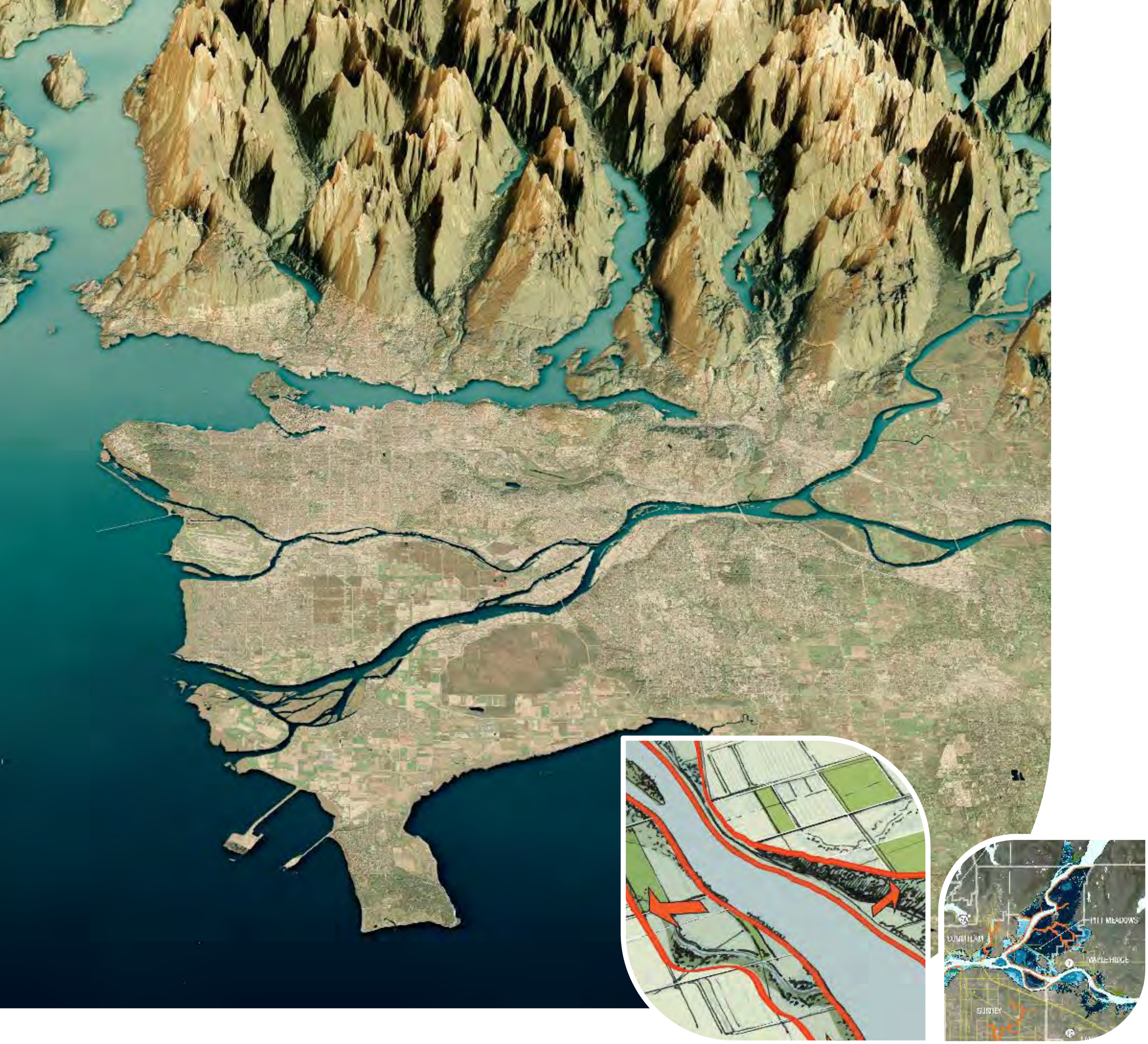

LOWER MAINLAND FLOOD MANAGEMENT STRATEGY

Synthesis of Technical Analysis

Summer 2023

Fraser Basin Council

Prepared by the Fraser Basin Council for the
Lower Mainland Flood Management Strategy (LMFMS) Initiative

Acknowledgements

This report summarizes information developed through several projects that were undertaken as part of the Lower Mainland Flood Management Strategy initiative (LMFMS). This report was prepared with financial support from the National Disaster Mitigation Program (NDMP), through the Province of BC (Emergency Management and Climate Readiness) and Public Safety Canada. The work that is profiled within this report was overseen by the Joint Program Committee for Integrated Flood Hazard Management in addition to several project-specific advisory committees. On behalf of all LMFMS participating organizations, the Fraser Basin Council would like to thank the scores of individuals that served as advisors and contributors through this process. FBC would also like to thank the consultant teams that led the technical work, including:

- *Analysis of Flood Scenarios – Kerr Wood Leidal*
- *Regional Assessment of Flood Vulnerability – Northwest Hydraulic Consultants*
- *Lower Mainland Dike Assessment – Northwest Hydraulic Consultants*
- *Analysis of Flood Protection Infrastructure, Practices and Policies – Thrive Consulting*
- *Hydraulic Modelling and Mapping in BC's Lower Mainland – Northwest Hydraulic Consultants*
- *Lower Mainland Flood Risk Assessment – IBI Group*

Contributing authors from the Fraser Basin Council team include Frances Woo, Jenny Koss, and Steve Litke.

