and nearby communities within one study. Further, potentially, to gain a picture of provincial risk, representative communities for an area could be also leveraged as a first step to achieve a sense of risk for that area.

On the other hand, however, the number of communities above does not yet include the unincorporated settlements under the jurisdiction of a regional district. These would however likely be assessed within a regional FRA led by the regional district.

5.3.2 Bottom-up Approach – Proposed Method

Although, not promising, given the current state of FRA availability (see above), a proposed method is provided below that would support this bottom-up approach going forward. Three overarching steps are proposed to support a consistent and comprehensive FRA for the province.

5.3.2.1 Develop Consistent Minimum Standard for Flood Risk Assessments

If the goal of a provincial flood risk assessment is for prioritization and allocation of funding, risk assessments have to be aggregated. However, this is not a straight-forward process. One of the challenges of aggregating local FRAs is the large diversity in risk assessment approaches that have been applied to date. For instance, the existing FRA studies use different scoring systems, indicators, and data proxies, as well as different underlying hazard information (the different approaches are discussed in more detail in Section 7.2). Given that only a small percentage of local communities have so far conducted FRAs, this

[25] Civic Info BC: https://www.civicinfo.bc.ca/municipalities; accessed on 2020-04-27.

could be remedied for future FRAs, once federal risk assessment guidelines (and potentially, provincial counterparts) become available, and a standardized component is included in each FRA.

A local FRA would ideally go beyond the standardized component to capture local values, but the standardized component could be scaled to provincial level. However, even with inclusion of a standardized component, there will likely still be many variations in local FRA approaches, as different consulting firms typically approach risk assessments differently. Furthermore, it would take a relatively long time to complete FRAs for all at-risk communities in BC, and the province-wide FRA should ideally be available soon, to allow risk-based prioritization of flood mitigation funds.

The risk for a location is typically described by risk scores. This allows for aggregation and comparison of risk assessments across a province or country. Risk scores are calculated as the product of consequence scores and likelihood scores. These scores are assigned based on a set of pre-determined rules, where for instance different AEP scenarios are associated with a likelihood score, and ranges of different consequences (e.g., number of affected people from 100 to 1,000) associated with a specific consequence score.

Currently, no consistent framework for likelihood and consequence scoring exists across BC or Canada, which might change with the development of the NRCan Federal Flood Risk Assessment Guidelines. In the absence of such a framework for scoring and consistent approaches used for the FRA, resulting risk scores will strongly depend on the method that has been applied in a specific study.

One way that risk assessments are currently aggregated and prioritized across Canada is through the National Risk and Resilience Aggregation Tool (NARRA), which pulls in information from the Risk Assessment Information Template (RAIT), which was part of the NDMP funding program requirements. A 2017 review of this tool found that the RAIT and NARRA was not an effective means to support a national understanding of flood risk in part because of flaws within the RAIT (e.g. not aligning with best practice with regards to indicators of risk, inconsistent scoring methods, etc.), but also because aggregation itself posed a challenge (Stantec Consulting Ltd. and Ebbwater Consulting Inc., 2017). As part of the 2017 review, likelihood and consequence scoring rules were suggested, however, they have not yet been implemented.

Another aggregation challenge is that relative risk is variable. For example, if using only absolute measures of risk (e.g., likelihood of the loss of one life), then risk will be perceived to be greater in large urban centres; whereas, arguably the loss of one life or one structure in a remote and isolated community is likely to have a larger effect than in a large populated centre. In the case of the proposed NARRA update, this was addressed through the use of regional scaling (e.g., % loss of regional gross domestic product (GDP) attributed to flood). This approach however also has its challenges, as a 'regional' scale must be pre-defined, and the selection of the geographic scale will implicitly affect outcomes. Simply, aggregation of risk information is extremely challenging. This is further supported by anecdotal data from the North Shore Resilience Strategy, where an all-hazards risk assessment of three north shore municipalities was attempted. Even in the case where the communities were relatively consistent (in land use, development, government resourcing), this proved to be a difficult task.

Therefore, if the purpose of a local FRA is to inform on provincial risk priorities, consistent risk scoring rules should be applied across all local FRAs, with scoring rules (including approach to relative/absolute risk) developed by the Province (potentially in alignment with federal guidelines but recognizing the need to reflect BC-specific issues).

As local FRAs should also reflect what is locally important to a community – and this might differ widely between different regions and communities, between urban and rural centres, between coastal and interior towns with different dominant flood hazards, between municipalities and First Nations with different priorities. Thus, ideally, the provincial scoring rules would be applied at an overarching level to provide input for province-wide risk-based prioritization, but local context and priorities would be preserved within the local FRA and inform risk management at the local level.

5.3.2.2 Conduct local/quantitative FRAs

Next, the local/quantitative FRAs would need to be conducted for all communities with flood hazard, which currently do not have a local/quantitative FRA available. Recommended methods for local comprehensive FRAs are provided in Section 7.

The authors note here that the FRAs would need to be conducted after the flood hazard mapping has been completed. However, it is **recommended that flood hazard mapping is conducted as a separate project from the flood risk assessment**, as the focus of flood hazard mapping is quite different (e.g., provide information for establishing flood construction levels), and in the authors' review of projects that contained both flood hazard mapping and risk assessment within one project, the flood risk assessment was typically conducted as a qualitative, add-on component, and did not have the appropriate depth (see most studies under category 2 – local/qualitative studies in Section 5.2.3). However, flood hazard mapping should be conducted in a way that flood risk assessments can be conducted in a straight-forward, and best-practice way. **This requires that flood hazard mapping provides flood extents and depths for multiple likelihood (ideally 5 or more scenarios for a local/quantitative FRA), ideally includes climate change scenarios, and that hazard data is provided well-accessible and well-documented.**

5.3.2.3 Aggregation

Next, all the reports of the existing (local/quantitative) FRAs would need to be collected (which may be difficult based on similar experience collecting reports for this project and for the National Flood Hazard Data Layer project (Ebbwater Consulting Inc., 2020), and relevant information teased out. This might be challenging for local quantitative FRAs that were conducted before the development of a provincial risk scoring method (see 5.3.2.1), and thus, will likely involve some extra analysis for studies where information is only available in a format different to what is needed for the defined approach on risk scoring. The information from all the local FRAs (existing and newly completed) would then need to be aggregated from a province-wide perspective, prior to prioritization with consideration of regional differences.

5.3.3 Class D Cost and Capacity Estimates

Class D cost estimates[26] are provided here for the bottom-up approach, i.e., conducting and aggregating local FRAs for a province-wide perspective of risk.

5.3.3.1 Develop Consistent Minimum Standard for Flood Risk Assessments

First, a standards/best practice approach would need to be developed on risk scoring for a province-wide FRA, including appropriate engagement of decision makers (cost estimate ~$250,000). The cost estimate assumes that the work is contracted but includes some provincial staff time to manage. The expected scope of work assumes that the National guideline is an appropriate base for a provincial guideline document, but that locally relevant information is considered and included. It is assumed that this guidance document would be developed in consultation with several risk assessment practitioners to ensure that a diversity of voices and approaches are considered.

5.3.3.2 Conduct local/quantitative FRAs

Next, additional local, quantitative FRAs would need to be conducted for all communities, which are at potential risk from flooding and currently do not have a flood risk assessment available. Based on rough estimates (see Section 5.3.1), approximately 322 more local/quantitative FRAs would need to be conducted. Based on budget analysis of existing local/quantitative FRAs (Section 5.2.4), the existing FRAs typically fall into three budget/detail categories (Table 17). Therefore, **the cost estimate for this task includes a wide range, from 16.1M$ – 32.2M$ for high-level FRAs, to 48.3 M$ - 64.4 M$ for comprehensive FRAs**. Further, the cost estimate depends on the number of FRAs to be conducted; the number might be reduced if several smaller communities are combined in one FRA. For efficiency, it is worthwhile to consider that if one is going through the effort of conducting local FRAs, ideally, these FRAs would be conducted at a comprehensive level, to provide most insight for the communities (this will increase costs). Further FRAs would need to be conducted for the 889 unincorporated settlements, however, these FRA would likely be bundled within a regional district.

It should be noted that t**he cost estimates assume that flood hazard data is available**, and no additional flood hazard mapping is required as part of the flood risk assessment. Cost for flood hazard assessment are provided by the B-2: Flood Hazard Information Report (Northwest Hydraulic Consultants Ltd., 2021a). Further, the authors note that the estimates have been made based on historical efforts, and with standards in place, and ideally readily accessible datasets (see Section 4), there may be efficiencies and therefore cost reductions overtime.

[26] A class D estimate (± 50%) is a "preliminary estimate which, due to little or no site information, indicates the approximate magnitude of cost of the proposed project, based on the client's broad requirements. This overall cost estimate may be derived from lump sum or unit costs for a similar project. It may be used in developing long term capital plans and for preliminary discussion of proposed capital projects." (EGBC, 2009).

Table 17: Budget range for different detail of local, quantitative FRAs.

Detail level / Area	Description	Budget per Study ($)
High-level / small area	FRA conducted at high-level with likely only older/screening-level flood hazard data availability, and limited calculation of vulnerability. Alternatively, it could also cover a more detailed FRA, but only for a very small area (e.g., one industrial park).	$50,000 - $100,000
Moderate-level / local community	FRA conducted at moderate level, including several indicators and available hazard data.	$100,000 - $150,000
Comprehensive/local community	Comprehensive FRA conducted for a local community, including multiple indicators, stakeholder and public engagement workshops, and vulnerability assessments, for multiple (high-quality) flood hazard scenarios. (Note – more budget would be required if a detailed FRA is conducted for a larger area than a local community)	$150,000 - $200,000

To set these numbers into context, so far approximately 3 M$ have been spent on local/quantitative FRAs throughout BC (see Section 5.2.4). This is in contrast to the estimated 17 B$ to 156 B$ in total building assets in defended flood prone areas[27] alone. Simply, relatively little investment has been made to understand a very significant risk.

5.3.3.3 Aggregation & Prioritization

A class D cost estimate for aggregation and prioritisation is about $150,000 to $200,000, based on previous experience of similar studies (e.g. BC's Orphaned Flood Protection Structures Risk Assessment). This estimate assumes that previous recommendations have been followed and that a minimum standard has been applied to all completed risk assessments.

5.3.3.4 Class D Cost Estimates - Total

Assuming that 322 additional local FRAs would need to be conducted, the Class D cost estimate for a bottom-up approach towards a province-wide perspective of flood risk could range from 16.35 M$ (for

[27] This was estimated based on the Risk Assessment for BC's Orphaned Flood Protection Structures (KWL and Ebbwater Consulting Inc, 2020), where a total of 1,940 M$ of building value was found to be exposed to flooding due to orphaned protection structure failure. Based on the total length of orphaned structures and of non-orphaned flood protection structures in BC, the approximate exposure value for all defended flood areas was estimated, where also a multiplier (10) was applied to the estimate for the non-orphaned structures, as it was assumed that these are likely protecting higher consequence assets than the orphaned structures.

high-level FRAs) to 64.75 M$ (for comprehensive FRAs). This cost estimate range is further broken down in Table 18 and depends largely on the type of FRA which is anticipated (high-level, moderate-level or comprehensive), as well as the number of communities which would need a local FRA conducted.

It should be noted that these cost estimates are only preliminary Class D cost estimates and should be considered with caution. Further refinement of these estimates can be discussed with the FBC/the Province, and potentially, professional costing experts.

Table 18: Class D cost estimate for a bottom-up approach for a province-wide FRA.

No.	Task	Class D cost estimate range	
1	**Develop Minimum Standard**	$100,000	$250,000
2	**Conduct local FRAs (322 FRAs)**		
	High-level FRAs ($50,000 - $100,000 per FRA)	$16,100,000	$32,200,000
	Moderate-level FRAs ($100,000 - $150,000 per FRA)	$32,200,000	$48,300,000
	Comprehensive FRAs ($150,000 - $200,000 per FRA)	$48,300,000	$64,400,000
3	**Aggregation and Risk Prioritization of FRAs**	$150,000	$200,000
	Total		
	(High-level FRAs)	$16,350,000	$32,650,000
	(Moderate-level FRAs)	$32,450,000	$48,750,000
	(Comprehensive FRAs)	$48,550,000	$64,850,000

5.3.3.5 Capacity Estimates

A capacity estimate is provided here, based on the approximate number of local areas that don't currently have risk assessments and estimated current professional capacity levels in BC. These capacities might increase in the future, as more and more individuals and companies acquire knowledge on flood risk assessments, thus decreasing the time estimate. Assuming 322 local/comprehensive FRAs, which each would take 12 months to conduct, and assuming that there are 10 different consultants in BC who could conduct such FRAs (this estimate is high, but further capacity development is assumed), which could each work on approximately 3 FRAs simultaneously, it would take more than 10 years to conduct all local comprehensive FRAs, plus another year for the aggregation and prioritization study. A range of different time lengths and assumptions is provided in Table 19 to indicate the range of time.

As the key input for FRAs is the availability of flood hazard data, prior to the local FRA being conducted, local flood hazard assessments have to be conducted, which will take further time.

Table 19: Capacity and time estimate for conducting local/comprehensive FRAs.

FRAs (#)	Time period for 1 FRA (Month)	Consultants with FRA expertise (#)	Simultaneous FRAs per consultant (#)	Concurrent FRAs (#)	Total month to conduct FRAs (months)	Total years to conduct all FRAs
322	12	10	3	30	129	**10.7**

322	6	10	3	30	64	5.4
322	9	10	3	30	97	8.1
322	9	10	4	40	72	6.0

The implications of this process taking more than 10 years is discussed in more detail in Section 5.5, however, it should be noted that this would majorly delay any flood risk prioritization at the provincial level, and delay the implementation of flood risk reduction measures.

Note that the advantages and disadvantages of the bottom-up approach will be discussed in comparison with the top-down approach in Section 5.5.

5.4 Top-down Approach

In a top-down approach, a province-wide FRA would be led by the Province, in contrast to local governments. This would allow for a consistent methodology for hazard, consequence and risk assessment and scoring over the whole province. This could then be used to indicate high-risk areas throughout the province and support prioritization.

In this section, first, currently available regional FRAs and their methodology are reviewed (Section 5.4.1), a top-down method is discussed (Section 5.4.2), followed by Class D cost and capacity estimates (Section 5.4.3). Regional FRAs are typically using a screening-level approach to flood risk assessments, due to the larger area to be covered. Therefore, they can provide insights on methodologies that would be appropriate for a province-wide, screening-level FRA.

5.4.1 Summary of Regional Flood Risk Assessments Methods in BC

A province-wide FRA for prioritization and initial risk identification would be done at a screening-level (similarly to Tier 1 in the preliminary NRCan Flood Risk Assessment guidelines) (see also Section 2.6.2). As discussed in Section 5.2.2, a number of regional studies already exist in BC, covering about 222,000 km^2, or approximately 24% of land area in BC (Figure 22). These studies and the applied methodologies are discussed below in more detail, to evaluate if they can potentially be leveraged to achieve screening-level FRA coverage throughout all of BC, and to consider currently used methods in a recommendation towards a top-down FRA approach.

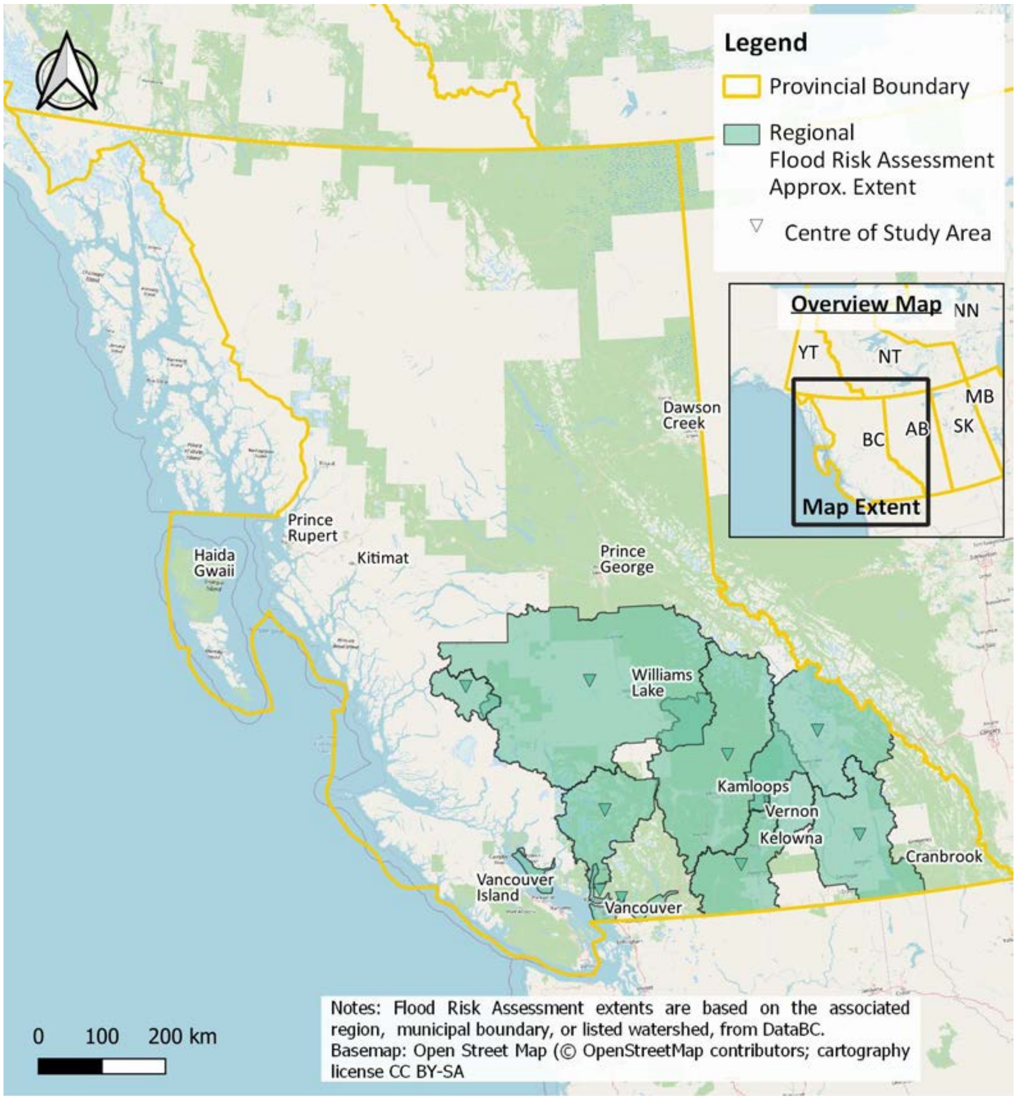


Figure 24: Regional/quantitative FRAs currently available for BC.

Of the 9 identified regional/quantitative FRAs, 5 technical reports were obtained (*Powell River Regional District Overview Coastal Risk Assessment* (Tetra Tech, 2018); *Thompson River Watershed Geohazard Risk Prioritization* (BGC, 2019), *Flood and Steep Creek Geohazard Prioritization Regional District of Central Kootenay* (BGC Engineering Inc., 2019); *Syilx Okanagan Flood and Debris Flow Risk Assessment* (Ebbwater Consulting Inc., 2019c), and the *Flood Risk Assessment for BC's Lower Mainland* (IBI Group and Golder Associates, 2020). The methods applied in these studies are briefly discussed below. Information gained in consultations with practitioners are also included, where relevant. This included consultation with BGC on their regional approach, as well as with IBI Group and FBC on the *Lower Mainland Flood Risk Assessment* (IBI Group and Golder Associates, 2020), approaches taken by Ebbwater for regional studies are also implicitly included. Further, methods used for the *BC Dike Consequence Study* (NHC and Sage on Earth, 2019), the *Risk Assessment for BC's Orphaned Flood Protection Structures* (KWL and Ebbwater Consulting Inc., 2020), and the *Strategic Climate Risk Assessment for British Columbia* (ICF, 2018) were also considered, as they can provide insight on regional FRA approaches. It is important to note however that the BC Climate Risk Assessment used an approach which did not cover and assess all of BC but took a single-scenario case study approach (i.e. only one river system and scenario was considered). This is quite different to the other regional studies, which covered either the entire extents of regional districts, or focused on floodplains and geohazard extents behind flood protection structures throughout all of BC.

Table 20 provides an overview of the hazard input used in the 8 assessed FRAs (from 5 technical reports, plus the 3 additional studies listed above). Most studies considered riverine flood hazards, and some coastal and geohazards (debris flood and debris flow); ice jams and other hazards were not considered. Typically, screening-level hazard data (i.e., flood hazard data which was not based on detailed hydraulic modelling) was used. In some cases, detailed flood hazard data was available as input or calibration for the FRA, but further hazard data needed to be developed for some parts of the study area (e.g., for the Lower Mainland FRA), or in another example, study extents were relatively small (e.g., Powell River) and detailed coastal flood hazard data was developed as part of the study.

Screening-level hazard data was developed as part of the FRA for the Thompson, Central Kootenay and Syilx Okanagan studies, which considered both clear-water floods (riverine) and geohazards. This included a regional flood frequency analysis and base level floodplain mapping (following Federal Emergency Management Agency (FEMA) guidance) and a geomorphic flood mapping approach for clearwater, as well as imagery-based delineation and debris flow modelling for geohazards.