Executive Summary

This document is a synthesis of the findings from analyses of flood hazards, risk, and risk reduction and resilience that have been undertaken as part of the Lower Mainland Flood Management Strategy (LMFMS) initiative since 2014. It describes the relevance of these analyses to the initiative to date and ways that this information can be used or built on to advance development of flood strategies at regional and local scales.

To support continued discussions and decisions developing a regional flood strategy, this report addresses the following:

- **What did we learn from the LMFMS projects about flood hazards, risk, and risk reduction and resilience in the Lower Mainland?**
- **How does – and can – the information we have gained inform a regional strategy?**
- **What additional information is needed to continue developing and finalize a regional strategy?**

Findings are presented from these main projects:

- *Lower Mainland Dike Assessment*
- *Analysis of Flood Scenarios (Phase 1)*
- *Regional Assessment of Flood Vulnerability*
- *Analysis of Flood Protection Infrastructure, Practices and Policies*
- *Hydraulic Modelling and Mapping in BC's Lower Mainland*
- *Lower Mainland Flood Risk Assessment*

This report also includes relevant information from several related analyses, as well as knowledge shared by some First Nations participants throughout the strategy development process.

Flood Hazards

The LMFMS focuses on understanding and reducing risk from Fraser River flooding and coastal storm surge flooding, two types of flood hazards that are known to have regionally significant consequences. The *Analysis of Flood Scenarios* and *Hydraulic Modelling and Mapping* projects are key contributors to the regional understanding of these flood hazards.

In general, the total area of land flooded, and the number of dikes overtopped increases with the magnitude of flood. When a dike breaches, flooding would progress rapidly, cutting off major evacuation routes within a few hours. In large parts of the lower Fraser River floodplain, deep water would be the most critical safety hazard in a dike breach scenario, with depths exceeding 1 metre in large areas of the floodplain.

A 500-year Fraser River flood today, which is almost equivalent to the 1894 Fraser River flood of written record, would cause 20 dikes to be overtopped (and potentially more to fail in other ways) and flood nearly 300 km^2 of land.

Climate change is expected to increase the size and frequency of floods along the lower Fraser River due to sea-level rise and larger peak flows on the Fraser River. A 500-year flood event — i.e., a flood of a magnitude that currently is estimated to have a 0.2% chance of occurring in any given year — could, by the year 2100, be 10 times more likely to occur (2% chance in any given year) due to the effects of climate change. Another way of considering the increase is that a flood with a 0.2% chance of occurring in 2050 and 2100 would cause a two- and three-fold increase in the area flooded, respectively, compared with a flood with that same probability occurring today because of significant additional dike overtopping. Today, approximately 20 dikes would be overtopped by such a flood, but by 2100, that flood would cause all existing river dikes to be overtopped, unless significant dike upgrades were implemented.

Under climate change, major coastal floods in the Lower Mainland are also expected to increase in magnitude and frequency due to sea-level rise. Compared with Fraser River flood hazards, coastal flood hazard information developed as part of the LMFMS has been more limited. Although the flood model can simulate coastal flood scenarios, the model extent is currently limited to the Fraser River floodplain, excluding areas like Boundary Bay and English Bay/Burrard Inlet. Many coastal communities in the region, such as Surrey and Vancouver, have undertaken their own detailed coastal flood hazard analyses.

Flood Risk

The *Regional Assessment of Flood Vulnerability (Flood Vulnerability Assessment)* and the *Lower Mainland Flood Risk Assessment (Flood Risk Assessment)* both found that **a 500-year coastal or Fraser River flood would result in damages of billions of dollars.** Both studies also found that, with few exceptions, a 500-year coastal flood would result in greater consequences than a 500-year Fraser River flood, both in terms of direct monetary losses and exposed assets. However, there are key areas in which a Fraser River flood would cause greater impacts, including flooding of environmentally sensitive areas, infrastructure damages, and interrupted cargo shipments resulting from the flooding of rail lines in the Fraser Valley. Four times more First Nations reserves are exposed to a 500-year Fraser River flood than a 500-year coastal flood. A major difference in findings between the two projects, which differed in methodologies and assumptions, was in the agricultural losses in a coastal flood scenario. The *Flood Risk Assessment* reported nearly 10 times the losses that were estimated in the *Flood Vulnerability Assessment*.

The greatest potential damages in a 500-year flood event (coastal or river) tend to be concentrated in a few communities, notably Richmond, Delta, and Chilliwack. However, many First Nations communities regularly experience impacts from frequent, smaller-magnitude floods. Over 60 First Nations reserves and treaty lands in the Lower Mainland are exposed to coastal and/or Fraser River flooding. Vulnerable values and assets that First Nations participants have identified as particularly important include: cultural, archaeological, and sacred sites; fishing and traditional harvesting sites; access roads; and water sources and waterways.

Flood Risk Reduction

Generally, Fraser River dikes can contain the 100-year flood, with some containing the 200-year flood. However, some dikes are low enough to experience localized overtopping at the 20-year flood level.

Across the Lower Mainland, a variety of structural and non-structural measures are used to help reduce communities' flood risk, with dikes being the primary structural measure used by many communities. In addition to overtopping during a flood event, there are many other potential factors that can lead to dike failure, such as seepage and geotechnical stability. Through a desktop review of available information, the *Lower Mainland Dike Assessment* rated close to 20% of the diking it assessed in the region as "poor to unacceptable" in terms of potential for failure. The noted dikes were in Pitt Meadows, Maple Ridge, Barnston Island, Nicomen Island, and along the Squamish

River, as well as along the coast in Delta and Surrey. Only 6% of the dikes assessed in the Lower Mainland were deemed “good to fair”, with most dike segments rated “fair to poor.”