Most FRAs assessed risk solely for a single scenario, while some regional studies (e.g., the Syilx Okanagan study and the Lower Mainland FRA) considered several flow and downstream scenarios. Most studies included the 0.5% AEP scenario (for both riverine flows and coastal storm surge), while for instance the BC Climate Risk Assessment focused on the 0.2% AEP. The Lower Mainland FRA explored several AEP scenarios for riverine and coastal floods and included a dike fragility analysis. Dike fragility was also considered for the Risk Assessment for BC's Orphaned Flood Protection Structure study.

Climate change was dominantly either qualitatively discussed or not included. The only regional FRA, which quantitatively assessed risk for a climate change scenario, was the Powell River study (this was a coastal study, where consideration of sea level rise was mandated). The BC Climate Risk assessment did not apply quantitative scenarios for climate change but estimated potential changes to present-day scenarios.

Table 20: Overview of hazard data input into the regional FRAs, indicating the number of studies.

Hazard type			Hazard Method		Scenarios		Climate Change		
Riverine #	Coastal #	Geo-hazard #	Screening Level #	Detailed #	Single Scn. #	Multiple Scn. #	Not incl. #	Qual. Discussed #	Quant. assessed in FRA #
7	3	4	5	3	5	3	3	4	1

The assessed exposure and consequence indicators varied between the studies (Table 21). All studies included people, financial losses from structural damage to buildings, and critical infrastructure and basic services/lifelines. Some studies delved more into the economic aspects and provided information on business impacts as well. Agricultural exposure was assessed in 6 studies. Most studies also included an environmental indicator, typically focusing on exposed environmentally sensitive areas, and some studies also included information on potential environmental contamination sources and impact to fish habitat. The culture indicator was assessed in limited detail in most studies. Six studies provided information on exposed community buildings, while not many studies considered indigenous cultural sites, nor any other intangibles; cultural inputs were the most robust in the Syilx Okanagan study thanks to strong participation of Syilx community members and elders, and because of the considerable budget ($400k) that enabled additional research into environmental and cultural issues.

For two regional studies (the Lower Mainland FRA and the Syilx Okanagan study), workshops were conducted with the local community to learn about local knowledge and incorporate local values. For the Indigenous-led Syilx Okanagan study, these workshops were enhanced through 3 watershed tours where Elders shared their traditional knowledge and lived experience of the *Syilx* Nation with respect to flooding. For the Syilx Okanagan study, qualitative mapping was also used as part of the workshops to record local knowledge.

Table 21: Consequence indicators considered in regional FRA, indicating the number of studies which considered a specific indicator.

People	Mortality	Economy - Buildings	Economy - Businesses	Agriculture	Critical Infrastructure	Basic Services (Lifelines)	Environment - Sensitive Areas	Environment - Contamination Sources	Environment - Fish	Culture - Community buildings	Culture – Indigenous archaeological Sites	Culture - Intangibles	Workshops & Local Knowledge
8	3	8	4	6	8	8	8	3	3	6	3	2	2

The regional FRAs focused on exposure assessment as a proxy for consequence and did not use depth-damage curves or other vulnerability considerations. The Thompson and Central Kootenay FRAs applied hazard intensity as a proxy for vulnerability (assuming that elements at risk would be more vulnerable to destructive flows). The BC Climate Risk Assessment and the Syilx Okanagan study discussed vulnerabilities qualitatively. The Lower Mainland FRA is the only regional study that conducted a full vulnerability and damage assessment for buildings and infrastructure.

Lastly, likelihood, consequence and risk scoring varied widely between the studies (Table 22), making comparability challenging. One study did not include risk scoring (Powell River) at all, and solely listed exposed assets. The Dike Consequence study only included consequence scoring, but no likelihood and risk scoring (presumably, as all sites were assessed for the same scenario (0.5% AEP), i.e., the same likelihood and the study goal was prioritization and comparability between structures). Three studies used a logarithmic approach to likelihood scoring, where scoring classes are defined by logarithmic intervals between AEPs (e.g., class 1 < 0.01% AEP, class 2 = 0.01% - 0.1% AEP, class 3 = 0.1% - 1% AEP, etc.) (Table 22). The BC Climate Risk Assessment study used a non-logarithmic approach. The orphaned flood protection structure study focused likelihood scoring on dike failure likelihood/dike fragility (instead of hazard likelihood). The Lower Mainland FRA calculated full statistical accounting of risk (the estimated annual damage) for all tangible (monetized) consequences and reported exposure/consequences per hazard scenario for all other intangible consequences (it is therefore not included in Table 22); additional information related to scoring is available in an interactive portal where users can adjust areas of interest and weighting of indicators of risk.

While there was some consistency in likelihood scoring between studies, consequence scoring varied widely. This included differences in which proxies were scored, if a logarithmic or non-logarithmic approach to score classes was applied (which also varied from indicator to indicator for some studies), and if relative or absolute scoring was conducted (e.g., relative to the total number of assets of a local jurisdiction). Lastly, studies varied in how different proxy data was integrated for one indicator (e.g., if different proxies were weighted and added), and if a total risk score was calculated by addition of all indicator risk scores.

Table 22: Overview of likelihood, consequence and risk scoring indicating the number of studies[28].

Likelihood Scoring		Consequence Scoring				Risk Scoring	
Loga-rithmic	Other	Log.	Non-log.	Relative	Absolute	Weigh-ting/ Additive	No weigh-ting
3	2	6	4	2	3	4	2

The advantages/disadvantages of the different regional FRA approaches will be discussed in relation to recommendations for a province-wide FRA in the next section (Section 5.4.2).

5.4.2 Top-down Approach - Methods

In the top-down approach, a province-wide FRA would be led by the Province, in contrast to local or regional governments. Due to the effort involved in conducting such a large-scale FRA, the authors

[28] Logarithmic scoring describes scoring classes which increase in logarithmic steps (i.e., by one order of magnitude) from one class to the next, while non-logarithmic classes may use different intervals. Relative consequence scoring describes the normalization of exposure/consequences to the study area of interest (e.g., number of affected people relative to number of all people in study area/regional district. In contrast, absolute consequence scoring refers to e.g., the total number of affected people, without normalizing it. Weighting of risk scoring involves the addition of individual risk scores for different indicators (e.g., for affected people and economy) to one final risk score, while no weighting reports risk scores for each indicator category without addition.

recommend conducting this province-wide FRA at a screening-level. In the following method recommendations, the authors draw on the regional FRA methods discussed for BC in the previous section, as well as national/international best practice. It should be noted however, that these recommendations are not intended to be a detailed guideline on regional/screening-level FRAs but indicate important aspects and trade-offs which should be considered in the methods approach. Upcoming guidelines, such as the NRCan Flood Risk Assessment guideline (which was not yet available at time of this project), will provide more detail on a screening-level FRA.

In general, a flood risk assessment has several steps (Stantec Consulting Ltd. and Ebbwater Consulting Inc., 2017; UNDRR, 2017). First, the consequences are determined, based on hazard characteristics, exposure and vulnerability. Next, the likelihood of the hazard event to occur is determined, and risk is calculated as the product of consequence and likelihood.

5.4.2.1 Consequences

Hazard Extents

Coastal and riverine clearwater floods as well as geohazards (debris flood and debris flow) should ideally be considered in the province-wide FRA, in line with what has been done for most of the regional FRAs to date. The authors of this report note here that the authors of the B-2 report (Northwest Hydraulic Consultants Ltd., 2021a) disagree that that high-level flood mapping should be conducted, and that all mapping should be done to a high technical standard. However, given that at this time we are years and millions of dollars away from having high quality mapping available across the province, and recognising that even with guidelines in place, there will be consistency challenges, the authors strongly believe that there is a place for consistent, comprehensive high-level flood mapping to support risk assessment and other prioritisation activities.

Note that consequences and risk should be assessed separately for each natural hazard (e.g., riverine flooding, coastal flooding, or debris flows), as hazard characteristics (and associated consequences) are drivers (see Section 2.3). Learning from the completed regional FRAs, a screening-level approach to hazard mapping is appropriate for the province-wide FRA. Further, one of the outcomes of a province-wide FRA is to allow further prioritization, and for instance, determine areas of high risk, where detailed flood hazard mapping is needed. The screening-level hazard extents should however be evaluated by comparison to detailed (hydraulic/hydrodynamic) hazard mapping, where it exists, to assess its accuracy.

Here, three potential methods for a screening-level clearwater flood hazard assessment are briefly identified, and the B-2 Flood Hazard Information issue briefly discussions screening-level flood hazard (Section 2.5.2).

1) **Base level engineering approach** (riverine floods): This approach has been chosen for the Thompson and Central Kootenay FRAs. It is based on an approach from the U.S., where however base flood hazard data is available across the country (FEMA, 2020), in contrast to Canada. For analysis in Canada, it typically involves (regional) frequency analysis of available Water Survey Canada stations, water elevation estimates based on representative cross-sections and 1D

hydraulic modelling, and triangulation to estimate flood extents. While it allows to report flood extents for different AEPs, it involves substantial analysis, and has some uncertainties in how water levels are related to actual flood extents. BGC has used this approach in all their studies, and have a comprehensive and consistent dataset for much of the province. However, it is been calibrated on the assumption that the whole province has a homogeneous hydroclimate. If this approach were to be adopted, research and refinement of approach would absolutely be required.

2) **Geomorphic Approach** (riverine floods): This approach has been chosen for the Syilx-Okanagan study, and is also used by some national data layers used primarily by the insurance industry. In a geomorphic analysis, the underlying assumption is that the geomorphic (topographic) features of a landscape can be indicative of flood prone areas. The approach allows a consistent assessment of potentially flood prone areas, and if using a tool such as the QGIS plugin Geomorphic Flood Area (GFA) tool, it can be calibrated to hydraulic flood maps of different AEPs. This approach has been successfully applied for several regions, but does require that there is data available for calibration (e.g. detailed hydraulic mapping), and requires additional effort over and above the more simple base level engineering approach. However, it does result in appropriately robust results. This is the recommended approach at this time.
3) **Use existing datasets.** There are many existing international datasets that are used to support the insurance and re-insurance industries (e.g. JBA, Fathom, etc.). As part of this project, the authors contacted JBA Risk Management, who have a Canada-wide flood map, primarily targeted at the insurance industry. It provides undefended riverine, coastal (storm surge) and pluvial flood data for seven AEP scenarios, based on terrain data, hydrological modelling, and inundation mapping. While it is also a screening-level approach, flood hazard data is already available for BC, and could potentially be purchased with a license agreement. Ebbwater reached out to JBA for consultation and obtained flood data for four sample locations in BC. A preliminary evaluation of this data in comparison to hydraulic flood maps indicated however that at least for the four investigated locations, the results were overall not reliable enough; in particular coastal flood hazard mapping showed challenges. Therefore, at this point, the authors do not recommend using JBA screening-level flood maps for BC. However, the authors note a similar exercise conducted in Ontario, where higher quality topography is publicly available (e.g. LiDAR), and the quality of data is excellent. Further, JBA is also regularly updating and improving their flood maps, and it should be assessed again in the future, if the data can be used for a screening-level flood risk assessment. It is particularly interesting for input into an FRA that flood extents and depths are produced for 7 different AEPs, although climate change is not included[29]. Details on the evaluation are in Appendix A.

It is recommended that a minimum of three hazard scenarios would be considered, with a likelihood ranging from almost certain/likely (something that has been experienced by a community within a lifetime, such as 20%, 10% or 5% AEP) to unlikely (typically, the 0.5% AEP has been used in most regional FRAs to date) to rare (this could be 0.2% AEP or lower). While a full statistical accounting of risk assessment

[29] This approach of using multiple flow or AEP scenarios to manage shifts related to climate change is widely used. For example, this the approach currently adopted by the Government of Alberta.

is often not possible within the frame of a regional FRA, the range of hazard scenarios can provide information on the cumulative impacts of frequent but small flood events and rare but high magnitude events (see also Section 2.5.4). These hazard scenarios would be consistently applied throughout the province to ensure comparability.

Lastly, climate change should also be considered. For coastal areas, the consideration of sea level rise is relatively straight-forward (as was for instance done for the Powell River study). For riverine floodplains however, the consideration of climate change is more challenging, and a consistent approach throughout the province is warranted. More details on the application of climate change for flood hazard mapping are provided in Issue B-1: Climate Change (Associated Engineering Ltd., 2021). Along with the climate, however, exposure and vulnerability can also change (dynamic risk), resulting in a multitude of possible scenarios (see also Section 2.2.2). Therefore, careful trade-offs between additional scenarios and the additional costs and time to conduct these must be considered. The consideration of climate change however, with assumption of business-as-usual for exposure and vulnerability, is an essential first step, and the authors strongly believe that at least one climate change scenario should be included in a province-wide FRA, especially, if the goal is to use the FRA for prioritization and long-term planning. For instance, if sea level rise is not considered, some communities may not appear to be at risk, and poor decisions may result.

Exposure

Exposure indicator and data proxies are discussed in more detail in Section 4. While the trade-off between extra work and addition of extra datasets should be carefully weighed, the authors believe that a screening-level province-wide FRA should address a wide range of holistic indicators, to capture the full spectrum of possible consequences to flood hazards. These indicators could include the following (see Section 2.5.5 for background on national/international best practice on indicator selection): People, Mortality/loss of life, Economy, Critical Infrastructure Facilities and Basic/Critical Services), Environment, and Culture. It is important to consider a wide range of indicators, as different aspects may be important to different regions or groups. Different exposure datasets are discussed in Section 4. Important for a province-wide assessment is consistency in data across the province, i.e., only province-wide datasets can be used.

Vulnerability

For a province-wide FRA, the data necessary to quantitatively assess vulnerability will likely not be available consistently throughout the study region. For instance, flood depth data as well as more detailed building inventory data would be needed to understand the vulnerability and associated damages to the building stock. A province-wide dataset for socio-economic vulnerability based on census data is currently developed by NRCan, which could potentially be used to provide additional information (see also Section 4.3.3.1).

It should also be noted that within the Province, there is also a push to apply a Gender-Based Analysis Plus (GBA+) framework to risk assessments, which would include reporting on more details within the demographic data (e.g., segregation by age, gender, income, etc.), some more information on this is provided in the recently completed *BC Climate Risk Assessment Framework Customization Recommendations* (ICF Consulting Canada Inc, 2020). Thus, in a province-wide FRA, there is an opportunity to characterize the types of vulnerable populations in different regions, based on demographic information for people within the flood hazard extents. This analysis can then support planning and policy.

Consequences

For a province-wide FRA, likely, exposure will need to be used as a proxy for consequence, as consistent vulnerability and hazard severity (e.g., flood depth) data will not be available across the province. A consistent approach for consequence scoring will need to be applied, to ensure aggregation of results across the province is consistent (see also Section 5.3.2.1).

As noted in Section 2.5.2, spatial scale for analysis is an important consideration. When consequence, and ultimately risk scoring is conducted, these results must be summarized over a specific area (for local/quantitative FRAs, this is typically done for the entire municipality) that defines the 'spatial unit'. Some options for spatial scale include:

- for each hazard extent (which may however differ in size, and further, the hazard extent of one river system could be very large),
- for each local government and First Nation reserve lands (this however does not include unincorporated communities),
- regional districts (this scale would not provide enough local detail),
- for (sub-)watersheds, for First Nation traditional territories,
- or using a pre-set grid system, which would cover BC in a consistent way (which would however not consider jurisdictional boundaries).

The selection of the spatial area for scoring will have substantial impacts on how hazard likelihood, consequence and ultimately risk are scored and compared across the province. The spatial scale needs to be fine enough to identify the risk for individual communities (so that in case of high risk, the community can be prioritized for more detailed analysis and flood risk reduction measures). On the other hand, it also needs to be large enough, so that the province-wide picture is visible. One potential option could be focus on the community level first (municipalities, First Nation reserve lands), and then also aggregate the information at a larger spatial scale (e.g., watersheds or regional districts).

With respect to scoring, it has also to be ensured that results are reflective of, for instance, population dynamics across the province. Relative scoring ensures that the population centres of Southern BC do not 'outrank' more rural communities in other parts of BC. Relative scoring considers for instance the number of affected people in comparison to all people within a jurisdiction, in contrast to absolute scoring, which considers solely the total number of affected people. In practice, it can be challenging to define the unit to which the exposed assets should be compared to (local jurisdiction, regional district, a grid unit, etc.), and to apply consistent logarithmic scoring scales (as differences between logarithmic classes increase rapidly). Again, a consistent approach needs to be applied throughout the province.

Lastly, the integration of different data proxies to one indicator (e.g., where weights are assigned to different types of economic consequences to one 'economy' score) needs to be approached carefully, and if used, should only be conducted in discussion and with feedback from stakeholders and decision makers, or be applied consistently throughout the province (at least in the first instance). Otherwise, it involves subjective judgement by the contractor (e.g., how important are buildings in comparison to businesses in comparison to agriculture?). For a provincial FRA, such decisions could potentially be made at the provincial level for setting priority levels. However, it is still recommended to present results for individual data proxies separately, and also ideally, discuss different priorities with different regions (see Section 5.4.2.4 on workshops). If priorities differ widely between regions, it could be considered to use different weighing in different regions. One option can also be to present results in an interactive online tool, where decision makers can change weighting of different data proxies, or indicators, based on their priorities and values, and observe the changing picture of risk. This was done as part of the LMFRA, where an interactive FRA portal was created.

5.4.2.2 Likelihood

A hazard likelihood is connected to each of the selected hazard scenarios. To calculate a risk score as the product of consequence and likelihood score, a score must be assigned to each hazard scenario. As discussed for consequence scoring, most best practice documents (e.g., AIDR, 2015; UNDRR, 2017) suggest using a logarithmic scale, as it best represents the statistics related to extreme events. In a logarithmic scale, scoring classes are defined by logarithmic intervals between AEPs (e.g., class 1 < 0.01% AEP, class 2 = 0.01% - 0.1% AEP, class 3 = 0.1% - 1% AEP, etc.). From the assessed regional FRAs, 3 FRAs used a logarithmic approach to likelihood scoring (Table 22).

5.4.2.3 Risk

For a provincial FRA, aggregation via a scoring approach is appropriate, as likely, not enough hazard likelihoods are available to conduct a full statistical accounting approach (i.e., to calculate the average annual loss, see Section 7.3 for details on this approach). Risk scores for each indicator are calculated by combining the consequence score with the likelihood score. It is recommended that no total risk score is calculated as the sum of the risk scores for individual indicators, as this involves weighing of indicators (e.g., how do people count versus the economy versus the environment?). It is essential that consistent likelihood, consequence, and risk scoring approaches are applied across the province, as only this will allow comparability and prioritization. Lastly, it is recommended that risk is spatially visualized by producing risk maps that indicate risk for different indicators across the province and zoomed-in to regional districts or MFLNRORD regions.

5.4.2.4 Intangible Consequences and Workshops

It is challenging to include intangible and indirect consequences in assessments; however methods do exist to provide some context. For example, several FRAs conducted within the province (e.g. City of Dawson Creek, District of Tofino, Syilx Okanagan, Reginal District of Kootenay Boundary) used workshops (both in-person and online) to elicit intangible values of concern. Some of these were mapped, others were scored.

While a provincial FRA provides an overview of the entire province, regional differences and priorities should still be considered. For instance, different priorities may exist between rural and urban centres, between Southern and Northern BC, between the coast and the interior, between Indigenous and non-Indigenous communities. Workshops conducted in different regions (e.g., at a minimum, for each regional district) could inform on these priorities and ensure that the risk assessment results capture the variability across the province (e.g., with reference to risk scoring, or which indicators and data proxies are selected). Potentially, if substantial differences between regions exist, results could be displayed in a) a province-wide consistent manner (where priorities are determined at the provincial level) and b) reflecting different values for each region, based on information obtained in workshops.

What is measured, matters, and workshops can inform on what indicators and proxies should be measured. They can also inform on the more intangible consequences, which cannot be summarized in a data proxy, but are nonetheless important. These intangible consequences can be reported via qualitative risk mapping approaches.

5.4.2.5 Indigenous Inclusion

Limited information on Indigenous Inclusion for risk assessment was collected through the FBC survey. However, a few learnings from Ebbwater's experience co-developing flood risk assessments with First Nations is noted below:

- Better outcomes have occurred when the projects were co-lead and directed by Indigenous Peoples.
- Earnest effort on the part of non-Indigenous participants and consultants is important; general principles of reconciliation should be applied.
- Projects take significant time and budget resources to support a period of trust-building.
- It is key to acknowledge that some data (e.g. sensitive archeological sites) will not and should not be published or publicised. Careful data sharing agreements must be developed.

5.4.2.6 Confidence Rating

Lastly, ideally, confidence ratings should be assigned to both hazard and exposure/consequence data, and a combined confidence rating should be calculated for each indicator (e.g., following the approach in AIDR, 2015). The consequence confidence rating describes how well the proxy data can capture the consequences associated with an indicator. The hazard confidence describes the quality of the hazard data. A risk confidence is then calculated as the combination of these two confidence ratings (e.g., as shown in Table 23, based on AIDR, 2015). A confidence rating is particularly important for a province-wide FRA, where data quality might be low for the more indirect and intangible consequences. The AIDR also provides an example of measures to score confidence ratings.

Table 23: Risk confidence rating, as combination of consequence confidence rating and likelihood confidence rating (from AIDR 2015).