The region maintains significant residual risk as many of the dikes not only do not meet provincial crest height standards, but also have geotechnical challenges, are older, are not adapted for larger floods due to climate change, and rarely meet the current seismic standards for high-consequence dikes. Indeed, the *Geotechnical Investigations and Seismic Assessment* found that two-thirds of dikes deemed as having “high consequence” in the case of their failure would experience subsidence of over 50 cm in a 2,475-year return period earthquake, the design event in BC, and thus do not comply with provincial standards.

Land use policies and regulations are the primary non-structural approach to managing flood risk in the region. The *Analysis of Flood Protection Infrastructure, Practices and Policies*[1] found that there is wide variation in the use of land use policies and tools by different jurisdictions across the Lower Mainland. Flood construction levels (FCLs) are usually specified by local governments through bylaws, development permit area guidelines, or other policy documents. Some jurisdictions allow the use of third-party analyses in lieu of pre-calculated FCLs. Existing regulations do not always use current flood hazard information, although some communities have updated their FCLs based on newer information. Some First Nations governments are developing land use plans for their communities; however, common non-structural measures — such as FCLs or building outside of the floodplain — are not always viable due to limited available land outside the floodplain or challenges in raising buildings substantially.

The *Hydraulic Modelling and Mapping Project* also simulated five hypothetical mitigation scenarios — dike raising, dike setback, sediment removal, land raising, and upstream storage — to better understand their effects on flood depth and extent. The mitigation scenarios generally resulted in flood water level changes within the Fraser River corridor in the range of 10–40 cm. As a comparison, flood simulations based on climate change projections found that flood water levels could increase by 0.5–2 m in 2050 and 2100.

Relevance of the Analyses to the Lower Mainland Flood Management Strategy

The information developed has informed the strategy development process — in particular, decisions regarding further analysis — as well as the scope of the strategy and recommended actions in Draft 1.

Moving forward, results of these analyses can continue to support strategy development. For example:

- Understanding limitations and challenges of completed analyses can inform the refinement of actions in the strategy related to improving understanding of flood hazard, risk, and risk reduction.
- Information about flood risk and the distribution of impacts of flooding across the region can serve as a basis for a framework for regional-scale prioritization of flood risk areas, a fundamental concept in the LMFMS. To create a successful framework, regional-scale, high-quality coastal flood hazard information and regional-scale information about flood risk in First Nations communities and Traditional Territories are key information gaps that need to be addressed.
- An understanding of the current state and limitations of existing flood risk reduction measures is needed to inform risk reduction actions in the strategy and on the ground. If participating organizations would like the strategy to provide stronger direction on the use of risk reduction actions throughout the region, further analyses will need to be undertaken to better understand

[1] This draft report is available upon request from the Fraser Basin Council: floodstrategy@fraserbasin.ca

the potential applicability of a wider range of risk reduction measures within diverse conditions across the Lower Mainland, in addition to diking, zoning and FCLs.

The use and usefulness of the flood hazard, risk, and risk reduction information and tools developed through the LMFMS initiative depend on the direction being taken for the strategy. Depending on the directions ultimately desired by participating organizations, additional gaps in the regional understanding of flood hazards, risk, and risk reduction may need to be addressed before the strategy can be finalized. In other cases, gaps could be addressed through implementation of the final strategy.

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Preamble

Local and regional flood impacts have long been a concern for those living in the Lower Mainland. Over the past several years, the Lower Mainland Flood Management Strategy (LMFMS) process has produced robust flood data to inform flood risk reduction in the region.

Phase 1 of the LMFMS was initiated in 2014 by the Joint Program Committee for Integrated Flood Hazard Management, following a consultative process and the development and approval of a business case for a regional flood strategy. Phase 1 focused on analyses of flood scenarios, flood vulnerability, and flood planning, practices and policies. This included technical reports focusing on Fraser River and coastal flooding impacts. The catastrophic scale of damage that these reports estimated provided rationale for participating organizations to proceed with developing a regional flood strategy.

Phase 2 of the LMFMS developed more detailed regional studies on Fraser River and coastal flood hazards, including the development of a regional flood model including the lower Fraser River floodplain and a comprehensive regional flood risk assessment that estimated the impacts of eight Fraser River and eight coastal flood hazard scenarios across 20 categories of risk.

In November 2021, a series of damaging atmospheric rivers with extreme precipitation led to the widespread flooding from the Nooksack River as it overflowed into the Sumas Prairie area of Abbotsford — formerly Sema:th Lake. The atmospheric rivers also resulted in countless landslides in the mountains, creating widespread impacts felt throughout the Lower Mainland and Canada as supply routes were cut off. At this time, technical studies for the LMFMS have not examined the regional impacts of atmospheric rivers, nor other river floodplains in the Lower Mainland, as the potential for regionally significant consequences were not fully understood. Following November 2021, participating organizations may wish to revisit the inclusion of other flood hazards, such as atmospheric rivers within the LMFMS process.

Since the reports profiled in this synthesis were completed, more than 30 Lower Mainland communities and organizations have used the regional flood model and its mapping outputs to support a range of projects to assess flood and erosion hazards and risks at local scales. Additionally, the regional flood risk assessment has been used by several individual communities as a foundation to add local risk data and undertake tailored risk assessments for their jurisdictions.

1. Introduction

1.1 Purpose and Intended Use of This Document

The Lower Mainland Flood Management Strategy (LMFMS) development process has involved a combination of technical and policy analyses and engagement with participating organizations. This approach has achieved the following:

- Improved knowledge about — and developed tools for assessing — flood hazards, risk, and risk reduction measures in BC's Lower Mainland region.
- Engaged and increased awareness among decision makers, stakeholders, and the public about Fraser River and coastal flooding.
- Encouraged LMFMS participating organizations to consider flooding and flood planning activities through a regional lens.
- Supported the development of Draft 1 of the LMFMS.

Results and outputs from projects undertaken as part of the LMFMS initiative were shared with participating organizations as they were completed, including through the *Phase 1 Summary Report* (2016). Draft 1 of the LMFMS (2021) contains descriptions of each of these projects. Feedback on Draft 1 indicated that: not all participants are aware of the information available; there are gaps in knowledge about flood hazards, risk, and risk reduction; and greater clarity is desired about how the analyses inform — or can inform — a regional strategy.

The Fraser Basin Council prepared this document to respond to the Draft 1 feedback and to support further discussions and decisions in the development of the strategy. It addresses the following:

- What did we learn from the LMFMS projects about flood hazards, risk, and risk reduction in the Lower Mainland?
- How does the information we have gained inform the strategy?
- What additional information is needed to continue developing and to finalize a regional strategy?

Sections 2 to 4 synthesize information that was developed as part of the LMFMS initiative to date about regional flood hazards, flood risk, and flood risk reduction. Section 5 discusses the relevance of these analyses in the LMFMS initiative to date and ways they can be used or built on to advance development of a regional strategy. Section 6 summarizes some of the ways that the information and tools developed can be used by organizations to further their own flood planning.

1.2 Scope of This Document

This document is primarily a synthesis of the findings and results from the projects completed as part of the LMFMS related to flood hazards, flood risk, and flood risk reduction and resilience in the Lower Mainland (see Figure 1). It also includes additional relevant results from a limited number of related sources, a summary of outputs from LMFMS projects and how they can be used, and identification of potential gaps in knowledge in these three areas as relevant to the LMFMS.

Figure 1. LMFMS Projects and their Outputs

2015

Lower Mainland Dike Assessment

Evaluated dike conditions in the Lower Mainland

OUTPUT	KNOWLEDGE CONTRIBUTION
Report	State of the region's dikes

Analysis of Flood Scenarios (Phase 1)

Produced simplified coastal and Fraser River flood hazard mapping

OUTPUT	KNOWLEDGE CONTRIBUTION
Report and GIS datasets	Fraser River and coastal flood extents

2016

Regional Assessment of Flood Vulnerability

Assessed impacts of major coastal and Fraser River flooding on people and vulnerable assets

OUTPUT	KNOWLEDGE CONTRIBUTION
Report and maps	Possible impacts of a major flood in the region

Analysis of Flood Protection Infrastructure, Practices and Policies

Analyzed use of flood risk reduction measures in the Lower Mainland

OUTPUT	KNOWLEDGE CONTRIBUTION
Draft report	The diversity of risk reduction measures used in the region

2019

Flood and Environmental Atlas

Mapped environmental values and features as well as dikes and flood extents in the lower Fraser River and coastal foreshore areas

OUTPUT	KNOWLEDGE CONTRIBUTION
Online mapping platform	Environmental features in the river corridor and floodplain

Hydraulic Modelling and Mapping in BC's Lower Mainland

Developed a 2D hydraulic model for the lower Fraser River floodplain; simulated and mapped Fraser River and coastal flood scenarios as well as simulations of dike breaches and mitigation options

OUTPUT	KNOWLEDGE CONTRIBUTION
Hydraulic model; hazard mapping; visual media; report and project primer	Flood extent, velocity, and depths in multiple flood scenarios, including climate change, dike breach, and mitigation scenarios

2020

Lower Mainland Flood Risk Assessment

Assessed coastal and Fraser River flood risk to identify the magnitude and distribution of impacts and higher flood risk areas

OUTPUT	KNOWLEDGE CONTRIBUTION
Report; online analysis tool; flood depth-damage functions	Flood risk in the region, including 20 risk categories and comparisons among geographic areas

Sources of information that were not undertaken as part of the LMFMS, but are included in this document to supplement the core information, are:

- **Comments and contributions from First Nations participating in the LMFMS (2017–2021).** This document includes knowledge that First Nations participants in the LMFMS process have shared about flood hazards, risk, and risk reduction. This information was typically shared verbally in meetings or workshops and was generally unavailable to consultants that undertook the technical analyses. It is included in this synthesis report in recognition of the importance of this knowledge to complement and add to other scientific methods.
- ***BC Dike Consequence Classification Study (2019)*.** This study classified regulated dikes based on the relative magnitude of consequences if the dikes failed. It is relevant to consider alongside the regional flood vulnerability assessment and the *Lower Mainland Dike Assessment.*
- ***Geotechnical Investigations and Seismic Assessment (2021).*** This project assessed the vulnerability of high-consequence dikes resulting from different earthquake scenarios. This is relevant to the long-term flood protection associated with high-consequence dikes.

This document is **not** an analysis or synthesis of all existing literature on flood hazards, risk, and risk reduction or a history of flood management in the Lower Mainland. It does not include a synthesis of input from participating organizations, advisors, and experts (other than First Nations' comments); details about project methodologies or limitations; or a comprehensive presentation of "new" insights or recommendations. The full account of limitations, methodologies, and results of the projects can be found in their respective project-specific reports.

2. Flood Hazards

Flooding has shaped the Lower Mainland landscape since time immemorial and has resulted in rich and diverse ecosystems and fertile agricultural soils. First Nations' oral histories of flood events in this region include accounts of a Great Flood long ago. Significant flood hazards in the Lower Mainland include Fraser River flooding, coastal winter storm surge, flooding from other rivers and creeks, and extreme rainfall events like atmospheric rivers.