	Consequence Confidence Rating				
	Very low	Low	Moderate	High	Very high

Delineation Confidence Rating	**Very high**	Moderate	Moderate	High	Very high	Very high
	High	Moderate	Moderate	Moderate	High	Very high
	Moderate	Low	Moderate	Moderate	Moderate	High
	Low	Very low	Low	Moderate	Moderate	Moderate
	Very low	Very low	Very low	Low	Moderate	Moderate

5.4.2.7 Leveraging of Existing Studies

The results of existing regional FRAs could be leveraged towards a provincial FRA. However, similar challenges exist here, as discussed for aggregation of local FRAs, as different methods have been used for risk analysis and, for risk scoring. A potential approach could be to use quantitative exposure results (e.g., number of affected people, number of critical infrastructure facilities) from these studies, and apply a consistent scoring approach. However, studies also did not include the same indicators. For instance, the Cambio Communities approach applied in the Thompson and Central Kootenay studies did not include any cultural indicators or intangible concepts and the Syilx Okanagan study did not include business activity. There are also differences in the underlying hazard data approach. Therefore, while some information from existing regional FRAs could potentially be leveraged, additional work would be necessary.

5.4.2.8 Challenges and advantages of a top-down province-wide FRA

While a province-wide FRA could provide a consistent picture of risk that would support many decisions in support of disaster risk reduction, it is not without obstacles. One major challenge is the availability of consistent and robust underlying flood hazard maps, which should cover the entire area consistently. The detailed hydraulic mapping typically done by local jurisdictions cannot be used as it does not cover the whole province (non-comprehensive, albeit generally consistent); even if only the larger population centres of the province was analysed in the first instance, the existing flood mapping is not adequate. In contrast, a province-wide FRA should provide information on all areas, including rural settlements and potentially unpopulated areas, which nevertheless may have assets that are exposed to flooding (for instance Indigenous cultural sites).

Similarly, another challenge is the availability of consistent and robust datasets across the province which, if available, need to be quality-controlled, processed, and analyzed. The efforts for this should not be underestimated (in most FRAs, data collection and processing is the largest, or second largest effort, see also Section 4). A province-wide assessment would limit the inclusion of intangible or qualitative information simply because of the size of the province; this may limit buy-in from some communities. Further, different priorities from region to region would necessarily be ignored in the battle to develop a consistent picture across the province.

Despite the above challenges and limitations, there is absolutely value in the development of a top-down FRA to support prioritisation of all flood activities in the province.

5.4.3 Class D Cost and Capacity Estimate

Class D cost estimates are provided here for the top-down approach to conduct a province-wide FRA.

5.4.3.1 Develop refined method for province-wide FRA (incl. hazard analysis approach, exposure, risk scoring)

As a first step for a province-wide FRA, a refined methods approach should be developed. Preliminary method recommendations are provided in Section 5.4.2. This method recommendation should be refined, ideally engaging stakeholders and First Nations. The approximate class D cost estimates for this methods development would be between $100,000 (basic) and $200,000 (with engagement).

5.4.3.2 Conduct the province-wide FRA

Cost estimates for conducting a province-wide FRA were based on regional FRAs. Total budget per regional FRA ranged from ~$70,000 (for the small qathet (formerly Powell River) RD, $150,00 for the Cariboo RD, $500,000 to $600,000 for most others, $645,000 for the Thompson River RD, to $725,000 for the Lower Mainland (noting that these are the budgets reported in the NDMP funding list, and actual budget available to conduct the analysis may vary). The average budget per project was $450,000. The approximate (reported) budget per area for a regional FRA ranged between 2 $/km^2 to 238 $/km^2, with an average of 55 $/km^2. If the Lower Mainland FRA is excluded as it was a more in-depth study than most other regional FRA), the average budget per area was 32 $/km^2. It is unlikely or even beneficial that a provincial FRA could be done to the level of the Lower Mainland FRA. For a province-wide FRA, the screening-level approach of other regional FRAs is therefore considered appropriate. It should be noted that these average costs included hazard analysis.

If using the average cost per area for a regional FRA (32 $/km^2) and extending this to total landmass of BC, the average cost would be 30 M$. These costs would include a high-level hazard analysis as the projects used as the basis of this estimates also included hazard mapping. However, these costs can likely be reduced, as a) not all of BC's landmass is exposed to flood hazards, b) efforts can likely be leveraged if the study is conducted for a large area, instead of multiple smaller studies, and c) many areas may be excluded as they are not populated. However, even in unpopulated areas, other activities such as natural resource extraction may be a concern, both for impacts to the economy in case of flooding, and as potential contamination sources if damaged during a flood. Further, agricultural lands or Indigenous cultural sites might also be exposed to flooding in unpopulated areas.

Another way to estimate total costs would be to base the cost estimate on the total cost per RD (average cost $450,000; lower end of costs $150,000 (discounting the very small qahet RD, which is not representative of most other RDs). With 28 RDs in BC, the total costs would be $12.6M, or $4.2 M (based on $450,000 and $150,000 per RD, respectively). Note that all these estimates assume the use of existing datasets as opposed to a future flood exposure specific dataset as described earlier.

It is likely that many efficiencies can be achieved for a provincial FRA (e.g., provincial exposure data would only need to be processed once, for the entire province), the lower end of the cost estimate ($4.2M) seems more reasonable. This estimate considers the use of workshops to gather some data at a regional district scale. Based on experience, gathering and processing data from one workshop costs an estimated $40,000; for 28 RDs, this would result in $1.12M, considering one workshop per RD. If several workshops were to be conducted (for instance, separate workshops for First Nations and other stakeholders), these engagement costs would increase, e.g. to $2.24M for two workshops per RD. It is possible that costs could be reduced through the use of online surveys or tools. However, the authors note that there are many intangible benefits (such as trust-building) associated with deep and meaningful engagement processes.

Potentially, work done for existing regional FRAs can also be leveraged to reduce the costs.

5.4.3.3 Aggregation and Prioritization Analysis

Lastly, a province wide assessment would need to be analyzed for prioritization recommendations and highlight different areas of concern. These costs are estimated around $100,000 to $200,000.

5.4.3.4 Class D Cost Estimates – Total

Based on the above analysis, the lower end of the cost estimate is around $4.45M. This could potentially be further reduced through efficiencies, and detailed methods planning as part of task 1 (i.e., investment in task 1 will likely pay out in much reduced costs for a provincial FRA). The reduction in costs through well-designed planning (such as, via task 1) and efficient analysis (and keeping in mind that it will be a screening-level analysis) could be 50-75%.

Table 24: Class D cost estimate for a top-down approach for a province-wide FRA.

No.	Task	Class D cost estimate range	
1	**Develop refined method for province-wide FRA (incl. hazard analysis approach, exposure, risk scoring)**	$150,000	$200,000
2	**Conduct screening-level hazard analysis**		
	Analysis for 28 RDs (based on $150,000 and $450,00 per RD)	$4,200,000	$12,600,000
	Workshops for 28 RDs (for 1 and 2 workshops per RD)	$1,120,000	$2,240,000
3	**Aggregation and Prioritization Analysis**	$100,000	$200,000
	Total	$4,450,000*	$15,240,000
	50% reduction through efficient planning/analysis	$2,225,000	$7,620,000
	75% reduction through efficient planning/analysis	$1,112,500	$3,810,000

**assumes workshop costs are already included in total analysis costs.*

It should also be noted that these cost estimates are preliminary Class D cost estimates (+/- 50%) and should be considered with caution. Further refinement of these estimates can be discussed with clients, and potentially, professional costing experts.

5.4.3.5 Capacity and Time Estimates

Task 1 is estimated to take about 6 months. The actual analysis, including workshops, would likely take at least 1 year, more likely 2 years, and would ideally involve cooperation of several companies to ensure a well-balanced approach and distribute the capacity. Aggregation and prioritization analysis might take another 6 months. Therefore, in total, it is estimated that this analysis would take between 2 to 3 years.

5.5 Trade-offs Between a Bottom-up and a Top-down Approach

To complete a provincial FRA, either a bottom-up or a top-down approach can be chosen. In the bottom-up approach, local FRAs are aggregated towards a provincial picture of risk, whereas in the top-down approach, a consistent screening-level FRA is conducted for the entire province.

While it will eventually be necessary to conduct locally relevant and quantitative FRAs for most local jurisdiction, un-incorporated community, and First Nation (e.g. those that are identified as high-risk in provincial-scale assessment) that are exposed to flood hazard, this will take considerable time to achieve (more details on methods for local FRAs are discussed in Section 6, but in general, they are more comprehensive and time-intensive to conduct than regional FRAs). In the meantime, it is prudent to consider a provincial scale assessment.

In this study, 27 local and quantitative FRAs have been identified throughout BC, which leaves many communities for which currently no local FRA exists. If the purpose of a provincial FRA is to obtain a consistent picture of flood risk across the province to inform prioritization and allocation of funding for risk reduction measures, aggregation of local FRAs is necessary. However, due to the large diversity in local FRAs in terms of indicators, data proxies, scoring, hazard scenarios, and other method details, the aggregation and scaling of currently available local FRAs to a provincial FRA is challenging, and not recommended. Furthermore, local FRAs typically focus solely on population centres, while for instance, smaller communities, unincorporated settlements, agricultural areas, natural resource extraction sites, or environmentally sensitive areas may not be captured. Furthermore, the total costs for conducting local FRAs and aggregating them is high (between 17-64 $M, depending on comprehensiveness and number of FRAs), and might take up to 10 years. This approach does result in comprehensive and locally valid assessment that can be used to support local decisions related to flood risk reduction.

In contrast, in the top-down approach, a screening-level FRA is done for the entirety of the province. This allows a consistent picture of risk. However, at a provincial-scale, local features and values cannot fully be integrated. Therefore, a provincial-scale FRA can only provide an initial and consistent overview of risk, which should then be followed up by local comprehensive FRAs for high-risk areas, that incorporate local values and can provide recommendations on risk reduction measures which are locally relevant. The costs are much lower in contrast to the bottom-up approach, ranging from approximately 1 $M to 15 $M, and it is estimated it would take about 2-3 years.

If the goal of a provincial-scale FRA is to support resourcing, funding, and prioritisation, then a top-down approach is much preferred. It would provide a transparent, repeatable, and consistent information, and would require less funding and time.

5.6 Recommendations

Table 25 lists recommendations based on the above analysis for a province-wide FRA. It includes high-level estimates of priority and cost (primarily dollar cost, but also in some instances human resources and skills) are provided in this table as High (red, 10s of $M), Medium (yellow, $Ms) and Low (green, $1000s to <$M). These costs will be further refined and aggregated in Issue D-1: Resources and Funding (AECOM Canada Ltd., 2021). A note to whom the recommendation is targeted at in the Recommendation/Option Column.

Table 25: Recommendations related to the development of a provincial-scale Flood Risk Assessment.

Recommendation	Rationale	Priority	Cost
Topic 1: FRAs in BC			
1. Make FRA reports available to the general public in central location at the Province **(Province)**	One challenge of this project was the availability of FRA reports, which were not available in a central location. As most of the FRAs are funded by public money (e.g., NDMP), it is recommended that FRA reports are required to be shared with the Province upon completion of the project, and then be made available to the general public in a centralized database. This will better support future cross-analyses, allow the public to gain information on flood risk for a specific region, and ensure that the information of tax-funded projects is available to everyone. Sensitivities, such as for FRAs conducted by First Nations which may contain delicate information, will need to be considered, and if the community is not comfortable sharing the report, it should be noted as such at the provincial level.	M	L
2. Define quality standard, and develop an FRA guideline for BC **(Province, leveraging Federal Materials)**	The analysis of the FRAs showed a wide range in quality between different FRAs. Some were conducted with simple (e.g. non-rigorous) qualitative assessments, while others included comprehensive quantitative analysis, and others included qualitative information in a robust manner. Yet, all were referred to as flood risk assessments, and local decision makers may not have the capacity to judge the quality of the FRA they received. Therefore, minimum quality standards should be set within a guideline (see Issue A: Flood Governance (Ebbwater Consulting Inc. and Pinna Sustainability, 2021) for a description of the mandate and authority of guideline documents). While it is important to keep flexibility, in particular for local comprehensive FRAs, which should reflect local priorities and values, it is recommended to develop provincial guidance towards a more consistent approach. This is especially true for risk scoring, so that risk of local FRAs can	H	M

Recommendation	Rationale	Priority	Cost
	be compared (see discussion in Section 5.3). These guidelines should address both local (more comprehensive) and regional (more screening-level) FRAs. Currently, several guidelines are under development by the federal government, and could likely be leveraged and adapted to BC.		
Topic 2: Provincial FRA			
3. Develop a consistent, province-wide FRA **(Province)**	It is recommended that a consistent province-wide FRA is conducted. This will provide important information on the Risk Profile of BC, highlight regions/communities of particular concern, and inform prioritization. While there is an initial cost to this (between 4 and 15 $ M), it will allow more efficient funding allocations later on (i.e., to communities with highest risk). Further, it will also provide a consistent picture of risk across the entire province. Lastly, it will cover areas which are outside of population centres (and might thus not be covered by local FRAs), but where other assets (Indigenous cultural sites, industry, agricultural land, electricity infrastructure, etc.) may be at risk of flooding.	H	H
4. Choose the top-down approach with a consistent, screening-level FRA **(Province)**	Based on the discussion in preceding sections, a top-down approach with a consistent, screening-level FRA is recommended. The diversity in local FRAs is too high to allow efficient aggregation, and further, many more local FRAs would need to be conducted before a provincial picture of risk can emerge. The costs for this would be high and take many years to complete. In contrast, the top-down approach is more cost-and time efficient and ensures a consistent approach.	H	M
5. Choose Province to lead province-wide FRA **(Province)**	It make senses for the Province to lead such a province-wide FRA, in contrast to the analysis being conducted individually for instance by each RD. A Province-lead would ensure consistency in methods, and cost/time efficiency in analysis (e.g., exposure data can be processed for entire province at the same time). Further, capacity and interest for such a project might differ from RD to RD, and regional	M	M

Recommendation	Rationale	Priority	Cost
	FRAs (led by RDs, and specific to each RD) are already being conducted.		
6. Develop detailed method for province-wide screening-level FRA before starting the analysis. **(Province)**	To be time- and cost-efficient, it is recommended to develop a detailed methods approach before embarking on the province-wide screening-level FRA. Preliminary methods recommendations are provided in Section 5.4.2, which should be further refined, also based on upcoming federal guidelines.	H	L
7. In province-wide FRA, ensure that multiple flood hazard scenarios are considered. **(Province)**	It is important to not focus on solely one hazard scenario for assessing risk, but it is recommended to include at least three hazard likelihoods (likely, rare, very rare) to assess both the risk for rare but often dramatic floods, as well as more frequent, smaller floods, where impacts can cumulatively add up over the years. Ideally, five or even seven scenarios should be considered. This need should be clearly articulated in any flood hazard mapping guideline (see Issue B-2, (Northwest Hydraulic Consultants Ltd., 2021a)). Consideration of multiple flood hazard types (e.g. coastal, riverine, etc.) should also be considered; where there are joint probabilities of both occurring, they should be considered both independently and together.	H	H
8. Consider climate change. **(Province)**	As the main objective of a province-wide FRA is prioritization and future planning, it is important that FRAs reflect this, and include incorporation of climate change. While this is challenging, the authors nevertheless believe it is an essential component of a forward planning FRA. For a screening-level FRA, simplified approaches could be considered, and for instance, only one future time period/emission scenario could be included. In a more comprehensive FRA, dynamic risk (with changing exposure) could be assessed for 2 or 3 time horizons, but as this would involve extensive analysis with many scenarios. The time horizons should consider the present-day, 15-20 year time horizon and a 70-80 time horizon (these are recommended based on preliminary discussions with NRCan on forthcoming guidelines for Sea Level Rise). This will	M	H

Recommendation	Rationale	Priority	Cost
	significantly increase the number of scenarios, however with automated methods the effort is not linearly connected to the number of scenarios. For a screening-level FRA, it is believed that the focus on climate change is sufficient to identify the dominant consequences of changing hazard.		
9. Include tangible and intangible consequences (holistic FRA)	It is recommended to use a holistic approach to the FRA, where not only tangible (monetizable) consequences are considered, but also more intangibles, such as impacts to culture and environment. This is important, if the FRA is used for prioritization. 'What is measured, matters' – and if for instance, cultural and environmental impacts are not captured, it might skew the risk assessment towards solely protecting the built environment, which might not be inline with the values and priorities of communities, especially First Nations. In the short-term this could be developed using the methods for holistic risk assessment applied in the Syilx Okanagan and Orphan Dike Assessment projects for example.	H	M
10. Include regional engagement	While a provincial FRA will not be able to capture all local priorities and values, it is recommended that workshops are conducted at a regional with stakeholders, to identify regional values. This must include Indigenous engagement. These should then be incorporated into the provincial FRA. A consistent workshop format should be developed, which would then be conducted for each RD. Lessons learned from recent workshops conducted in-person and online for recent projects (e.g. Syilx Okanagan, RDKB, District of Tofino, Southern Dakelh Nation Alliance, etc.) could be applied to develop these.	H	M
11. Develop consistent weighting methods	To manage multiple indicators in an efficient manner, it would be helpful to use weightings to sum each indicator. This will require that weightings be developed, for local FRAs this should be done in consultation with the local community. However, for a province-wide assessment and as a starting point for local projects, one set of weights	H	M

Recommendation	Rationale	Priority	Cost
	should be developed in consultation with practitioners, researchers and ideally decision-makers.		
12. Indigenous Inclusion	Recognise the importance of Indigenous Inclusion, and fund projects appropriately. Further, reasonable timelines for these projects should be developed. See also Section 5.4.2.5.	H	M
13. Leverage existing regional FRA methods and datasets	Potentially, components of existing regional FRAs could be leveraged – specifically for their methods and datasets (see summary of methods in Section 5.4.1), as well as for validating results. In most cases it will be necessary to significant augment the existing work to make it consistent and comprehensive.	M	M
Topic 3: Next steps			
14. Use province-wide FRA for prioritization	A province-wide FRA could be used for risk-based prioritization of communities with high flood risk. For these communities, more detailed flood hazard mapping and flood risk assessments can be supported, if they do not exist. The local FRAs can then provide more detail for locally-relevant risk reduction measures.	M	L
15. Update the provincial picture of local FRAs	Keep track of where local FRAs have been conducted, ideally also spatially. This can then be compared to the province-wide picture of flood risk. (See also related recommendation #10)	M	L
16. Use FRA for initiating flood risk reduction measures	The FRA can support risk-based decision making for flood risk reduction measures. While flood risk reduction measures are typically implemented at the local level, the province-wide FRA can provide a big picture and highlight potential efficiencies and similarities between different communities, which can increase collaboration (see also Issue B-4, (Kerr Wood Leidal Associates Ltd., 2020).	M	L
17. Regularly review province-wide FRA	To ensure that the province-wide FRA stays up-to-date into the future, and emerging information (such as new climate change projections) or changes in exposure (such as new neighborhoods) are adequately incorporated, it is recommended to conduct a brief review of the FRA every	M	L

Recommendation	Rationale	Priority	Cost
	5-10 years. This review does not need to involve a full new analysis but should highlight changes from the previous FRA.		

6 Investigation B-3.4 Coarse Local Flood Risk Assessments

6.1 Introduction

In the Risk & Resilience primer, various scales and uses for flood risk assessments were discussed (see Section 2.5). In this section, the focus of the investigation is on coarse local FRAs, while the following Investigation B-3.5 focuses on comprehensive local FRAs. The focus is also on local FRAs, in contrast to regional FRAs, which are discussed in Sections 5.2.2 and 5.4.1.

6.1.1 Research Objectives

Research objectives and questions related to a coarse local scale FRA were defined jointly by FBC and MFLNRORD. The primary goal of this work was to **investigate the level of effort to develop a coarse local-scale flood risk map based on available flood hazard map**(s). Where, local-scale is assumed to represent the approximate jurisdiction of a municipality or First Nation reserve.

6.1.2 General Approach

Here, brief discussion and methods overview for coarse local FRAs is provided (Section 6.2), Class D Cost and Capacity Estimates (Section 6.3), and Recommendations (Section 6.4). The authors note that the reader may wish to refer to the Risk & Resilience primer to understand the various scales and characterisations of risk assessments that are discussed here (see Section 2.5).

6.2 Coarse Local Flood Risk Assessments – Methods Overview

A coarse local FRA could be considered similar to the Tier 1 – Initial FRA in Figure 8; while coarser information and analysis is used, it is still a quantitative analysis (see Section 5.2.4). This is different to the local qualitative FRA reports that are summarized in Section 5.2.3, which apply a qualitative and/or aspatial approach for the entire FRA, where actual risk as the product of consequence and likelihood was not quantified.

Typically, recently completed coarse local FRAs are used to support applications for detailed flood hazard mapping funding, e.g., via the Risk Assessment Information Template (RAIT) for the NDMP funding program. Therefore, these studies are often conducted before high-quality and up-to-date flood hazard data exists for the study location. Examples for this are the *Oyster River / Saratoga Beach Flood Risk Assessment Final Report* (Ebbwater Consulting Inc., 2018b) and the *City of Dawson Creek Flood Mitigation Planning Final Report* (Ebbwater Consulting Inc., 2018a). In both these projects, interim low-quality flood mapping was prepared to support the assessments.