Historically, large Fraser River floods originate from the spring freshet (spring snowmelt). The freshet is considered the dominant mechanism driving floods on the Fraser River.

Figure 2. Annual Exceedance Probability (AEP) and Return Period

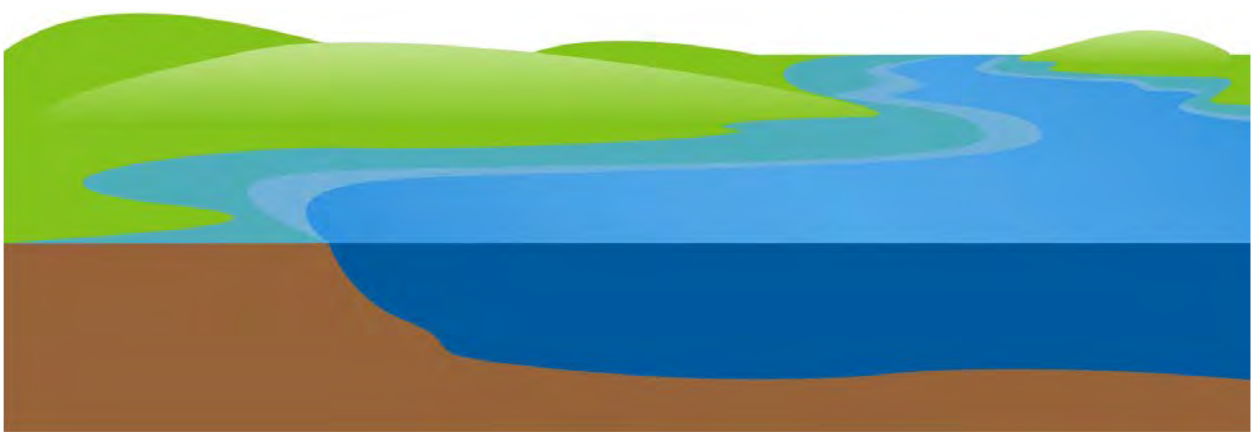
ANNUAL EXCEEDANCE PROBABILITY (AEP) AND RETURN PERIOD

Annual exceedance probability, or AEP, refers to the probability, expressed in percentage, of a flood of a given size being equalled or exceeded in any year.

For example, a flood that is estimated to recur once in 100 years on average has an AEP of 1%, meaning a 1% chance of occurring in any year. While AEP is emerging as the preferred terminology, this document will use the return period as it is more readily understood.

The higher the flood return period (lower the AEP), the greater the magnitude of the flood.

Return Period	AEP
10-year	10%
30-year	3.3%
50-year	2%
100-year	1%
200-year	0.5%
500-year	0.2%
750-year	0.13%
1000-year	0.1%



2.1 LMFMS Projects Related to Flood Hazards

At the start of the LMFMS initiative, participating organizations recommended focusing on Fraser River and coastal flood hazards because they were known to have regionally significant consequences. The hazard analyses to date have therefore focused on these two flood types. The following projects have contributed to knowledge on flood hazards in the region.

Analysis of Flood Scenarios (Phase 1): Simplified flood hazard maps were developed as a basis for a regional-scale flood vulnerability assessment. It included four scenarios:

A. Coastal Storm Surge – Present-day 500-year return period event (still water, i.e., excluding wind and wave effects)
B. Coastal Storm Surge – Year 2100 500-year return period event (adding 1 m sea-level rise [SLR] to scenario A)
C. Fraser River Flood – Present-day design flood event (1894 flood event, slightly larger than a 500-year return period flood)
D. Fraser River Flood – Year 2100 500-year return period flood event (adding a 17% higher peak flow and 1 m sea-level rise to scenario C)[2]

In all four scenarios, the estimated water levels in the ocean (coastal storm surge scenarios) and Fraser River corridor (Fraser scenarios) were extended across the landscape until they reached higher ground (as if all dikes overtopped or otherwise failed) (Figure 4). As a result, all scenarios likely overestimate the extent of flooding. This assumption was informed by the *Lower Mainland Dike Assessment*, which indicated that most dikes would overtop or otherwise fail under these water levels.

Hydraulic Modelling and Mapping Project:[3] In 2019, a HEC-RAS 2D hydraulic model (2D model) was developed for the lower Fraser River and its floodplain (see Figure 3 and Appendix D: Map 1) to learn more about the hazard and risks associated with a wide range of flood scenarios. HEC-RAS is an open-source computer software that can simulate the extent, depth and velocity of water associated with specified river flows and ocean levels. In 2022, the model was updated to the latest software version and now includes the most recent dike survey data.

Figure 3. Lower Fraser 2D Model Boundaries

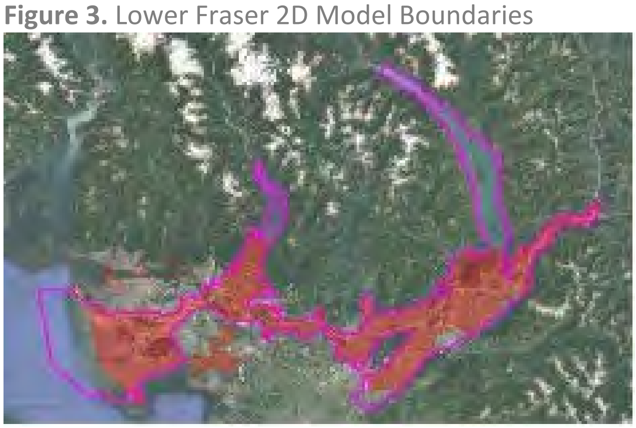


Table 1 summarizes the 27 flood scenarios modelled and/or mapped as part of this project. The Fraser River and coastal scenarios account for dike overtopping but not dike failures that may occur before being overtopped (see Figure 4). As a result, for diked areas, actual flood extents could be greater than what is shown on the maps if some dikes failed.