Typically, the methods for a coarse local FRA would be like the methods discussed for the province-wide FRA in Section 5.4.2. Where, screening-level flood hazard information is used, ideally with consideration of multiple flood scenarios (i.e. AEPs). Exposure information is collected for a range of diverse indicators – even at the coarse FRA scale, the inclusion of diverse indicators (such as discussed in Section 4 and Section 5.4.2) is still important to capture the full picture of risk. Further, similar to the screening-level province wide FRA, some engagement activities should be conducted for a coarse local FRA to capture local priorities and values. Lastly, risk is determined based on an exposure score (as proxy for vulnerability and consequences) and a likelihood score; an actual risk scoring exercise has not been applied in many recently completed coarse FRAs in the province.

6.3 Class D Cost and Capacity Estimates

Class D cost estimates for coarse local FRAs are based on the lower range of local quantitative FRAs, as assessed in Section 5.3.3 and in Table 17, where budget was associated with different detail of FRA. These coarse local FRAs typically ranged in budget from $50,000 to $100,000, noting however that the $50,000 budget range was for conducted for very small area. For instance, the Oyster River/Saratoga Beach FRA falls into this category, which was a coarse but quantitative FRA, conducted as part of the NDMP Stream 1, which was then used to apply for funding for more detailed flood hazard mapping (and therefore falls in the middle of the spectrum of truly coarse and truly comprehensive assesssments). Budgets in the range of $100,000 to $150,000 typically included more detailed FRAs, some of which were conducted as part of the NDMP Stream 1. However, for these more expensive studies, limited flood hazard information was available, and thus additional (screening-level) flood hazard mapping was conducted as part of the study.

Thus, the required budget for a coarse local FRA ranges from approximately $100,000 to $150,000 if screening-level flood hazard information needs to be developed as part of the project. It should also be noted that these estimates are impacted by the available funding programs. For example, the CEPF that funded both the above-mentioned projects haw a cap of $150,000 and the projects were scoped to this value rather than having projects scoped to need.

Table 26: Budget range for coarse local FRA.

Detail level / Area	Description	Budget per Study ($)
Coarse local FRA	FRA conducted at screening-level with likely only older/screening-level flood hazard data availability, and limited consideration of vulnerability.	$50,000 - $100,000
Coarse to moderate scale FRA	FRA conducted at coarse to moderate scale, including several indicators. In some cases, screening-level hazard data has to be developed as part of the FRA, for locations where no hazard data is yet available.	$100,000 - $150,000

Time estimates for coarse local FRAs are lower than for comprehensive local FRAs, and probably range more in the 6-8 months time frame (based on previous work experience, and as estimated from reviewed reports). However, if no hazard data is available, and screening-level flood hazard data needs to be developed, the capacity and time estimates would be higher. While a coarse local FRA involves less detailed analysis than a comprehensive FRA, technical risk assessment understanding is still needed to conduct the project efficiently, thus requiring the adequate technical capacity.

6.4 Recommendations

Overall, coarse local FRAs can play an important role in providing an initial picture of potential flood risk for a community and can support funding applications for more detailed flood hazard and risk assessments (should the current funding program format persist). However, they should be taken for what they are – an initial assessment of potential risk, often based on screening-level hazard information. Thus, for detailed flood risk reduction planning, comprehensive local FRAs are still needed, and a coarse local FRA cannot replace the detailed work of a comprehensive local FRA, which should be based on more reliable flood hazard information. Therefore, **if a province-wide FRA is conducted at screening-level, as discussed for the top-down approach in Section 5.4, the need for coarse local FRAs would become obsolete**, as funding priorities across the province would become obvious (i.e., reduce the need to conduct a coarse local FRA to fill a RAIT to describe the (screening-level) risk for a community). Further, if such a province-wide FRA is made public, communities would have access to preliminary coarse FRA information, to assess their initial risk to floods. Therefore, in the case of a province-wide FRA, the funding costs for coarse local FRAs could likely be eliminated. It should be highlighted however, that regional FRAs (as discussed in Sections 5.2.2 and 5.4.1), conducted by regional districts, would likely still be required, to allow better incorporation of regional values than a provincial FRA can do. Table 27 summarizes the recommendations for Investigation B-3.4.

The recommendations include high-level estimates of priority and cost (primarily dollar cost, but also in some instances human resources and skills) are provided in this table as High (red, 10s of $M), Medium (yellow, $Ms) and Low (green, $1000s to <$M). These costs will be further refined and aggregated in Issue D-1: Resources and Funding (AECOM Canada Ltd., 2021). A note to whom the recommendation is targeted at in the Recommendation/Option Column.

Table 27: Recommendations based on Investigation B-3.4.

Recommendation	Rationale	Priority	Cost
1. Focus on province-wide FRA instead of coarse local FRAs	A province-wide FRA, conducted with a top-down approach, would provide screening-level flood risk information for local communities, and allow identifying funding priorities, thus making the need for coarse local FRAs obsolete. Funding needed otherwise for coarse local FRAs can be saved and applied to other FRA projects.	H	L
2. Recognize that coarse local FRAs are limited	While coarse local FRAs can provide an initial picture of risk at a location, they should be recognized for what they are, and cannot replace a comprehensive local FRA, based on high-quality flood hazard data.	L	L

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7 Investigation B-3.5 Comprehensive Local Flood Risk Assessments

7.1 Introduction

In the Risk & Resilience primer, various scales and uses for flood risk assessments were discussed (see Section 2.5). In this section, the focus of the investigation is on comprehensive local FRAs, while the previous investigation B-3.4 focuses on coarse local FRAs. The focus is also on local FRAs, in contrast to regional FRAs, which are discussed in Sections 5.2.2 and 5.4.1.

7.1.1 Research Objectives

Research objectives and questions related to a comprehensive local scale FRA were defined jointly by FBC and MFLNRORD. The primary goal was to **determine the effort required to undertake a local-scale comprehensive flood risk assessment for multiple types of flood hazards (e.g. riverine, coastal) and for varying degrees of available data on flood hazard, exposure, vulnerability and risk**. Where, local-scale is assumed to represent the approximate jurisdiction of a local government.

7.1.2 Definitions

The authors note that no definition was provided for a "comprehensive" FRA, which is understandable given the many potential dimensions and characterisations (see Section 2.5) of risk assessments. In general, the report correlates "comprehensive" with "quantitative" as a first cut at understanding the state of these types of FRAs in the province. The report also considers, albeit less rigidly, variations in the holistic nature of approaches to consequences, indicators, and proxies – where the more indicators and more robust methods to calculate consequences are considered 'more' comprehensive. Further, the report only briefly consider scenario/full statistical accounting variations. This type of assessment is considered to be at the opposite end of the effort spectrum to the coarse assessment described in Section 6.

7.1.3 General Approach

In this section, local-scale comprehensive FRAs are discussed. First, a brief overview of available local/quantitative/comprehensive FRAs in BC and used methods is provided (Section 7.2), next, preliminary recommendations for a comprehensive local FRA approach are given (Section 7.3), Class D cost and capacity estimates are provided (Section 7.4), and recommendations are given (Section 7.5). The authors note that the reader may wish to refer to the Risk & Resilience primer to understand the various scales and characterisations of risk assessments that are discussed here (see Section 2.5).

7.2 Available Local/Quantitative Flood Risk Assessments and Methods in BC

In total, 27 of local and quantitative FRAs have been identified in BC (see 5.2.4; Figure 25). Of these, 10 technical reports have been obtained:

1. *City of Vancouver Coastal Flood Risk Assessment Phase II* (Compass Resources Management Ltd. and Ebbwater Consulting, 2015);
2. *Oyster River / Saratoga Beach Flood Risk Assessment Final Report for Comox Valley Regional District* (Ebbwater Consulting Inc., 2018b), noting that this project has some elements of a

coarse assessment (e.g. limited hazard data), but some elements of a comprehensive assessment (holistic approach, multiple scenarios, qualitative data);
3. *City of Armstrong Flood Mapping and Risk Assessment Report* (Interior Dams Incorporated, 2018);
4. *City of Dawson Creek Flood Mitigation Planning Final Report* (Ebbwater Consulting Inc., 2018a), noting that this project has some elements of a coarse assessment (e.g. limited hazard data), but some elements of a comprehensive assessment (holistic approach, multiple scenarios, qualitative data;
5. *Village of Zeballos – Zeballos River Floodplain Modernization & Future Landslide Risk Assessment* (BGC, 2018);
6. *Geohazard Risk Assessment North Slope of Cowichan Lake* (Ebbwater Consulting and Palmer Environmental Consulting, 2019);
7. *Quantitative Risk Assessment for Squamish River Floodplain* (KWL, 2019);
8. *Risk Assessment of Floodplains and Coastal Sea Level Rise: Strategic Climate Risk Assessment for the Cowichan Valley Regional District* (NHC, 2019a);
9. *District of Tofino Comprehensive Coastal Flood Risk Assessment - Final Report* (Ebbwater Consulting Inc., 2019);
10. *Squamish-Lillooet RD Flood Hazard Mapping and Risk Assessment Upper Squamish* (NHC, 2019b).

Furthermore, a methods overview sheet was obtained for the *North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy* (KWL, 2020).

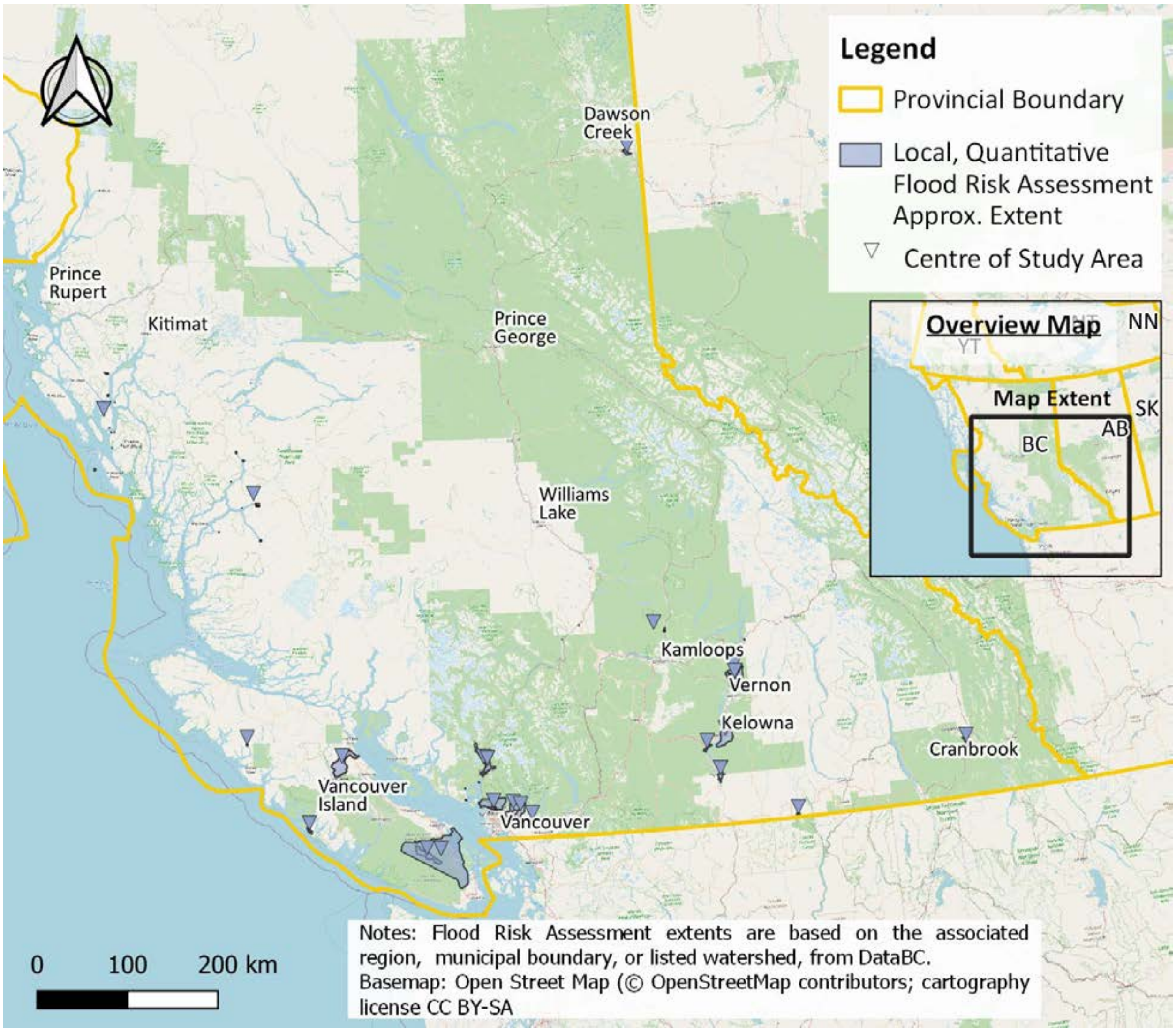

Figure 25: Local/quantitative FRAs in BC, as identified in this report.

An overview of the methods applied in these reports is given below, to indicate the range of methods used currently in local and quantitative FRAs in BC. Note that some of the FRAs (e.g., the Dawson Creek, Oyster River/Saratoga Beach) were done as initial risk assessments to support the application of further funding for more detailed flood hazard mapping. As they were done however as quantitative FRAs at a local scale, they were included in this category (components of them are also included in the previous analysis on coarse local flood risk assessments).

A range of different hazards was assessed in the FRAs, including riverine floods, coastal storm floods, tsunamis, geohazards as well as dike breaches (Table 20). Most studies applied detailed hazard mapping as input for the FRA; in some cases, the detailed hazard mapping was conducted as part of the FRA study. Most studies assessed risk for several scenarios, and quantitatively assessed climate change. With respect to climate change, however, it should be noted, that many studies assessed coastal flooding, where the application of a sea level rise scenario is more straight-forward then estimating potential changes in peak flows in rivers. Of the 7 riverine FRAs, 1 described climate change qualitatively, 1 did not discuss climate change, 3 applied the generic 10% or 20% climate change increase factors given in the EGBC guidelines (EGBC, 2018), and only 2 studies incorporated a climate change analysis, which related change to emission scenarios for the area.

Table 28: Overview of hazard data input into the regional FRAs, indicating the number of studies.

Hazard type				Hazard Method			Scenarios		Climate Change		
Riverine #	Coastal Storm #	Tsunami #	Geo-hazard #	Dike Breach #	Detailed #	Screening level #	Single Scn. #	Multiple Scn. #	Qual. Discussed #	Quant. assessed in FRA #	EGBC Factor Approach
7	7	1	3	1	9	2	1	10	2	8	2

The variability of assessed indicators was also large (Table 21). Most studies considered affected people (i.e., typically expressed as the number of people living within the flood hazard area) and economy (financial losses associated with structures/buildings), basic and critical services (lifelines), environmentally sensitive areas and cultural buildings. However, only some studies considered business disruptions, critical infrastructure facilities specifically, environmental contamination sources, Indigenous cultural sites and more intangible cultural values. Workshops for incorporation of local knowledge were conducted in 6 of the 11 studies. Agriculture was not considered in any of studies (potentially also due to location of the study sites and focus on population centres, where agriculture might play less of a role).

Table 29: Consequence indicators considered in local/quantitative FRAs, indicating the number of studies which considered a specific indicator.

People #	Mortality #	Economy – Buildings #	Economy – Businesses #	Agriculture #	Critical Infrastructure #	Basic/Critical Services (Lifelines) #	Environment - Sensitive Areas #	Environment - Contamination Sources #	Environment – Fish #	Culture - Community buildings #	Culture – Indigenous #	Culture – Intangibles #	Workshops & Local Knowledge #
10	6	11	4	0	5	9	9	5	2	9	1	4	6

Different consequence methods were also applied (Table 30). Some studies focused on exposure, while some other studies applied damage curves, mostly based upon HAZUS, as well as ER2[30] (which also uses the HAZUS depth-damage curves) and Japanese tsunami damage curves. HAZUS depth-damage curves are developed by FEMA for U.S. building types, and such, do not always well-represent Canadian buildings (Lyle and Hund, 2017). The ER2 program includes both HAZUS curves, as well as some curves from Ontario.

Table 30: Consequence methods applied in local/quantitative FRAs, indicating the number of studies which considered a specific indicator.

Exposure-based	Damage Curves	HAZUS	ER2	Mortality Curves	Business Disruption	Social Vulnerability
4	7	5	1	3	2	2

Lastly, the approach to estimating risk also varied widely (Table 31). Of the 11 studies, 4 studies reported consequences and exposure, and did not provide any risk estimates. For one study (the North Shore FRA), no information was yet available on risk scoring methods. 5 studies conducted risk scoring, with varying methodologies on how likelihood and consequences were scored. 2 studies (the Tofino FRA and the Squamish River Floodplain FRA) conducted a full statistical accounting of risk FRA, in which the average annual loss was determined (for Tofino, this was done for a range of indicator and sea level rise scenarios, and for Squamish, focused only on financial damages). The Squamish study used the average annual loss, which was determined for several dike upgrade options, for a cost-benefit analysis.

Table 31: Consequence methods applied in local/quantitative FRAs, indicating the number of studies which considered a specific indicator.

No information	No Risk Estimate	Risk Scoring / Risk Matrix	Average Annual Loss	Cost-Benefit Analysis
1	4	5	2	1

As can be seen, the studies varied largely in their focus, methods, and thus, resources to conduct the work. Some studies addressed several hazards or developed hazard mapping as part of the FRA. Some studies conducted a full statistical accounting of risk assessment, whereas other studies focused on consequences alone and did not estimate risk as the product of likelihood and consequence.

7.3 Comprehensive Local Flood Risk Assessments – Methods Overview

In this section, general recommendations for comprehensive local FRAs are given, as well as challenges and advantages of these FRAs are discussed. Coarse local FRAs are discussed as part of investigation B-3.4 (Section 6). It should be noted that there is a continuum between coarse and comprehensive local FRAs, which is also discussed in Section 6.

[30] NRCan Rapid Risk Evaluator (ER2): http://hmcgrat1.ext.unb.ca/er2.html

The method approaches discussed below are not intended to be a detailed guideline on comprehensive local FRAs, but indicate important aspects and trade-offs of different approaches, based on the analysis of FRA methods used in BC in Section 7.2, and best national/international practice (e.g., AIDR, 2015; UNDRR, 2015, 2016, 2017). Upcoming guidelines, such as the NRCan Flood Risk Assessment (not published) and the NRCan Coastal Flood Risk Assessment guidelines (newly published (Murphy *et al.*, 2020), will provide more details on local FRAs.

7.3.1 Consequences

7.3.1.1 Hazard Characteristics

For a comprehensive local FRA, detailed hazard information obtained by standard engineering practices (e.g., hydrodynamic and hydraulic modelling) is required; comprehensive local FRAs can only be conducted after flood hazard analysis has already been completed. It is recommended that flood risk and flood hazard are assessed within two separate projects. Analysis of available FRAs in Investigation B-3.2 (Section 5.2) indicated that for most FRAs, where flood hazard and risk assessments were conducted within the same project, the flood risk component was mostly an 'add-on' and typically only conducted qualitatively.

The foci of flood hazard and risk assessments are different, and by separating the projects, it is ensured that the appropriate focus and associated expertise is put on each of the projects. The skillsets of consulting companies to conduct these analyses also differ, and not all companies that develop flood hazard mapping have appropriate experience to conduct flood risk assessments. However, it needs to be ensured that flood hazard mapping provides the required inputs for FRAs, as discussed below.

For a comprehensive FRA, flood hazard data should be up-to-date (at the minimum, newer than the 1980s-1990s FRDP flood hazard maps, and ideally developed within the last 5 to 10 years).

Furthermore, **several AEPs need to be included to allow a full picture for risk**. At the minimum, 3 AEPs should be included, ranging from high to low likelihood. However, to be able to conduct a full statistical accounting of FRA, where risk is integrated across several likelihoods to inform on the average annual loss (see Section 7.3.3), it is better to have at least 5 to 8 different likelihood scenarios. The importance of AEP selection is highlighted in the theoretical example in Figure 17 from IBI Group and Golder Associates (2020). A set of discrete AEPs is typically used to develop an exceedance-probability-curve, which in turn is used to estimate the average annual loss (see Section 7.3.3). However, if there are thresholds upon which risk becomes much higher (e.g., the water level at which a dike overtops), the risk results can differ greatly, based on which AEPs were selected (Figure 17). Therefore, as part of the Lower Mainland FRA, IBI Group conducted a preliminary risk assessment, in which they assessed damages for 13 different AEPs, ranging from 10% to 0.1% AEP. They then scanned for thresholds, and ultimately selected 8 AEPs for the risk assessment (10%, 3.3%, 2%, 1%, 0.5%, 0.2%, 0.1% AEP). Similarly, research by Ward, De Moel and Aerts, (2011) indicated the impact that selection of AEPs, as well as the number of AEPs considered, has on the resulting risk calculation. For instance, the incorporation of only 3 AEPs led to a substantial overestimation of risk (for their example). Furthermore, they found that the choice of the high likelihood (low consequence) scenario was important, as it had a substantial influence on calculated risk, and they recommended using a likelihood that is as close to the point of zero consequences as possible (e.g., a 67% AEP (or 1.5-year return period). Further, while it is important to include a very low likelihood (high consequence) scenario (such as, in their example, a 0.01% AEP), it is more critical to include additional scenarios for the more frequent likelihoods as the risk curve typically changes more dramatically in this range, and tends to flatten out in the low likelihoods. Messner et al. (2007) recommend using at least 6 AEP scenarios to develop an exceedance-probability curve and estimate risk, which should include both high likelihood and low likelihood scenarios, thus, depending on flood hazard assessments to provide such availability of scenarios.