[2] For the year 2100 climate projections, 1 m of sea-level rise was based on provincial guidance and an increased peak flow on the Fraser River was informed by a literature review of climate projections at the time. Under a "moderate climate change scenario", a peak flow of 19,900 m^3/s was assumed.
[3] The link provided is for the Primer of this project. It is an 11-page public-facing document that details key information from this work. A more thorough technical report is available via the Fraser Basin Council.

Table 1. Scenarios from the *Hydraulic Modelling and Mapping Project*

Type	Runs	Notes
Fraser River runs	**10 scenarios** (present-day 50-, 100-, 200-, 500-year, and 1894 flood; 100- and 500-year flood in 2050; and 100-, 200-, and 500-year flood in 2100) (modelled)	Model extent is from Hope to the Strait of Georgia and includes Harrison Lake and Pitt Lake
Coastal storm surge runs	**2 scenarios** (50-year and 500-year) (modelled)	Limited to the extent of the Fraser River floodplain
Coastal storm surge mapping	**2 scenarios** (500-year present-day and 500-year in 2100 with 1 m SLR) (simplified[4])	Includes coastal areas within and outside of the Fraser River floodplain, such as Boundary Bay and English Bay
Dike breach scenarios	**6 single- and 2 multiple-location** dike breach scenarios at different locations along the Fraser River (modelled)	To understand the effects of simulated dike breaches and flood dynamics in floodplain areas[5]
Mitigation scenarios	**5 scenarios** along the Fraser River (4 modelled, 1 simplified)	To understand the effect of flood mitigation measures on water levels and flood extent (see Section 4.2.3)

***Lower Mainland Flood Risk Assessment (Flood Risk Assessment)*:** Additional hazard analysis was done to support the *Flood Risk Assessment* (see Section 3.1). Mapping was developed for 16 flood scenarios (8 each for Fraser River and coastal): 10-, 30-, 50-, 100-, 200-, 500-, 750-, and 1000-year return periods. The Fraser River scenarios used the model and outputs from the *Hydraulic Modelling and Mapping Project*, while the coastal scenarios are based on a simplified water surface level analysis whose methodology differs from previous projects. The analysis for both river and coastal flooding incorporated probability of dike failure from overtopping and piping using a dike fragility curve and dike crest information. Mapping for dike failure, no failure, and probable failure scenarios for each of the 16 flood scenarios was developed. See Figure 4.

[4] The simplified approach extended ocean flood levels through or overtop of existing sea dikes across the landscape until they reached higher ground. It considers tide levels and storm surge but not localized wind and wave effects.

[5] See *Hydraulic Modelling and Mapping in BC's Lower Mainland – Final Report,* NHC (2019) section 7.2 for the method for selecting dike breach locations. Contact the Fraser Basin Council for access to this technical report.

Figure 4. Differences in Dike Failure Treatment in the *Analysis of Flood Scenarios (Phase 1), Hydraulic Modelling and Mapping,* and the *Flood Risk Assessment.*

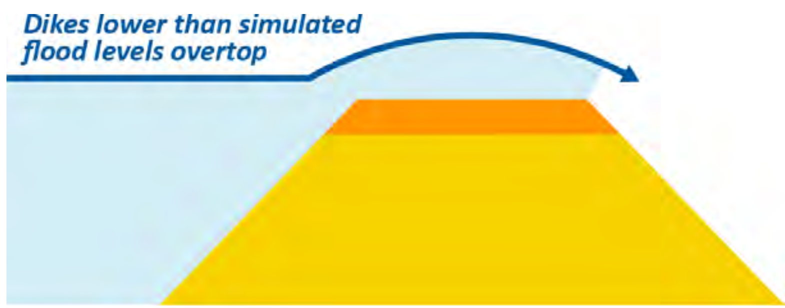
ANALYSIS OF FLOOD SCENARIOS (PHASE 1)

Assumption:
All dikes fail.

**For the Fraser River scenarios, water levels in the river corridor assume dikes are present and have thus increased the water level.*

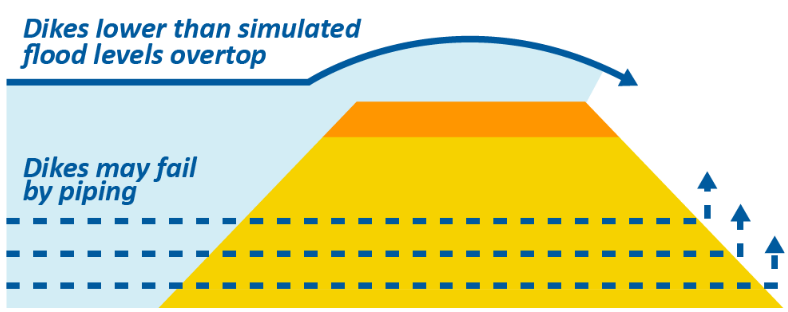
HYDRAULIC MODELLING & MAPPING

Assumptions:
1) Dikes that are lower than the river water levels are overtopped.
2) No dikes otherwise breach or fail.



LOWER MAINLAND FLOOD RISK ASSESSMENT

Assumptions:
1) Dikes that are lower than river water levels are overtopped.
2) All dikes are assigned the same likelihood of failure via piping.