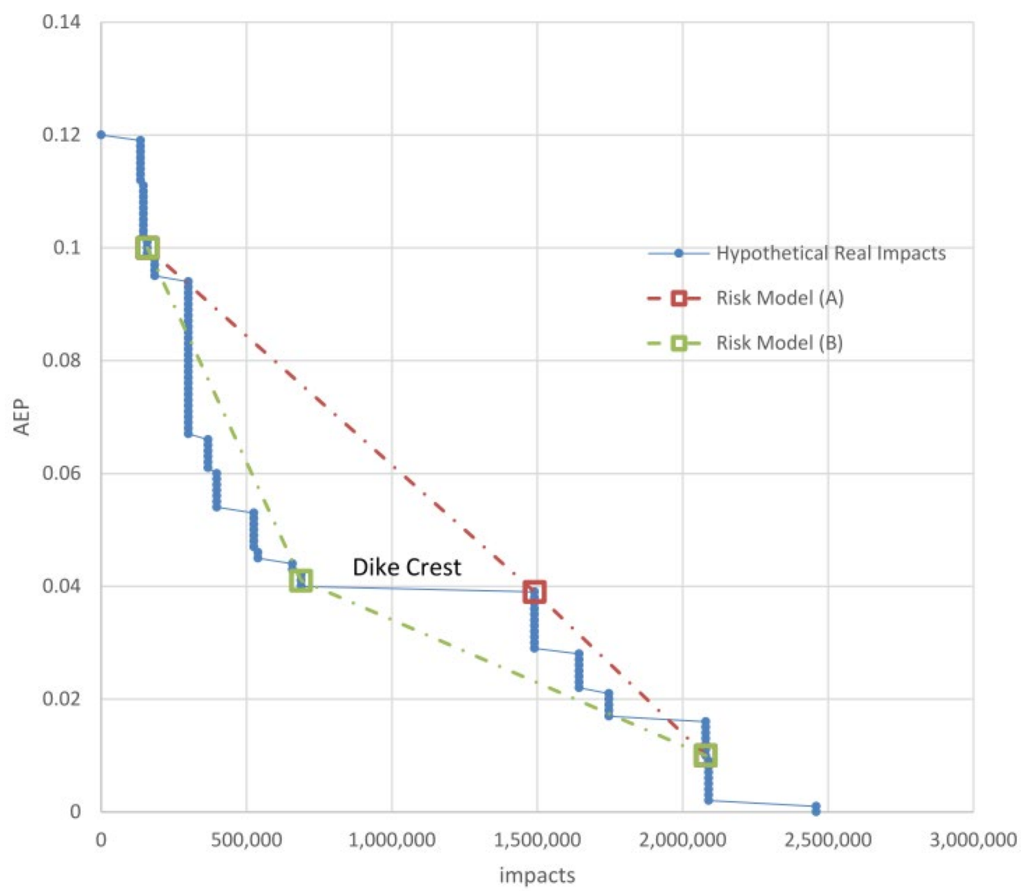

Figure 26: Hypothetical Impacts-Likelihood Relations (Figure from IBI Group and Golder Associates, 2020).

Quantitative climate change scenarios should also be included, ideally for each of the multiple AEPs that are also addressed for the present-day. These climate change scenarios should be based on general circulation model (GCM) projections for the region and an emission scenario (e.g., representative concentration pathway 8.5), in contrast to adding a generic 10-20% increase to present-day peak flows. Issue B-1 Impacts of Climate Change (Associated Engineering Ltd., 2021) provides more details on appropriate incorporation of climate change into flood hazard mapping, and currently available sources of information. While it involves more work to assess dynamic risk and include climate change into a flood risk assessment, it is key to include as flood risk assessments are used to make decisions and plan for the future, and thus, need to consider climate change. For this, however, flood hazard mapping needs to quantitatively include climate change, which, as the review of FRAs in BC showed, is not the case for all or event most current flood mapping. Trade-offs have to be made in terms of scope and costs within a project. However, it is the belief of the authors, that **consideration of at least one climate change scenario in an FRA should be standard**.

For a comprehensive FRA, not only flood extents are needed (to assess what is within the flooded area), but also hazard characteristics such as flood depth, and flow velocities. Flood depths are key for determining vulnerabilities and consequences; the damage to a building depends strongly on how deep flood waters are at the location (and building material). Similarly, the risk to people depends largely on how deep flood waters are and how fast they are flowing. This is visualized in Figure 27.

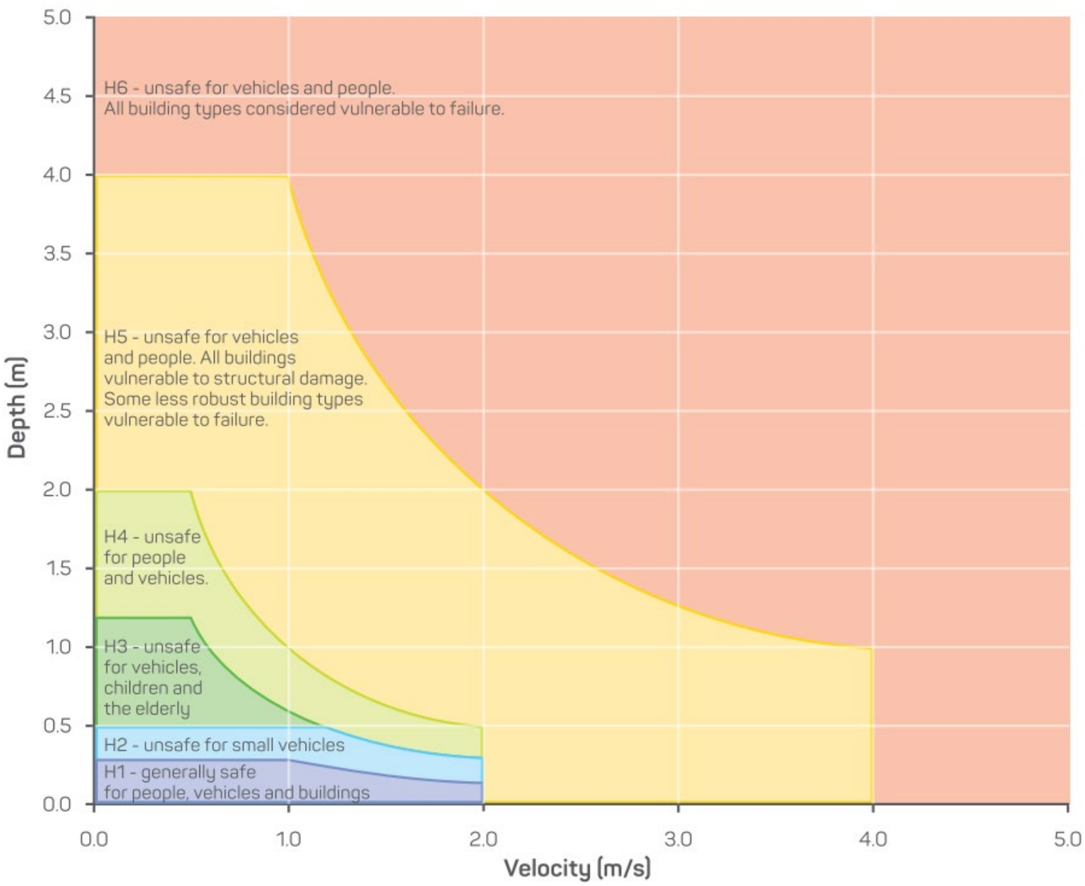

Figure 27: Hazard vulnerability classification (H1 to H6), based on limiting still water depth (D) in metres (m) and velocity (v) in metres per second (m/s), from Australian Disaster Resilience Guideline 7-3 Flood Hazard (AIDR, 2017), CC BY 4.0.

Lastly, for a local FRA where parts of the floodplain are protected by dikes and other flood protection structures, the fragility of these structures needs to be estimated and incorporated into the hazard likelihood estimate for the FRA. The B-2 Flood Hazard Issue reports on dike fragility assessments in more detail (see Appendix E, Issue B-2, Northwest Hydraulic Consultants Ltd., 2021a). For areas with dikes, an assumption has to be made (e.g., ignoring the existing dike altogether, adopting a fragility curve, or assuming failure above certain threshold flood level etc.), and information on dike fragility will help to guide this. Two of the reviewed FRAs included consideration of dike fragility, the *Quantitative Risk*

Assessment for Squamish River Floodplain (KWL, 2019) and the *Flood Risk Assessment for BC's Lower Mainland* (IBI Group and Golder Associates, 2020). The Squamish FRA considered 8 different dike breach locations, assuming that dikes would be raised to the 0.5% AEP plus freeboard, and included 0.5%, 0.2% and 0.1% AEPs, with a 10% allowance for climate change. For coastal dikes, it was assumed that dikes will remain intact up to the design event, and then fail. In contrast, for riverine dikes, detailed flood failure probabilities were assigned. For the Lower Mainland FRA, two different methods were applied, based on the number of assets protected by the structure. In the simpler method, failure probability was taken as the "probability of the weakest dike segment in the dike ring", while in the more complex approach, the "failure probability was taken as the union of probabilities of all dike segments" (IBI Group and Golder Associates, 2020). Fragility curves were developed which related the flood depth to failure probability, and the joint probability was calculated.

7.3.1.2 Exposure

As discussed in Section 4, a wide range of indicators should be considered to ensure to capture the full picture of risk. This should include affected people (e.g., displacement), economy/financial losses (e.g., residential and non-residential buildings, and their contents, and infrastructure, businesses, agriculture where applicable), critical infrastructure facilities (e.g., hospitals, emergency response facilities) and basic/critical services (e.g., roads, telecommunication), environment (e.g., environmentally sensitive areas, species at risk, contamination sources), and culture (e.g., community buildings, heritage buildings, Indigenous and non-Indigenous archaeological sites, Indigenous cultural sites). Detailed discussion of exposure indicators, associated data proxies, and available exposure databases in BC is discussed in detail in Section 4.

Importantly especially for a local comprehensive FRA, local knowledge on exposure should be considered. This information can be obtained in workshops or through other engagement methods (see Section 5.4.2.4).

7.3.1.3 Vulnerability

In a local and comprehensive FRA, vulnerability should be considered. Social vulnerability information might be obtained from census data and the NRCan Exposure Model (discussed in Section 4), as well as from local knowledge in workshops.

Existing FRAs tend to account for vulnerable population by including consequence indicators such as number of elderly and children population affected. But we know that social vulnerabilities can modify individuals' propensity to negative consequences in different ways (e.g., low income new immigrants may have less capacity to manage and recover from being displaced due to less likely to be able to stay with friends/family when displaced or have financial means to stay at hotels). Therefore, the scientific literature (e.g., (Rufat, 2013)) is starting to encourage using social vulnerability indicators as a lens to consider the modelled impacts (overlaying the layers to identifying areas with high social vulnerability and high physical impacts) rather than being considered as a separate consequence. As expertise and knowledge develops in the field, and as more comprehensive FRAs are conducted, this type of layered analysis should be considered.

Building information is needed for building damage assessments. Critical infrastructure and services vulnerability (e.g., is the community only accessible by one road, which is located within the floodplain?) should also be discussed, and information might be obtained in workshops.

Similarly, environmental and cultural vulnerability information might be obtained in workshops. More details on vulnerability, and available data, are discussed in Section 4.

7.3.1.4 Consequences

If adequate flood hazard data (e.g. flood depth) and building information (e.g., details on building height, material, contents, etc.) is available, consequences from depth-damage curves can be estimated. The challenge is that often no detailed building data is available. Further, until recently, limited depth-damage curves existed that captured the building characteristics in BC. However, new depth-damage curves have been developed by FBC/IBI Group for the Lower Mainland, which should be applicable to other regions in BC. Other economic/financial consequences, such as business disruption or agricultural crop losses, and socio-economic consequences can similarly be estimated via models, albeit this is currently not often done in FRAs in BC. This is partially due to the fact, that similarly to depth-damage curves, that for instance many of the developed social vulnerability curves might not be directly transferable to BC. The Lower Mainland FRA did include economic crop loss estimates.

Mortality functions also exist from other countries, some based on empirical events, other on theoretical assumptions (Smith and Rahman, 2016). While mortality due to coastal and riverine flooding is low in Canada (Canadian Disaster Database; Public Safety Canada, 2019), mortality due to a tsunami is much higher, and should be considered in consequence calculation, for instance based on Japanese curves, developed after the 2011 Tōhoku tsunami. However, mortality estimates also depend on many factors (number of residential and visiting people at location of tsunami, tsunami preparedness and evacuation routes, warning time, tsunami depth and velocity), and therefore, it remains difficult to estimate reliable numbers. Mortality can also be higher for debris flow events. One approach to estimate mortality due to debris flow, which has been used in the Orphaned Flood Protection Structure Study (albeit a regional FRA), is to assume mortality as a fraction of number of affected people (i.e., number of people within the hazard extent), based on empirical numbers from actual debris flow events.

Once consequences have been determined based on exposure, vulnerability and hazard characteristics, a consequence score can be assigned, based on pre-determined rules (see Section 5.3.2 for discussion). Applying a consequence score can support aggregation of FRA results in a risk matrix for each indicator, and thus allow comparability across different FRAs, if the same scoring rules have been used. This depends on availability of a consistent methodology across BC (and Canada) to allow comparability, which may become available with the development of federal FRA guidelines, and may potentially be adapted, or refined, for BC conditions. While discussion of consequences should always be local, and consider local priorities and values, the main point of assigning scores is comparability between different FRAs, and for this, the same rules for assigning scores need to be applied (Section 5.3.2).

To visualize local, qualitative consequence information obtained in workshops, qualitative consequence mapping can be considered. An example for this is provided in Figure 26, where diverse local stakeholders marked on print-out maps, where they considered potential direct and indirect, tangible and intangible consequences to flooding. These were then digitized and visualized via hotspot mapping.

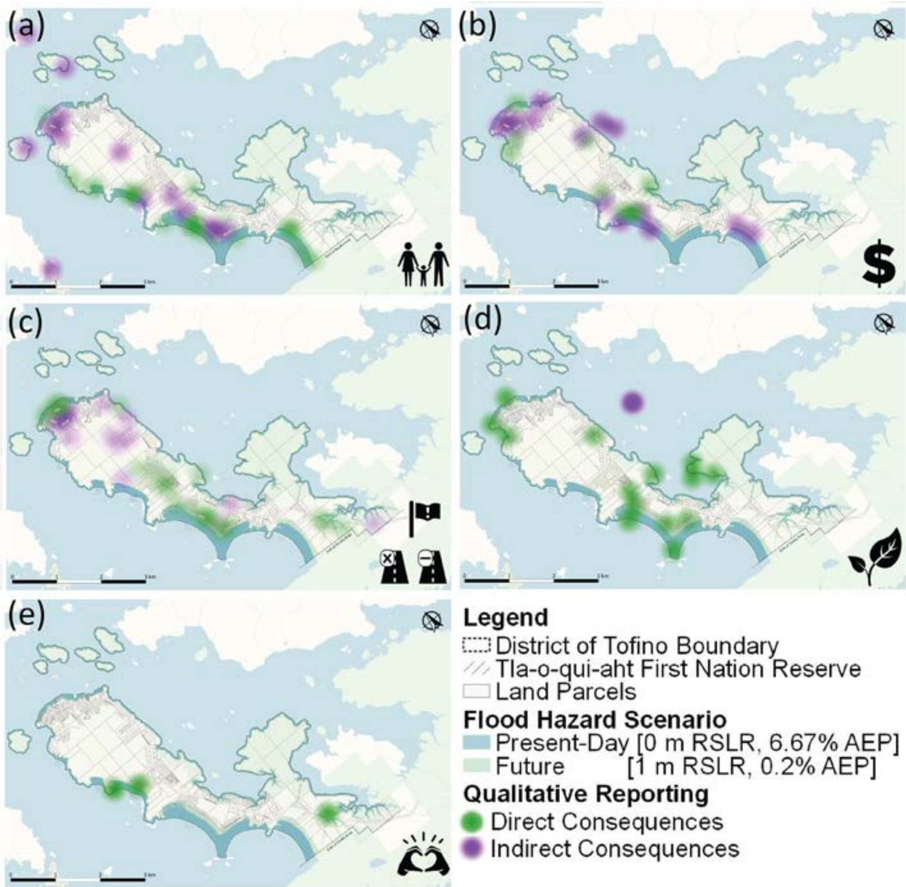

Figure 28: Qualitative consequence mapping for direct and indirect consequences, as drawn by local stakeholders on print-out maps in workshops, District of Tofino (Ebbwater Consulting Inc., 2019a; CC BY-NC-ND 4.0)

7.3.2 Likelihood

To determine risk, the hazard scenarios must be associated with a likelihood. Typically, this is represented by the AEP of the modelled hazard scenario. In locations with dike protection, the probability of dike failure might also be included.

If risk is calculated as the product of consequence score and likelihood score, a likelihood score has to be assigned, which typically relates the likelihood of the event to a score in between 1 to 5 (see Section 5.3.2). Similarl to consequence scores, for the risk results to be comparable between different local FRAs, consistent scoring rules should be applied throughout BC.

7.3.3 Risk

Several methods can be employed for risk estimation. Risk scores are calculated as the product of likelihood and consequence scores and can allow visualization of risk in a risk matrix. If consistent scoring rules are applied (see Section 5.3.2), risk scores also allow comparability of risk between different local communities.

Risk matrices can provide a visualization of risk, as a function of the hazard likelihood (horizontal axis) and the consequence (vertical axis) (Figure 2(Figure 27). Risk is indicated by the color range in Figure 27a, where for instance blue indicates very low risk and red indicates very high risk. Note that colour scheme and design of the risk matrix are based on the Australian Institute for Disaster Resilience National Emergency Risk Assessment Guidelines, an internationally recognized best practice document (AIDR, 2015)

Further, risk is dynamic and changes over time (GFDRR, 2016) (see also Section 2.2.2). Therefore, it is important to consider both present-day and future risk, especially when seeking means to maintain or reduce risk over time. In terms of comprehensive local FRAs this means, that at a minimum, climate change impacts on risk need to be included. It becomes more complicated when looking at future changes to exposure and vulnerability, as it is more challenging to develop adequate scenarios here, and the number of assessed scenarios multiply quickly (e.g. 4 climate scenarios times 4 exposure scenario = 16 scenarios).

Potential input information on future exposure can be provided by community development plans (assuming a business-as-usual development), population growth predictions, and discussion with local communities. Of the reviewed FRAs, only one FRA (the Squamish River FRA; KWL, 2019) considered future development to the year 2100. In this case, the focus of the analysis was entirely on the future (i.e., no current scenario was assessed), and, probably as a trade-off for the more complicated exposure scenario, a simplified climate change approach (adding 10% to present-day peak flows) was chosen.

Yip (2018) assesses flood impacts for a range of possible futures, considering multiple climate change (storm intensity, sea level rise), land use planning, power infrastructure resilience, and structural integrity of buildings scenarios for the City of Vancouver, for 14 different impact categories. The results for the 336 future scenarios were analyzed via a robust impact patterns approach, which visualized areas that are vulnerable to flooding consistently through multiple scenarios.

Trade-offs between consideration of dynamic risk, and inclusion of additional scenarios, with available time and project budget have to be made, however, given that flood risk assessments are used to plan for the future, one or two climate change scenarios should be included at the minimum in a comprehensive FRA. Further, with automated methods (e.g. as applied for the Orphan Dikes Assessment), it is relatively efficient to run multiple scenarios or assessments.

Further, for a local and comprehensive FRA, a full statistical accounting of risk approach should be considered (if the hazard data is available). A full statistical accounting of risk assessment is one that considers a range of hazard events and damage outcomes, i.e., the risk assessment is not only conducted for one single scenario, but for multiple likelihoods. See Section 2.5.4 for background information.

In a full statistical accounting of risk assessment, the **average annual loss (AAL)** can be calculated, which is the 'long-term expected loss on an annualized basis, averaged over time' (UNDRR, 2017). The AAL describes the average expected loss over a long period, which takes into account frequent events with potentially little loss, as well as infrequent events with potentially larger losses. In terms of dollar values, the AAL could represent the 'amounts of funds that need to be put aside annually in order to cumulatively cover the average disaster loss over time' (UNDRR, 2017). The AAL refers to the total risk (as a product of likelihood and consequence for each of the scenarios), and is calculated as the total area under the exceedance probability curve. Historically, the AAL has been determined for economic damages alone, as was for instance done for the Squamish FRA (KWL, 2019). However, the approach can also be applied to a holistic range of indicators (e.g., for affected people, it would indicate the long-term annual average of number of people affected every year). This was done for the Tofino FRA (Ebbwater Consulting Inc, 2019). The Lower Mainland FRA (IBI Group and Golder Associates, 2020) annualized exposure, financial damages and risk scores.

There are, of course, trade-offs between the scenario approach (where a single event likelihood, often an extreme event, is used to calculate consequences) and the full statistical accounting approach. Scenario approaches are the most used—primarily because of the smaller effort relative to full statistical accounting assessments, which can be resource intense (and require hazard data for many likelihoods). However, updates in technology and methods are slowly reducing the relative effort to conduct full statistical accounting approaches, and they are becoming more common. Full statistical accounting risk assessments are generally considered best practice as they provide an understanding of the impacts of frequent small events, as well as infrequent large events (i.e., a full picture of risk). This is especially true with climate change, as some smaller and medium events become more common, and it is important to consider the cumulative impacts of re-occurring smaller events alongside more extreme, but rare events. The full statistical accounting approach can also provide estimates for jurisdictions to plan with (as for instance done in a cost-benefit approach with different flood risk reduction measures, as was done for the Squamish FRA). Decisions are affected by the approach taken (Lyle, 2016), and it is therefore important to choose an appropriate approach given the available resources, data, and time. Please also see Section 7.3.2 for more information on the importance of selecting appropriate likelihoods to support a full statistical accounting assessment.

7.3.4 Stakeholder Engagement and Workshops

For a comprehensive local FRA, it is particularly important that the FRA reflects the local priorities, values, and circumstances of the jurisdiction to ensure that recommended risk reduction measures are adequate. This local knowledge can typically only be gathered in workshops, or other engagement activities, with local stakeholders. Workshops or other suitable engagement processes are also essential to collect information on potential intangible and indirect consequences from the communities, which may not be inferred from quantitative datasets alone.

More details on engagement approaches can be drawn from the NRC Coastal Flood Risk Assessment Guidelines for Buildings & Infrastructure Design Applications (Murphy *et al.*, 2020), as well as international best practice approaches (e.g., Cornell 2006, Australian Emergency Management Institute 2014, Australian Institute for Disaster Resilience 2015, Edelenbos et al. 2017, FLOODsite 2009, Sayers et al. 2014, UNISDR 2017, FEMA 2016). Further, the involvement of engagement specialists can support effective and rewarding engagement experiences for both participants, and risk assessors. The below information is drawn from Murphy *et al.*, 2020.

Stakeholders, partners, the general public and other interested or affected parties (stakeholders), and society as a whole, need to understand the risks they are exposed to and have a legitimate interest in the decisions that relate to flood risk reduction (Cornell, 2006; UNDRR, 2017; Murphy *et al.*, 2020). Further, meaningful engagement of stakeholders will enable risk assessors to better understand the diversity and the breadth of the problem. The goal therefore of a stakeholder engagement process within a risk assessment process is to ensure that broader societal goals, interests and challenges are ideally reflected in the assessment, or in some cases noted as a gap (Murphy *et al.*, 2020). Also, given the data-intensive nature of risk assessment, there are potential advantages to engaging stakeholders from whom data and local knowledge might be leveraged.

Engagement describes a broad spectrum of concepts related to the involvement of, and interactions with, stakeholders in decision-making processes (IAP2 Canada, 2020; Murphy *et al.*, 2020). In the context of flood risk assessment, this can range from informing stakeholders about the process, to checking-in that the process is on the right track, to fully inclusive processes where stakeholders have a say in how they are engaged, how often they are engaged and how they affect decision-making.

There are four steps to engage stakeholders (Murphy *et al.*, 2020):

1. Set context and purpose
2. Identify stakeholders and decision-makers
3. Work with stakeholders
4. Document activities and report back

The identification of appropriate stakeholders is key to success in flood management initiatives (Edelenbos *et al.*, 2017). Clearly, the voices around the table will affect the outcome of the process. Some examples of potential stakeholders for risk assessment processes are listed in Table 32; this list is provided as an example and may not be exhaustive for specific local conditions.

Table 32: List of stakeholders for FRA, based on Murphy et al, 2020.

List of potential stakeholders to be potentially engaged in FRA workshops and other engagement activities
• Indigenous Peoples and Governments • Local government officials (engineering, planning, etc.) • Regional government officials (engineering, planning, etc.) • Provincial/Territorial officials (engineering and planning, etc.) • Federal government officials (engineers/planners/scientists) • Professional associations (engineers/planners) • Critical infrastructure providers • Other affected partners • The public

While workshops and other engagement activities always involve substantial work, they should be considered a requisite for a comprehensive local FRA, to ensure it is relevant for the local context. As discussed above, additional information for quantitative datasets can be unearthed, along with qualitative narratives of community values, experienced impacts, and risk reduction ideas. Further, the weighting of different indicators, can be discussed with stakeholders in a workshop format.

The current COVID-19 pandemic poses substantial challenges to traditional engagement activities, such as workshops. And, there are a number of emerging online and digital engagement tools, that are emerging, such as the *Join the Conversation* web platform, where for instance, flood hazard maps can be uploaded, and stakeholders can interactively drop pins to where they have experienced, or would anticipated, impacts to flooding. However, in the experience of the authors' the information collected through these methods are less rich, and there is a smaller co-benefit of trust-building, which will be important when risk reduction options are being discussed or implemented. Further, several recent risk assessment projects (e.g. RDKB and Southern Dakehl Nation Alliance) were hindered by poor internet connectivity (both the lack of internet infrastructure, and the desire to use it).

7.3.5 Indigenous Inclusion

Limited information on Indigenous Inclusion for risk assessment was collected through the FBC survey. However, a few learnings from Ebbwater's experience co-developing flood risk assessments with First Nations is noted below:

- Better outcomes have occurred when the projects were co-lead and directed by Indigenous Peoples.
- Earnest effort on the part of non-Indigenous participants and consultants is important; general principles of reconciliation should be applied.
- Projects take significant time and budget resources to support a period of trust-building.
- It is key to acknowledge that some data (e.g. sensitive archeological sites) will not and should not be published or publicised. Careful data sharing agreements must be developed.

7.3.6 Intangible and indirect consequences

A quantitative FRA primarily considers tangible and direct consequences. However, some more intangible consequences can also be captured, via proxies. For instance, as a proxy for (intangible) impacts to the culture of a community, the number of cultural sites (heritage, archaeological sites), community buildings, schools, etc. within the flood hazard extent could be assessed.

Indirect consequences are even more challenging to quantify, especially, as an FRA can have cascading impacts on the wider society (for instance, in the case that an electrical sub-station is affected, and many areas outside of the immediate flood hazard zone lose power). However, stakeholder engagement can typically highlight concerns for indirect consequences. For instance, in the case of the small coastal community Tofino, a concern which was raised was that there is only one access road, which is may be impacted by flooding, and thus, cutting the community off resources. Further, this would not only impact Tofino itself, but also many remote boat-access-only communities, which rely on Tofino for food and hospital access. While information such as this is challenging to quantify in an FRA, the narrative itself should be included in the report, and considered in risk reduction recommendations.

7.3.7 Confidence Rating

As discussed for regional FRAs, confidence ratings should also be assigned for local FRAs. Confidence ratings should be assigned to both hazard and exposure/consequence data, and a combined confidence score should be calculated for each indicator (e.g., following the approach in AIDR, 2015). For instance, the Orphaned Flood Protection FRA, the BC Climate Risk FRA, and the Tofino FRA included reporting of confidence ratings. The consequence confidence rating describes how well the proxy data can capture the consequences associated with an indicator.

7.3.8 Next Steps

At the end of a comprehensive local FRA report, recommendations for next steps towards a flood-resilient community should be made. This can include general best practice recommendations, analysis/discussion of high priority flood risk areas, recommendations for priority actions, and quick-wins-and-no-regret actions. More detailed flood planning will be discussed in Issue B-4: Flood Planning (Kerr Wood Leidal Associates Ltd., 2020), as well as in Issue B-5: Structural Flood Management Approaches (Northwest Hydraulic Consultants Ltd., 2021b) and Issue: B-6 Non-structural Flood Management Approaches (Northwest Hydraulic Consultants Ltd., 2021c).

7.3.9 Challenges and Advantages of Comprehensive Local FRAs

A good local and comprehensive FRA depends on high-quality hazard data input. However, this is often not available for a location, especially not for multiple AEPs and climate change scenarios, which should be included especially if the FRA will direct flood risk reduction options and planning decisions.

Similarly, data limitations exist for exposure and vulnerability information. While province-wide datasets are available, which may be adequate for regional FRAs, these datasets may not be sufficient for local/comprehensive FRAs. Thus, the FRA is dependent on data availability at the local jurisdiction, which varies widely.

For instance, to estimate building damages, detailed building survey data is needed, which only exists for limited jurisdictions/communities. Further, adequate depth-damage curves are needed, which reflect BC housing styles. Development for some such depth-damage curves is currently under way at the FBC. Until these curves become available, one should however be careful to apply damage curves that have been developed for other locations (for instance, the FEMA HAZUS curves which were developed for the U.S.), and potentially report total exposed building values instead (while of course ensuring, it is clearly communicated that total exposed values are reported, and not estimated damages).

Social vulnerability data is often also limited, or, while available via census data, not at the aggregation level that allows straight-forward spatial processing for FRAs. This data will likely become more accessible through the NRCan Exposure Model, which is currently in development and is discussed in Section 4.3.3.1. Within the Province, there is also a push to apply a Gender-Based Analysis Plus (GBA+) framework to risk assessments, which would include reporting on more details within the demographic data (e.g., segregation by age, gender, income, etc.), some more information on this is provided in the recently completed *BC Climate Risk Assessment Framework Customization Recommendations* (ICF Consulting Canada Inc, 2020).

As discussed for regional FRAs, risk methods currently vary widely throughout the province, making comparability challenging. Further, while best practice for risk assessments is to apply a full statistical accounting approach and estimate the average annual loss, this is rare, likely due to the additional effort required, and potential limitations in available hazard data and knowledge capacity/guidance.

Further, even in a local and comprehensive FRA, it remains challenging to assess intangible and indirect consequences. Nevertheless, it should be attempted to document these, and even if they cannot be incorporated into a quantitative FRA, the narrative on intangible and indirect consequences should be included.

The possibility to delve into the local context is probably the main advantage of a local FRA – and should therefore be applied in the FRA, by engaging with the local community and by tailoring the FRA and especially risk reduction recommendations to the local context. Community and Indigenous engagement are essential for FRAs at the local level and can offer much towards making an FRA relevant for the local jurisdiction.

7.3.10 Generic Local-Scale FRAs

Developing a generic local-scale FRA assessment (based on a very specific FRA method drawn from the above method discussion), which would then be replicated across the province, could provide one means to ensure more consistency in FRA methods. A generic local-scale FRA would include the key components of the aspects discussed in the preceding sections but would leave less room to adapt the FRA to local values and priorities; it could however be enhanced after the fact.

However, especially for local and comprehensive FRAs, it is key that the FRA also reflects the local context and priorities to ensure that the local hazards, exposure, and values are captured. By applying a generic assessment approach, some of these local nuances might become lost. However, these local nuances are key for a local FRA, to inform locally relevant flood risk reduction measures. In contrast, the province-wide FRA will likely provide a more generic approach to FRAs.

7.4 Class D Cost and Capacity Estimates

7.4.1.1 Class D Cost Estimate for Local and Comprehensive Flood Risk Assessments

For a local and quantitative FRA, the allocated funding budgets for past projects were between $53,000 and $268,000, with an average budget of $133,000, or $8,600 per km^2 (Table 16). However, as discussed in Section 7.2, the FRA methods and depth of approach (i.e., how comprehensive these studies were) varied substantially. Further, the allocated budget also varied greatly between the listed studies, and not all the studies identified as local/quantitative would be considered a comprehensive FRA, as described in Section 7.3. The more comprehensive FRAs, such as the District of Tofino, Squamish River Floodplain, Cowichan Valley RD Coastal Sea Level Rise and Youbou/Lake Cowichan risk assessments had budgets ranging from $150,000 to $210,000 (the Cowichan Valley RD and the Youbou/Lake Cowichan risk assessments included a hazard mapping component). As far as can be determined from the reports, none of the above projects had a specific Indigenous engagement component, however, as part of the Tofino and Youbou/Lake Cowichan, general engagement activities were conducted, to which First Nations were invited. Thus, if a specific Indigenous engagement component were included, additional funds should be included to for example support Indigenous attendance through travel bursaries and honararia. The highest budgets were noted for the Grand Forks FRA ($225,700) and the Kelowna Major Systems FRA ($268,700), however, as no reports were available for these studies, it cannot be assessed how comprehensive these FRA were.

Therefore, in general, project budgets for a comprehensive FRA ranged between $150,000 and $210,000, plus potentially extra funds needed for specific Indigenous engagement (estimated at $40,000 for one workshop, and $20,000 for a watershed tour with Elders). Most of the comprehensive FRAs contained some engagement and workshops, otherwise, it would need to be accounted for additional budget for workshop ($40,000 per workshop). It should be noted that the cost estimates assume that flood hazard data is available, and no additional flood hazard mapping is required as part of the flood risk assessment. Cost for the flood hazard assessment are provided in Issue B-2: Flood Hazard issue. Some more details on cost and capacity estimates for comprehensive local FRAs are also provided in Section 5.3.3.

7.4.1.2 Capacity and timeline

The required time frame to conduct an FRA depends largely on data availability (hazard, exposure, vulnerability), how many scenarios are considered (AEPs, climate change, exposure change), on the extent to which communities are engaged to collect and include intangible and qualitative information, and the overall comprehensiveness of the study. For the incorporation of stakeholder and Indigenous engagement, adequate time frames have to be allocated. It is estimated that a 1-year time frame should be adequate for a comprehensive FRA, if the community is ready to engage and has already begun to collect and consider the information required to inform the process. This assumes that flood hazard data is available for input and would assume a larger engagement component (2-3 workshops, including Indigenous engagement). Shorter timelines might be applicable if limited engagement is conducted.

This estimate is based on previous work experience, and assumed from other FRA projects, which are known to the authors, or could be deduced from reporting. Typically, funding becomes available in late spring/early summer, and the FRA is due the following spring.

As discussed in Section 5.3.3, local FRAs are resource and capacity intensive. As currently only a small number of companies conduct quantitative FRAs throughout BC, and as appropriate funding will need to be allocated to conduct many local FRAs, it will likely take some time (about 10 years, see estimation in Section 5.3.3) to conduct local FRAs for all communities with flood hazard in BC. This will be improved over time if capacity in the field is increased through the development and dissemination of guidelines (e.g., the NRCan Flood Risk Assessment Guidelines, the NRCan Coastal Flood Risk Assessment Guidelines, and potentially, a BC-based guideline), and through natural increases as more projects are funded and completed across the country. Guideline development and application will also improve comparability between FRAs. Importantly, local FRAs also rely on local high-quality hazard information, which needs to be obtained before these local FRAs can be conducted, thus further delaying the availability of local FRAs.

Considering the work involved conducting a comprehensive local FRA, especially if conducting engagement, it is not recommended that a single firm conduct these across all of BC. However, it would be beneficial for multiple firms work together in a collaborative learning environment, so that new methods, datasets, and ideas are shared, and so that peer-review becomes part of the process. For the comprehensive FRAs, it is important to consider the local context and build relationships with local stakeholders, which would not be possible if conducted BC-wide.

7.5 Recommendations

Table 34 lists recommendations based on the above analysis for a comprehensive local FRA. The recommendations include high-level estimates of priority and cost (primarily dollar cost, but also in some instances human resources and skills) are provided in this table as High (red, 10s of $M), Medium (yellow, $Ms) and Low (green, $1000s to <$M). These costs will be further refined and aggregated in Issue D-1: Resources and Funding (AECOM Canada Ltd., 2021). A note to whom the recommendation is targeted at in the Recommendation/Option Column..

Table 33: Recommendations based on Investigation B-3.5.

Recommendation	Rationale	Priority	Cost
Topic 1: Support Continuing FRAs			
1. Continue to support the development of FRAs, and obtain funding **(Province)**	The analysis for this project showed, that currently, only a very small percentage of communities with potential flood hazard have FRAs. As FRAs provide the basis for decisions for flood risk reduction measures, it is essential that the Province continues to ensure there is funding available to do complete FRAs (through federal and provincial programs).	H	H
Topic 2: Increase Capacity and Consistency in FRAs			
2. Support flood risk assessment guideline development	Substantial diversity in FRA methods currently exists in BC. While for a comprehensive local FRA, it is important to consider local priorities and values, key elements of an FRA should be consistent between FRAs. Therefore, it is recommended to support the development of a BC - specific professional practice guideline. Currently, there are two new federal FRA guidelines underway by NRCan, and recently, one has been completed by NRC. These guidelines can be leveraged to ensure consistency with federal guidelines, and potentially be adjusted for BC-specific context. Potential gaps in the federal guidelines as they relate to BC include the lack of diversity of hazard characteristics presented (BC has a wide variety of different flood types), the lack of depth related to the	H	L

Recommendation	Rationale	Priority	Cost
	more holistic, intangible indicators, especially as these relate to Indigenous values.		
3. Encourage Knowledge sharing activities and workshops	To increase capacity in conducting FRAs, knowledge sharing activities (such as the recently started Flood Risk Collaboratorium, which meets every few months), workshops, and teaching activities should be encouraged, to increase capacity to conduct FRAs in BC.	M	L
4. Increase exposure and vulnerability data availability	A large part of a FRA is collecting and pre-processing exposure and vulnerability data. As discussed in B-3.2, the better availability of exposure/vulnerability data bases would make FRAs more efficient.	H	H
Topic 3: Comprehensive Local FRA – Methods Recommendations			
5. Conduct flood hazard assessment project separate from FRA project	Comprehensive local FRAs depend on high-quality flood hazard data. When flood hazard and risk assessments are conducted within one project, based on the reviewed reports, the focus was typically on flood hazard, and flood risk was mostly an 'add-on' and conducted qualitatively. It is therefore recommended to conduct these as separate projects – also as they require different foci, and different expertise. It is important to ensure that there is some connection between the two, and that the hazard information is appropriate for risk assessment (see also next recommendation).	M	L
6. Ensure availability of high-quality and up-to-date flood hazard data	Currently, high-quality and up-to-date flood hazard maps are not consistently available for all communities potentially exposed to floods. Therefore, an important step is to ensure that flood hazard mapping is funded and completed across BC. It needs to be ensured that flood hazard mapping is done according to professional guidance, via hydrodynamic/hydraulic modelling, is well-documented (detailed methods report, metadata), and data is made available to the community, and to the Province. (See also Issue B-2: Flood Hazard)	H	H
7. Include multiple flood hazard	To capture the full spectrum of risk, both frequent and very rare flood likelihoods need to be included in analysis. In particular, if a full statistical accounting FRA	H	L

Recommendation	Rationale	Priority	Cost
scenarios (frequent to rare) in FRA	approach is conducted (which is best practice), 6-8 different AEPs should be modelled during flood mapping. It is a marginal effort to include additional AEPs, but an essential base for a comprehensive FRA.		
8. Include dike fragility, where applicable	For flood hazard areas surrounded by flood protection structures, the probability of structure failure needs to be included, along with likelihood of flood scenario.	H	M
9. Include Quantitative Climate Change Scenarios in FRA	Given that FRAs are used to plan flood risk reduction measures into the future, it is essential that climate change scenarios are included in the FRA, especially in a comprehensive local FRA. For this, however, again, hydraulic flood mapping of climate change scenarios is needed. This should be done in a quantitative matter, based on projections for the regions, and ideally not by simply adding an 10-20% increase to historical peak flows. The B-1 Impacts of Climate Change issue provided more detail on this.	H	L
10. Include a diverse set of indicators in FRA	To capture a wide range of potential consequences to flooding, a diverse set of indicators should be included in the FRA. This should not only include tangible aspects (such as impacts to buildings and the economy) but also more intangible aspects (impacts to culture and environment). Social-vulnerability aspects should also be considered. If some intangible and indirect consequences cannot be captured quantitatively, additional narrative and qualitative mapping approaches can be used to include information in FRA report.	H	L
11. Conduct in-depth engagement activities with local stakeholders	Appropriate and in-depth engagement with local stakeholders is particularly important for a comprehensive local FRA, where it needs to be ensured that local values and priorities are captured, and stakeholders are well-informed of the FRA process and results. Engagement can include workshops, watershed tours, interactive mapping activities, and more. Costs can seem prohibitive, but there are many co-benefits	H	M

Recommendation	Rationale	Priority	Cost
	associated with these activities, such as trust-building and education.		
12. Use a full statistical accounting approach, where possible	Best practice is to use a full statistical accounting approach, where risk is assessed for many frequent to rare likelihoods. This allows to not only plan for the consequences of a catastrophic but very rare flood event, but also consider the cumulative impacts of small but frequent floods.	M	L
13. Provide confidence ratings	FRAs are always based on uncertain data, and in many cases, proxies must be used to describe an indicator category (e.g., community buildings and archaeological sites as proxies for impacts to the culture of a community). To capture the different uncertainties related to hazard and exposure data, confidence ratings should be assigned and reported along with the FRA results.	M	L

8 Investigation B-3.6 Valuing Costs and Benefits of Risk Reduction Actions

8.1 Introduction

The management of natural hazard risk is a classic 'wicked problem', where obstacles to good decision-making include multiple-stakeholders, infrequent but damaging events, short-term planning horizons and funding. There are no perfect solutions; prioritizing one objective or challenge will undo another. And, with climate change decisions are even more difficult; the uncertain nature of climate change, the unknown timescales and the intangibility of impacts makes decision-making incredibly difficult.

As described in this report, using risk as a feature of decision-making (rather than a standards-based approach – see Section 3) has many advantages. However, given that the use of risk to support decision-making (at least in the context of natural hazards) is a relatively new concept, there are few examples to follow.

The overall goal of this investigation is to explore **how risk can be used to make decisions** related to specific flood actions.