Orange top section represents freeboard

Yellow section represents water level for which dike is designed

2.2 What We Have Learned About Flood Hazards in the Lower Mainland

This section presents findings from the *Analysis of Flood Scenarios* and *Hydraulic Modelling and Mapping* projects. Differences in methodologies and assumptions between the two projects produced different results that should be interpreted carefully.

Fraser River flood hazards are dominant (i.e., generate higher water levels than coastal storm surges) upstream of the Alex Fraser Bridge, which connects Richmond and New Westminster with North Delta, while coastal flooding becomes dominant (i.e., generates higher water levels than a Fraser River flood) several kilometres downstream of the Alex Fraser Bridge. Sea-level rise is expected to shift the "transition point" between coastal and riverine flood dominance upstream over time.

The tables in Appendix A show the list of communities within the LMFMS study area that are located within the flood extent of different flood scenarios. A summary table of this appendix is below:

Table 2. Summary of Communities Exposed in Coastal and Fraser River Floods

Communities Exposed	Only Coastal	Only Fraser River	Both Fraser River and Coastal
First Nations	3	21	5
Municipalities/Electoral Areas	7	11	13

2.2.1 Fraser River Flood Hazards

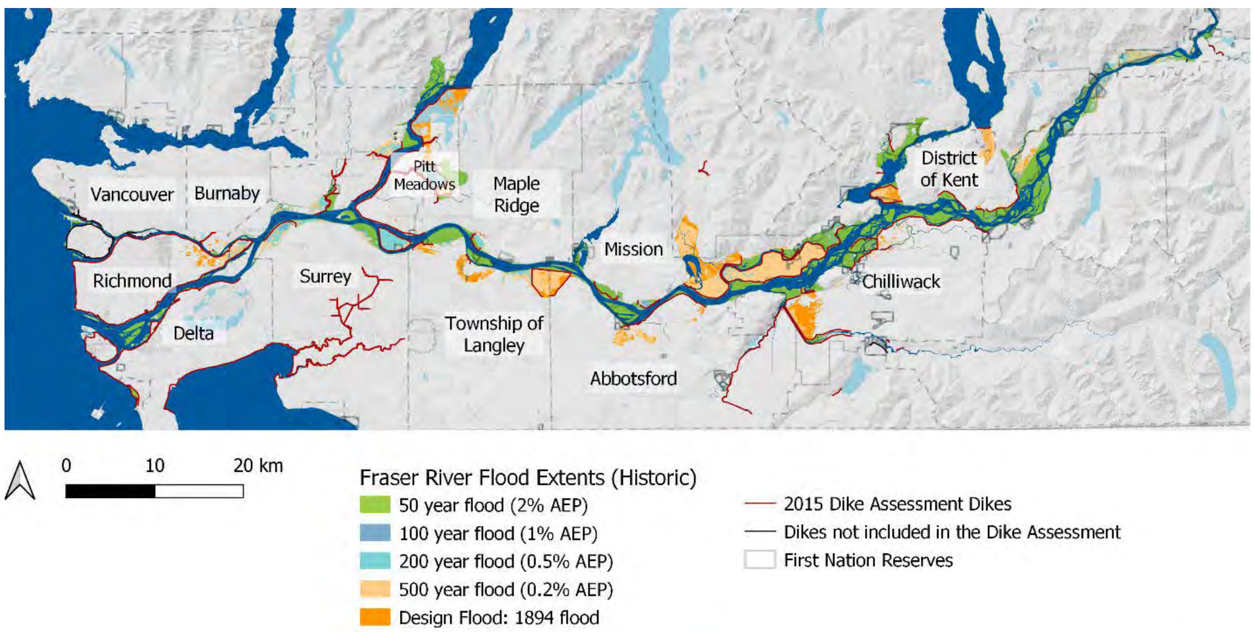
Historically, large Fraser River floods originate from the spring freshet, and as such the freshet is considered the dominant mechanism driving floods on the Fraser River currently. These freshet floods result from overlapping climatic factors, such as high snowpack from the previous winter, saturated and/or frozen ground, a sustained warm period causing a rapid snowmelt, and rainfall during the spring snowmelt. Over time, climate change might shift the Fraser to a rain-dominant flood mechanism. For Fraser River floods, the total area of land flooded and the number of dikes overtopped increases with higher magnitude floods, as shown in Table 3 and Figure 5 (Appendix D: Map 2).

Many First Nations reserves created through the Indian Act on the banks of the Fraser River are not protected by dikes. In some cases, dikes were built by others inland of a reserve. Areas unprotected by dikes can experience flooding at relatively low Fraser River flood flows, with flood impacts in those communities occurring more frequently.

Table 3. Characteristics of Modelled Fraser River Flood Hazard Scenarios (Present Day)

Scenario	Peak water levels at Mission (m)	Area flooded (km^2)
50-year return period (2% AEP)	7.5	159
100-year return period (1% AEP)	7.9	175
200-year return period (0.5% AEP)	8.3	203
500-year return period (0.2% AEP)	8.8	282[6]
1894 Event	8.9	325

Figure 5. Historic Fraser River Flood Hazard Extents



Note: Each flood extent illustrated is cumulative to previous smaller flood extents

1894 Fraser Flood

The 1894 Fraser River flood is the largest flood of written record and the design flood[7] for the lower Fraser River. The 1894 flood flow is estimated to be 17,000 m^3 (equivalent to the volume of 6.8 Olympic-size swimming pools) per second. It is slightly larger than a 500-year (0.2% AEP) flood event. By contrast, at

[6] By contrast, Phase 1 mapping estimated that approximately 993 km^2 of the Lower Mainland is within the 500-year Fraser River floodplain. This large difference is because both present and future flood scenarios of Phase 1 estimated all dikes would fail, whereas the 2019 modelling used dike heights to estimate areas of overtopping.