8.1.1 Research Objectives

Research objectives and questions related to costs and benefits were defined jointly by FBC and MFLNRORD. Specially, to investigate methods for valuing the benefits and costs/limitations of flood risk reduction actions in a holistic and consistent manner and develop a framework for project prioritization that could be applied or adapted across the province to reduce flood risk and improve environmental outcomes. Given the identified need to broadly engage, and to align a decision framework with any direction (i.e. Vision) from the Province, no framework was developed.

8.1.2 Definitions

The research question above uses the terminology of cost and benefit. Although this can be applied more broadly, it is generally understood to focus on tangible economic costs. Whereas, as described elsewhere in this report, consequences from flooding are much broader than just dollar costs. Further cost/benefit approaches imply a relatively black and white vision of a problem, where one issue is either a cost or a benefit. Whereas, many measures of flood risk exist on or across a spectrum of positive and negative impacts. For example, recent work for the ONA (Ebbwater Consulting Inc., 2019c), required a shift in thinking and terminology to define floods as "phenomena" rather than a "hazard" to make it clear that they are both a good and bad thing. Therefore the report adopts the use of the term "trade-offs" for this work to better reflect relative nuances between what are considered positive and negative flood events.

8.1.3 General Approach

In addition to the overall research methods documented in Section 1, the following was done in order to answer the research questions above:

- Earlier works prepared by the author were referenced and updated.
- Information provided by the FBC regarding the existing consideration of tools to understand tradeoffs were incorporated.
- Desktop research was conducted to build on an inform the analysis.

- A high-level recommendation was made based on the research, and the findings of earlier investigations.

It should be noted that this investigation was conducted under a relatively small scope and is by no means comprehensive. Decision-science, especially with the consideration of risk, for such a wicked problem as flood, is incredibly complex, and likely warrants a larger discussion and research effort.

In general, the process to come to decisions is rarely well studied or research and suffers from a general lack of not knowing what we do not know. The following is provided to support an understanding of the basics of decision processes so that it is hopefully clearer why more attention MUST be paid to how risk (or hazard) information is used to make decisions.

8.2 The Importance of Suitable Decision Processes (The Why)

Flood is classic wicked problem (see Section 3), where there is no perfect solution, and where actions can be seen as both positive (e.g., a dike stops the water damaging houses) and negative (e.g. a dike limits ecosystem values). It can be likened to a chaotic ball of wool, where tugging on a thread to improve the situation necessarily, affects a web of other issues, and can further tangle the problem. If we layer on the uncertainties related to flood, like the probability that a flood will not occur, or changing likelihoods and hazard severity due to climate change, the problem becomes even more complex.

A robust decision-making process is required to ensure that as many of the issues and uncertainties as possible are addressed. It is known that the choice of decision-making process can affect the outcome (Dean and Sharfman, 1996). Therefore, the selection of an appropriate decision-making process that explicitly considers as many of the facets of this 'wicked problem' as possible, will strengthen the overall decision process, and the resulting decision.

At the outset it is important to understand why decisions are being made. These are broadly grouped into decisions related to priorities. For example, selecting where in the province funds should be allocated to get the greatest risk reduction benefit. And second, decisions related to what type of action should be pursued to reduce risk.

8.3 Risk Reduction Targets (The What)

Planning and decision processes generally require a goal or target; it is not possible to make good decisions on how to get somewhere, without knowing where you are heading. As discussed in Section 3.5.5, we (as Canadians and British Columbians) lack general guidance on where we are heading. In general, broad statements have been made in the EPA modernization regarding a goal of "reducing risk", similar goals are found in the Vision statements for the Lower Mainland Flood Management Strategy. However, what specifically is meant by "risk reduction" is not defined.

A few options exist for targets that could be leveraged in support of a Provincial Strategy or for individual communities. For example, International Frameworks such as Sendai and the UN Sustainable Development Goals provide both general trends (either increase or decrease) as well as specific targets through the UN Working Group on Indicators (see also Section 2.7, where various frameworks, some of which have targets and goals are presented).

In the short-term, prior to setting specific targets, it is important to first have a baseline (we need to know where we are now before knowing where we might want to go). And, second to develop responsibility and authority to set specific goals (e.g. SMART goals).

8.4 Decision Processes to Enable Flood Risk Reduction (The How)

Prior to selecting an appropriate decision tool it is important to first establish objectives and measures for what would make a preferred process/tool. Some key considerations are noted below:

1. **Ability to consider multiple dimensions/characterisations of hazard.** As described in Section 2.3, flood is not one thing, but a complicated hazard with many dimensions. Decision processes should ideally be able to manage these many dimensions.
2. **Ability to manage uncertainty.** As described elsewhere, uncertainty is rife in flood. It is important that some uncertainty be included in a decision process. This can be the more straightforward uncertainties associated with climate change (science) or potentially more complex uncertainties associated with people and politics.
3. **Ability to consider multiple dimensions of consequence.** As described in Section 2.4, flood consequences are varied and complex. Fully holistic consequences are important to consider in evaluations. The choice of measures to include greatly affects outcomes. For example, in the City of Vancouver (described in more detail below), the choice of measures affects the choice of action. The more holistic of the recently completed FRAs in the province consistently show how focus shifts dependent on indicator.
4. **Ability to incorporate Indigenous values.** These are a specific, complex, but absolutely necessary consideration.
5. **Ability to incorporate broad public values.** Public and/or stakeholder engagement is generally seen as a necessary and important component of decisions processes.
6. **Ability to consider multiple geographic scales.** As noted in the investigation objectives, the Province wishes to consider multiple scales for decision-making – both provincial prioritization and local actions.
7. **Ability to consider full disaster cycle.** Decision processes should ideally be able to consider more than a snapshot in time. As it relates to flood, ideally decision processes should also consider pre- and post-shock states. See also below for a discussion of potential objectives and measures to support this.
8. **Ability to consider multiple timelines.** Decisions related to flood are generally required to answer questions on multiple timelines. For example, immediate structural responses versus long-term strategic land use planning. Any decision process should be able to look at multiple time horizons to explore both the short and long-term impacts of decisions.
9. **Transparency of process.** It is general considered important that decisions processes be repeatable and transparent in democratic societies.
10. **Implementability of process.** As for the various scales of FRA, there are various levels of effort associated with decision processes. It is important to consider whether a decision process is even possible given existing resources, data, governance structures, etc.

8.5 Existing frameworks and methods

The following provides a brief overview of decision processes that have been applied in BC and around the world to address flood problems.

8.5.1 Cost-Benefit Analysis

A cost-benefit analysis (or CBA) is one of the more familiar tools used when making decisions related to large infrastructure projects. At its simplest it looks at the dollar costs of building a specific piece of infrastructure and compares this to the benefit (in the case of flooding – saved damages) over the design life of the structure. The major benefit of this type of approach is that it has a standard methodology and is well understood by decision-makers and the public alike. However, CBA is known to have weaknesses, especially for tricky natural resource based problems. Specifically, a CBA analysis cannot adequately address intangible impacts or benefits – like habitat impacts or a loss of sense of community. Furthermore, the process is not well-suited to multi-stakeholder problems, as it is difficult to meaningfully engage and involve stakeholders in what is essentially a mathematical exercise.

8.5.2 Multi-Criteria Analysis

A multi-criteria analysis (or MCA) is a variation on a CBA that allows for the inclusion of non-monetary costs and benefits. It is a well-developed tool that is commonly used for natural resource and engineering problems. It uses multiple measures, and scores options across each measure. These are often ultimately weighted to give single score to each option.

An MCA approach is generally seen as an improvement to the CBA as it can consider non-monetary issues. Its weakness for flood management and planning is that it requires value judgements (usually by a single decision-maker or team) to weight the various criteria. It is generally considered a low-stakeholder involvement exercise, which may reduce long-term buy-in to project results. It also does not explicitly address uncertainty.

Although not complete and not strictly an MCA approach – the District of Squamish's in process Integrated Flood Hazard Management Plan project is using MCA to describe flood risk (under the categories of natural, economic, social, political and technical) – see Figure 29.

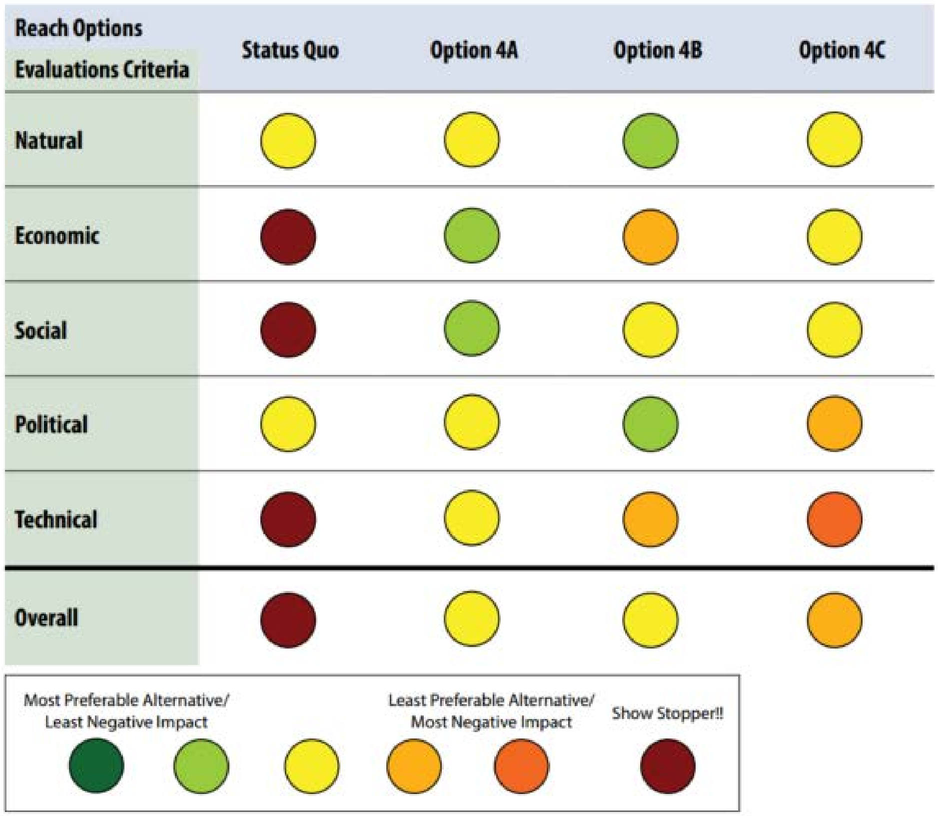

Figure 29: Example MCA Matrix for Squamish Coastal Hazard Options (KWL 2015)

8.5.3 Real Options Analysis

An alternative to traditional CBA analysis that attempts to include uncertainty (especially related to climate and sea level rise) is Real Options Analysis. This type of analysis evaluates the flexibility of a decision to changes in flood hazard or socio-economic vulnerability. It attempts to deal with the problem of an option that performs well against a range of criteria (see CBA and MCA) under one future, but poorly under another. This method explicitly considers the value of delaying a major investment decision until future uncertainties are reduced, and assigns value to options that are adaptable to various future scenarios. Figure 30 shows an example scenario of Real Options Analysis.

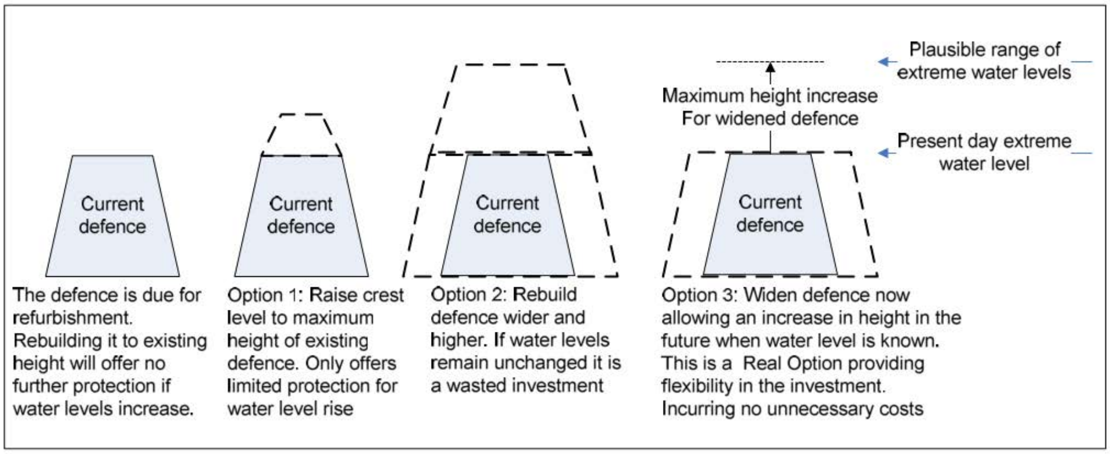

Figure 1 - Description of a flood risk management Real Option

Figure 30: Example of Real Options approach from Woodward et al 2009

The clear advantage of this type of approach is that it deals with the uncertainties in our future climate, and could be adjusted to include development (i.e. what will be the development pressures in the region with increased population growth) and regulatory uncertainties (i.e. will the Federal Government make changes to the Disaster Financial Assistance Arrangements or will the Provincial Government make the proposed amendments to the Flood Hazard Area Land Use Guidelines). It is well suited to large infrastructure decisions when there are only a couple of options to consider. This approach is described in academic literature (Woodward *et al.*, 2009; Woodward, Kapelan and Gouldby, 2014) (including case studies for the Thames Estuary in the UK), however no actual ongoing projects with local governments using this analysis for sea level rise studies were found. The main downsides the authors see to this type of approach is that it is technically complex and relatively opaque. It is not well suited for stakeholder or public engagement. Nor does it have the capacity to include multiple values – the academic examples focussed entirely on dollar benefits and losses.

8.5.4 Structured Decision Making

Structured Decision Making (SDM) is a framework for thinking critically about decisions that provides an organized approach to identifying and evaluating creative alternatives and making defensible choices in difficult decision situations. It is designed to engage stakeholders, technical experts, and decision makers in a deliberative decision process, using best practices in decision making. Its goal is to both inform and actively aid decision makers, not to prescribe a solution or to develop a summary number or ratio.

A decision framework does not by itself select a preferred management option but provides insights about the decision by clarifying the things people care about, identifying creative alternatives, and exploring the trade-offs or choices that need to be made. SDM is designed to deliver insight to decision makers about how well their objectives may be satisfied by alternative courses of action, how risky some alternatives are relative to others, and what the core trade-offs between the available options are. It is designed to engage stakeholders, technical experts and decision makers in a decision process that is both analytical and deliberative, using best practices in decision making. An SDM process is designed to make complex choices more explicit, better informed, more transparent, and more efficient. An example output of an SDM process, known as a consequence table, is presented in Figure 31.

Southlands Consequence Table

	Scale	Dir	BASELINE	PROTECT Shoreline Dike	ADAPT Multiple Tools	MANAGED RETREAT
PEOPLE						
People Displaced - Flood Events	# of people displaced	L	2094	0	1466	0
People Displaced - Permanently	# of people displaced	L	1572	0	1100.4	2094
at risk' people impacted	SVI weighted displacement	L	553	0	387	0
Park and Recreational Amenity Value	Area affected per event (sq-km)	L	1.6	0.0	1.6	1.6
Loss of critical services	# of pieces of infrastructure impacted	L	0	0	0	0
Aesthetics	-2 to 2	H	0	-1	-1	1
ENVIRONMENT						
Risk of Contaminant Release	# of sites w/ potential contaminants	L	2	0	0	0
Environmental Benefits	-2 to 2	H	0	-2	1	2
ECONOMY						
Damage to Infrastructure	Value-weighted km of roads impacted	L	14803	1348	10362	0
Damage to buildings	$M	L	40.1	1.4	28.1	0.0
Business disruption	# of employees impacted	L	400	0	280	0
Loss of inventory	$M	L	60.9	0.8	42.6	0.0
Emergency response costs	$M	L	1.5	0.0	1.0	0.0
IMPLEMENTATION						
Capital Costs	$M	L	0	90	150	990
Maintenance costs	$M	L	0	0.07	0.55	0.00
Adaptability	1 to 4	H		1	3	4
Ease Of Implementation	1 to 5	H		1	3	1

Figure 31: Example Consequence Table for SDM approach to sea level rise adaptation for Southlands Neighbourhood, City of Vancouver

The benefits of this type of an approach for flood management decisions is that it can fully engage stakeholders, especially diverse stakeholders with differing values, and it is good vehicle to develop new or improved options to those originally presented. The downsides of this type of approach is the level of effort required and the lack of an absolute decision at the end of the process; instead trade-offs are presented that requires decision-makers (usually senior decision-makers) to make a final call. Furthermore, this process does not explicitly address uncertainty, although it can be included implicitly.

This is the type of process that the City of Vancouver elected to use in their recent Coastal Flood Risk Assessment Project. The City is generally happy with the process (pers. comm with City Project Manager, 2016), although it would have been more suited to a problem with more diverse stakeholders who had differing values. More recently, this approach, and the risk-tolerance based decision framework that followed it, has been lauded internationally as best practice for sea level rise adaptation by the C40, and is under consideration by several major delta cities (e.g. London, New York).

8.5.5 Scenario Analysis

Scenario analysis is a process of analyzing the future by looking at alternative outcomes. It is increasingly used for analysing long term uncertainties that are not readily quantifiable. Whilst there are many versions of scenario analysis, they all tend to be based around construction of a small number of contrasting yet internally consistent narratives about the future.

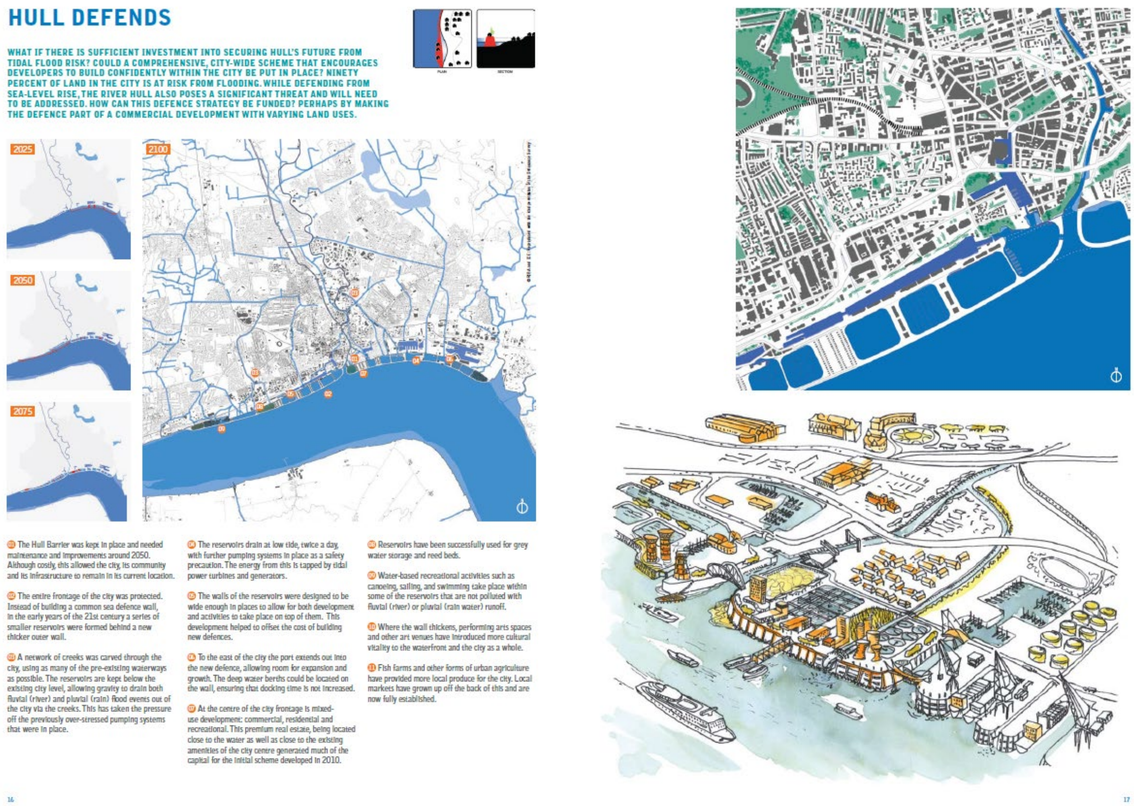

Figure 32: Example of single scenario used for analysis from ICE 2010

The benefits of this type of approach for SLR studies is that it is generally easily understandable; it is based on narratives and graphics. A scenario analysis approach can also explicitly consider uncertainties. The downsides of this type of approach, especially when decisions need to be made in the near future, is that it does not by itself produce concrete decisions and next steps.

This type of approach is commonly used in Europe, especially for projects that include public participation. It is most famously used and supported by the UK Institute of Civil Engineers as well as by the IPCC.

8.5.6 Robust Decision Making

Robust Decision Making (RBD) is a Bayesian-based approach to look at the most probable outcomes of climate change. It is being used by the USGS to map changes to coastal morphology of the eastern sea board of the US. It's a useful first-step tool (it establishes the most probable future hazard), but doesn't provide a lot of guidance in terms of what the best adaptation response might be. Yip (2019) provides an example of a robust decision-making tool for Vancouver, thereby showing that this is a possible and implementable option in BC.

8.6 Considerations for Objectives and Measures with a Risk AND Resilience Lens

A few objectives, beyond those that are normally considered (e.g. LMFMS list above), are worth mentioning here for discussion. These have been drawn from work conducted by Ebbwater in support of the Disaster Mitigation Adaptation Fund program criteria development, and provide additional context for developing provincial strategies that focus on resilience as opposed to just risk reduction (see Section 1.3)

8.6.1.1 No Risk Transfer (or No Adverse Impact?)

This measure considers that proposed projects/actions must not only work towards mitigation of natural hazard risk in the immediate area of the project, but also ensure that the risk is not transferred to a neighbouring area or community.

An example of risk transfer would be the construction of new dikes along a river to protect a segment of the floodplain. The dikes will confine the river, raising water levels upstream and increasing the velocity (and therefore erosive power) of the river downstream. The new dike may reduce hazard in the segment of river immediately adjacent to the structure but will transfer risk to upstream and downstream communities. The goal of overall risk reduction will not be achieved.

No adverse impact, or no risk transfer are standard concepts in Canada and around the world. For example, the Provincial Government in BC has within its Hydrologic and Hydraulic guidelines for Dikes a requirement for no risk transfer (BC Ministry of the Environment, 2008).

8.6.1.2 Pre-Shock Public Impact

Infrastructure built for disaster mitigation may reduce risk to natural hazards, but in many cases will only be used very occasionally when a rare natural event occurs. In the interim, the infrastructure may impact it's natural and social environment. Consideration of how infrastructure can negatively impact the public and natural environment over the course of its life is important. On the flipside, infrastructure can be designed to have multiple purposes (i.e. co-benefits) and be a benefit to society before a shock event.

8.6.1.3 Shock – Risk Reduction

Objectives and measures related to risk reduction during an event are arguably easiest to conceptualize. Ideally these would target a reduction (trend) or specific goal (target) for risk reductions under the indicator categories described above (e.g. mortality, affected people, etc.).

8.6.1.4 Post-Shock Public Impact

Recovery from a natural hazard event is integral to communities and to BC and Canada. Projects that are designed to ensure quick recovery will benefit the country.

- Resiliency is focussed on recovery
- E.g. Seismic project that protects for life-safety, but means buildings are not useable in aftermath
- Reduced costs of recovery

8.7 Analysis

The following table summarises a subjective analysis of the potential frameworks as compared to the objectives. Colour codes are provided on a three-part scale for each objective (note that measures are different).

Table 34: Summary trade-offs for different decision processes.

Objective/ Process	Priority Setting vs. Project Action	Hazard	Uncertainty	Consequence	Indigenous Values	Public/Stakeholder Values	Geographic Scales	Disaster Cycle	Timelines	Transparency	Implementability
CBA	Project	Possible	No	No	Not well	Not well	Possible	Not well	Possible	Medium	High
MCA	Project	Possible	No	No	Not well	Possible	Possible	Not well	Possible	Medium	High
Real Options	Project	Yes	Yes	No	No	No	No	No	Yes	Low	Medium
SDM	Both	Yes	Yes	Yes	Yes	Yes	Possible	Yes	Yes	High	Medium
Scenario Analysis	Project	No	Yes	Yes	Yes	Yes	No	No	Yes	Low	High
Robust DM	Both	Yes	Yes	No	No	No	No	Yes	Yes	Medium	Medium

The above table clearly shows (albeit subjectively), that some processes are much more effective for making robust decisions in BC for flood management. Specifically, the more involved Structured Decision-making processes show well across multiple measures, the main downfall being the effort required to conduct these types of processes. As a simpler, but similarly effective tool, Scenario Analysis could also be considered.

8.8 Recommendations

Table 35 lists recommendations based on the above analysis for a comprehensive local FRA. The recommendations include high-level estimates of priority and cost (primarily dollar cost, but also in some instances human resources and skills) are provided in this table as High (red, 10s of $M), Medium (yellow, $Ms) and Low (green, $1000s to <$M). These costs will be further refined and aggregated in Issue D-1: Resources and Funding (AECOM Canada Ltd., 2021). A note to whom the recommendation is targeted at in the Recommendation/Option Column.

Table 35: Recommendations based on Investigation B-3.5.

Recommendation	Rationale	Priority	Cost
14. Acknowledge importance of decision processes **(Province)**	It is recommended that the Province acknowledge the importance of the decision process to flood outcomes. As noted above, many decisions are made based on flawed processes, not flagrantly, but because the decision-makers were unaware of the importance of the process itself	H	L
15. Set risk reduction targets	In the short-term, prior to setting specific risk reduction targets, it is necessary to have a baseline (e.g. the flood risk assessments recommended above) (we need to know where we are now before knowing where we might want to go). And, second to develop responsibility and authority to set specific goals (e.g. SMART goals). In the longer term, risk reduction targets should be set. See also Issue A: Governance (Ebbwater Consulting Inc. and Pinna Sustainability, 2021).		M
16. Develop a guideline for decision processes	The authors recommend that the Province pursue further, more in-depth research into appropriate tools, and that is recommended that Structured Decision Making (and similar processes) and Scenario Analysis be included in this assessment. This should be included in a guideline document (possibly within a guideline for planning, see Issue B-4: Flood Planning, (Kerr Wood Leidal Associates Ltd., 2020).		L

9 Conclusions

This report explored the value and potential approaches and tools required to execute risk-based flood planning in the province. It included a comprehensive review of work to date in the province as well as best practices carried out elsewhere. The following conclusions are drawn:

- Risk-based approaches for flood management are superior to current standards-based approaches.
- Risk-based approaches require that flood risk assessments are conducted to support actions on risk reduction.
- Flood Risk assessments are complex, resource intensive and require deep and diverse expertise.

Given the importance of a risk-based approach to the future of BC's flood governance model, the report suggests that:

- A provincial-scale flood risk assessment let by the Province, using a top-down, consistent approach (at a cost of approximately $4.5M) is proposed to support large scale understanding or risk and prioritisation of activities across the province.
- Local and First Nation governments should continue to conduct local comprehensive risk assessments to support local decisions.

To enable the development of robust flood risk assessments:

- A flood risk assessment guideline, that leverages Federal draft and completed guidelines should be developed.
- The Province should support the development and ongoing maintenance of a consistent and comprehensive exposure database.

Beyond the development of flood risk assessments, it is important to consider how these assessments can be used to support risk reduction, through risk-based planning, risk reduction targets, and risk-based decision frameworks.

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11 Glossary

Term	Definition (if applicable)
Adaptation	The practice of adjusting or taking actions to limit or reduce vulnerability to changing hazard risk. In the context of climate change impacts on coastal flood hazard risk, specific adaptation actions might include improved coastal zone management, changes to planning, permitting, codes and standards, structural design, and social preparedness.
All Hazards	Referring to the entire spectrum of hazards, whether they are natural or human-induced. For example, hazards can stem from natural (e.g., geological or meteorological) events, industrial accidents, national security events, or cyber events.
All-Hazards Approach	An emergency management approach that recognizes that the actions required to mitigate the effects of emergencies are essentially the same, irrespective of the nature of the incident, thereby permitting an optimization of planning, response and support resources.
Annual Exceedance Probability	The probability, expressed in percentage, of a flood of a given size being equalled or exceeded in any year. Accordingly, a flood that is estimated to recur once in 100 years (on average) has an AEP of 1/100 or .01 (1% AEP meaning a 1% chance of occurring in any year). A flood estimated to recur once in 500 years on average has an AEP of 1/500 or 0.002 (.2% AEP).
Assets-At-Risk	Refers to those things that may be harmed by hazard (e.g., people, houses, buildings, cultural assets, or the environment).
Asset Inventory or Database	An inventory of assets-at-risk including the location, and sometimes vulnerability or resiliency measures.
Community Emergency Preparedness Fund	
Coastal Flood Hazard	A potentially damaging flood event (or multiple events) in coastal regions, which may cause damage to buildings and infrastructure, and/or the loss of life, injury, property damage, social and economic disruption, or environmental degradation.
Coastal Flood Risk	The combination of the probability of a coastal flood hazard event (or multiple events) and the associated negative consequences.
Contents Damages	The damages to the contents within a building, such as appliances, furniture, electronics, etc.
Critical Infrastructure	Processes, systems, facilities, technologies, networks, assets, and services essential to the health, safety, security, or economic well-being of Canadians and the effective functioning of government.
Damages	The financial and non-financial impacts/consequences of a hazard event. For buildings and infrastructure, this may include structural damage or loss of performance, or damages due to loss of serviceability/operability.

Term	Definition (if applicable)
Dike	An embankment designed and constructed to prevent the flooding of land. A dike is supported by related works, such as floodboxes, gates and pumps that serve to hold back floodwaters while continuing to discharge water from behind the dike.
Direct Damages	The financial costs to repair or replace an asset to its pre-flood condition. Direct damages include structure and contents damages.
Disaster	A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.
Disaster Risk Management	The application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses.
Disaster Risk Reduction	The concept and practice of reducing disaster risks through systematic efforts to analyze and reduce the causal factors of disasters. Disaster risk reduction includes disciplines like disaster mitigation and preparedness.
Exposure	The presence of people, infrastructure, housing, or other assets-at-risk (or parts thereof) in places that could be adversely affected by hazards.
Flood and Flooding	The presence of water on land that is normally dry. Often used to describe a watercourse or body of water that overtops its natural or artificial confines.
Flood Construction Level	The minimum height required for a development to protect habitable living space from flood damage.
Flood Maps (Mapping)	Maps (Mapping) that display information related to a flood, such as the estimated extent of flooding, water depths, water velocities, flood duration or other information.
Flood Risk Assessment	Evaluation of a flood hazard (including the expected flood extent, depth and direction of flow) together with information about assets and people that are vulnerable to flooding to identify potential economic, social, cultural and environmental losses from flooding.
Floodplain	A floodplain is flat or nearly flat land that is susceptible to flooding from a watercourse, lake or other body of water.
Floodplain Management	Floodplain management includes policies and regulations intended to reduce flood risks associated with land use and development in floodplains and flood hazard areas.
Hazard	A potentially damaging physical event, phenomenon, or human activity that may cause the loss of life, injury, property damage, social and economic disruption, or environmental degradation.

Term	Definition (if applicable)
Flood Hazard	A potentially damaging flood event that may cause the loss of life, injury, property damage, social and economic disruption, or environmental degradation.
Flood Mitigation	Steps to reduce flood damage by structural measures (such as dikes), non-structural measures (such as keeping populations and assets away from flood-prone areas or requiring floodproofing), or a combination of these measures.
Hazard Assessment	Acquiring knowledge of the nature, extent, intensity, likelihood, and probability of a hazard occurring.
Hazard Inventory or Database	An inventory of the location, nature, and extent of influence of any potential hazards in an area of concern. Generally compiled as a GIS database.
Hundred-Year Flood	A flood of a given size that is estimated to recur once in 100 years on average. This is an older term — the probability of flood recurrence is now more often expressed in terms of Annual Exceedance Probability (AEP).
Indirect Damages	The financial costs incurred as a result of a flood event. Indirect damages include flood fighting/mitigation, evacuation, temporary housing, employment and productivity losses, post-flood cleanup, etc. Areas outside the flood hazard may also experience indirect damages, such as business disruption.
Intangible Damages	The non-financial or otherwise non-quantifiable impacts due to a flood event including social, health, and environmental impacts. Areas outside the flood hazard may also experience intangible damages, such as due to the spill and transport of a deleterious material.
Likelihood	A general concept relating to the chance of an event occurring. Likelihood is generally expressed as a probability or a frequency of a hazard of a given magnitude or severity occurring or being exceeded in any given year. It is based on the average frequency estimated, measured, or extrapolated from records over a large number of years, and is usually expressed as the chance of a particular hazard magnitude being exceeded in any one year (i.e., the Annual Exceedance Probability, AEP).
Losses	Equivalent to damages that occur as a result of a flood event, both tangible and intangible.
National Disaster Mitigation Program	
Natural Hazard	Natural process or phenomenon that may cause loss of life, injury, other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.
Peak Flow	The maximum rate of water discharge during a flood at a given location on a river or other watercourse.
Probable Maximum	The largest conceivable hazard or risk event.

Term	Definition (if applicable)
Probability	In statistics, a measure of the chance of an event or an incident happening. This is directly related to likelihood.
Quantitative Risk Assessment	A risk assessment that is completed using quantified or calculated measures of risk.
Residual Risk	The risk that remains even when effective risk reduction measures are in place.
Resilience	The ability of a system (such as individual or multiple buildings or infrastructure assets), community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.
Risk	The combination of the probability of a hazard event and its negative consequences.
Risk Assessment	A method to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed buildings, infrastructure, people, property, services, livelihoods, and the environment on which they depend. Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards, such as their location, intensity, frequency, and probability; the analysis of exposure and vulnerability, including the physical, social, health, economic, cultural, and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities, with respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process.
Risk Management	The systematic approach and practice of managing uncertainty to minimize potential harm and loss.
Susceptibility	An asset that could be adversely impacted by exposure to a hazard is susceptible to the hazard. For example, a typical residential building is susceptible to damage from floodwaters. A properly constructed concrete landscaping wall that has some floodwaters around it may not be adversely impacted and is therefore not susceptible to a flood hazard.
Structural Damages	Damages to the structural systems of a building or infrastructure, such as walls, floors, heating and cooling systems, etc.
Tangible Damages	Measurable financial impacts due to a flood event.
Tsunami	A series of waves caused by a rapid, large-scale disturbance of water. Tsunamis can be triggered by earthquakes, landslides, volcanic eruptions, meteor impacts, human activities (e.g., explosions), and meteorological/atmospheric phenomena (meteo-tsunamis).

Term	Definition (if applicable)
Vulnerability	The characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard. For buildings and infrastructure assets, vulnerability is a product of both exposure and susceptibility to damage.

Appendix A - List of Investigations

Investigations in Support of Flood Strategy Development in BC

List of All Investigations

Theme A. Governance

Issue	Investigation
A-1 Flood Risk Governance	1. Identify the flood management services provided by each order of government in BC.
	2. Investigate the roles of non-government entities in flood management in BC.
	3. Identify challenges, gaps and limitations with current service delivery.
	4. Identify opportunities for improving collaboration and coordination within and across authorities and adjusting non-government entities' roles that would address challenges and improve efficiency and effectiveness.
	5. Recommend changes to support improved collaboration and coordination in flood management, including an analysis of benefits and costs/limitations for each recommendation.
	6. Investigate alternative options for distributing and integrating flood management responsibilities among authorities, including an analysis of benefits and costs/limitations for each option.

Theme B. Flood Hazard and Risk Management

Issue	Investigation
B-1 Impacts of Climate Change	1. Investigate the state of climate change science in relation to BC flood hazards and identify gaps and limitations in provincial legislation, plans, guidelines and guidebooks related to flood hazard management in a changing climate.
	2. Identify current sources of information and models used by experts in the province to predict future climate impacts and investigate opportunities for improved predictive modeling.
	3. Investigate the capacity of responsible authorities and other professionals and practitioners in the province to integrate climate change impacts and scenarios to inform flood planning and management.
	4. Investigate the legislative, policy, and regulatory tools available to responsible authorities in all levels of government for integrating climate change impacts in flood planning and management.

Issue	Investigation
B-2 Flood Hazard Information	1. Investigate the current state of flood mapping in the province, including gaps and limitations. Recommend an approach to improve the spatial coverage, quality, utility and accessibility of flood hazard maps and other flood hazard information.
	2. Investigate the approximate level of effort to prepare flood hazard mapping to address current gaps for existing communities and future areas of development (including floodplain maps and channel migration assessments).
	3. Investigate the current state of knowledge related to dike deficiencies and recommend an approach to improve the quality, consistency, review, utility and accessibility of this information.
	4. Investigate the status of LiDAR standards for flood mapping and develop recommendations to improve standards if applicable.
B-3 Flood Risk Assessment	1. Evaluate and compare the benefits and costs/limitations of taking a risk-based approach to flood management versus a standards-based approach.
	2. Investigate the effort required to develop and maintain a province-wide asset inventory and/or exposure dataset covering flood prone areas.
	3. Investigate approaches to completing a province-wide flood risk assessment, addressing effort required, level of detail, types of flood risk, current and future scenarios, scale, and any information required and data gaps.
	4. Investigate the level of effort to develop a coarse local-scale flood risk map based on available flood hazard map(s).
	5. Determine the effort required to undertake a local-scale comprehensive flood risk assessment for multiple types of flood hazards (e.g. riverine, coastal).and for varying degrees of available data on flood hazard, exposure, vulnerability and risk.
	6. Investigate methods for valuing the benefits and costs/limitations of flood risk reduction actions in a holistic and consistent manner and develop a framework for project prioritization that could be applied or adapted across the province to reduce flood risk.
B-4 Flood Planning	1. Investigate the ability of responsible authorities in the province to develop adaptation plans and strategies for flood management.
	2. Investigate opportunities to improve the knowledge and capacity of local authorities with regard to climate change adaptation and the benefits of proactive flood risk reduction.
	3. Investigate the potential content of a provincial guideline to support the development of local Integrated Flood Management Plans.
	4. Investigate the level of effort for a local authority to complete an Integrated Flood Management Plan and the possible role of the province in reviewing and/or approving these plans.

Issue	Investigation
B-5 Structural Flood Management Approaches	1. Investigate opportunities to incentivize or require diking authorities to maintain flood protection infrastructure and plan for future conditions such as changing flood hazards.
	2. Investigate opportunities to improve the knowledge and capacity of local diking authorities with regard to dike maintenance.
	3. Investigate opportunities to improve coordination amongst diking authorities under non-emergency conditions.
	4. Investigate impediments to and opportunities for implementing innovative structural flood risk reduction measures, including the role of incentives and regulation.
B-6 Non-Structural Flood Management Approaches	1. Investigate past and current approaches to land use and development decisions in floodplains by local and provincial authorities.
	2. Investigate alternatives to the current approach to managing development in floodplains, including returning regulatory authority for development approvals in municipal floodplains to the Province, and provide an analysis of the benefits and costs/limitations of both local and provincial authority.
	3. Investigate impediments to and opportunities for implementing available non-structural flood risk reduction actions, including the role of incentives and regulation.
	4. Investigate the nature of an educational campaign for regional, local and First Nations governments to raise awareness of flood risk and possible risk reduction options.

Theme C. Flood Forecasting, Emergency Response and Recovery

Issue	Investigation
C-1 Flood Forecasting Services	1. Investigate current capacity, coverage, value, and gaps in flood forecasting services.
	2. Visualize where flood forecasting gaps exist and estimate costs for improvement to end users.
C-2 Emergency Response	1. Investigate the future direction of the Federal government related to a National Flood Risk Strategy and the future of Disaster Financial Assistance Arrangements
	2. Investigate the Province’s expanding role in providing flood response to First Nations.
	3. Investigate the status of local authority flood response plans and recommend an approach to manage, update and improve this information.

Issue	Investigation
	4. Investigate flood response capabilities considering different flood hazards and different regions of the province.
	5. Investigate opportunities for improved organizational planning for emergency response in all levels of government.
C-3 Flood Recovery	1. Investigate the current status of coverage of existing overland flood insurance available to home-owners.
	2. Investigate the concept of "build back better" and impediments to implementation.

Theme D. Resources and Funding

Issue	Investigation
D-1 Resources and Funding	1. Investigate resource and funding needs associated with implementing recommendations to strengthen flood management in BC.
	2. Investigate evidence in support of investment in proactive flood planning and mitigation activities.

Appendix B - JBA Flood Map Evaluation

As part of this project, Ebbwater reached out to JBA Risk Management (JBA), and obtained their flood data (depth, extents) for four sample locations in BC. JBA Risk Management have developed a national flood hazard data layer, called the Canada Flood Map, for Canada that is primarily used by insurers and re-insurers to model risk.

The authors chose a diverse set of locations from different parts of the province, to capture different hydrological and hydraulic characteristics: Dawson Creek in Northeastern BC, Fernie in Southeastern BC, Bella Coola in Central BC, and Tofino on Vancouver Island. These locations were also selected because detailed hydraulic modelling exists. For Dawson Creek and Tofino, new hydraulic flood mapping was available, while for Fernie and Bella Coola, only older hydraulic flood maps from the Flood Damage Reduction Program (FDRP) were publicly available.

JBA provides undefended riverine, coastal (storm surge) and pluvial flood data for seven AEP scenarios (5%, 2%, 1.3%, 1%, 0.5%, 0.2%, and 0.067% AEP) (JBA Risk Management, 2018). JBA simulated rainfall totals, river flow volumes, and sea level (storm surge), and determined flood extents and depth by 'allowing the flooding associated with each to spread across the surrounding terrain data using hydraulic modelling and GIS" (JBA Risk Management, 2018). The Canada Flood Map has existed since 2014 and is regularly updated.

The data sharing agreement with JBA means that we are not able to show our mapping comparisons. However, we can provide some narrative analysis. Comparison of the JBA flood data and hydraulically modelled flood data showed that, while some riverine flood extents were reasonably close between the JBA and the hydraulic modelled flood data, others were quite different. In particular, coastal flood hazard mapping for the sample location in Tofino showed that JBA data did not appropriately capture flooding. Considering this preliminary evaluation, we do not recommend using JBA data for a screening-level flood risk assessment. However, the data quality could be further assessed in a wider evaluation study, which compares flood results for more locations than the four locations that could be compared here. Further, JBA is also regularly updating their results, and might have improved results available in the future.