[7] In BC, the design flood is a given flood magnitude that is used as a standard for designating flood construction levels, and flood levels for dike design, planning, and construction. The Fraser River design flood is the 1894 event (with an estimated peak flow of 17,000 m^3/s, and slightly bigger than a 500-year return period). For other rivers in BC and for coastal storm surge, the design flood is the estimated 200-year return period flood.

Hope Station, the historical average annual flow of the Fraser River is 2,713 m^3/s, and the average flood flow is 8,770 m^3/s.[8]

The *Hydraulic Modelling and Mapping Project* found that a flood of this magnitude (17,000 m^3/s) today would inundate areas unprotected by dikes (e.g., Seabird Island, MacMillan Island, Surrey Bend) and overtop multiple dikes (e.g., Nicomen Island, Hatzic Lake). It would also likely cause some dikes to fail in other ways (e.g., erosion, piping, and seepage), meaning that the flooding could be more widespread than shown in the mapping. Flooding of additional lands would also result as Fraser River flows increase water levels in tributaries, such as the Harrison, Vedder, Pitt, Alouette, and Coquitlam Rivers. In the simulated scenario, it would take 4 or 5 days for the river to rise at the Mission gauge from 6 metres (limited flooding) to 8 metres, the point at which major flooding and possible dike breaches would occur.

The Effects of Dike Breaches on Fraser River Flood Hazards

> *The* Hydraulic Modelling and Mapping Project *found that if one or more dikes breach, flooding would cut off major evacuation routes within a few hours.*

The rate of flow through a breach, and the extent of flooding, can vary; dikes associated with higher hydraulic head[9] tend to have significantly higher flow rates through the breach. However, even a breach with lower head can flood large areas within several hours, as demonstrated in the Upstream Kent dike breach scenario. High velocity zones (greater than 2 m/s) would be limited to relatively small areas within tens of metres to a few hundred metres of a breach location.

In most of the lower Fraser floodplain, deep water would be the most critical safety hazard in a dike breach scenario, with depths exceeding 1 m in large areas of the floodplains where breaches were modelled. Many areas have water depths exceeding 3 m, with a few areas reaching 7 m. Figure 6 illustrates the impacts of flood depths to people and homes.

Due to limited water storage capacity in the floodplain relative to flow rates during a large flood, single dike breaches do not significantly reduce peak flood levels or likelihood of dike failure in the lower reaches. In a 200-year (0.5% AEP) flood scenario in which dikes were simulated to fail at Kent, Chilliwack, Sumas, and Matsqui, flood levels were reduced by 0.7 m at Mission and 0.4 m at the Port Mann Bridge for 2 to 3 days. However, the maximum flood level was only lowered by approximately 0.1 m at these two locations.

In areas affected by tides, low tide may present an opportunity to close a breach or prevent further widening. However, this "tidal relief effect" decreases upstream of the Alex Fraser Bridge.

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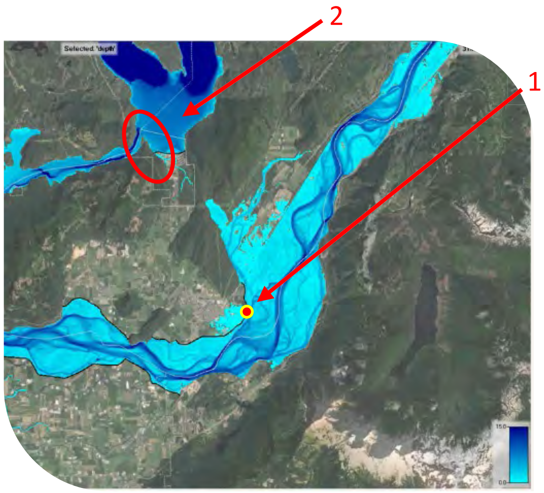
[8] Information on historical flows is limited, thus this data comes from two different sources. The Hope Station Fraser River average annual flows were derived from Canada's Open Government Dataset: Fraser River Flows, 1912 –1999. The Hope Station average flood flow is included in Comprehensive Review of Fraser River at Hope Flood Hydrology and Flows – Scoping Study Final Report (2008), using data from the years 1894–2008.

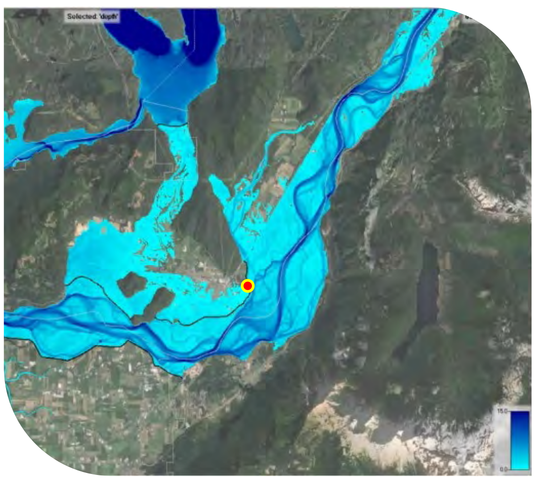
[9] Hydraulic head is the difference between the water level on the river side of the dike and the ground level on the land side of the dike.

Hypothetical Scenario – Breach of Kent dike at the most upstream location

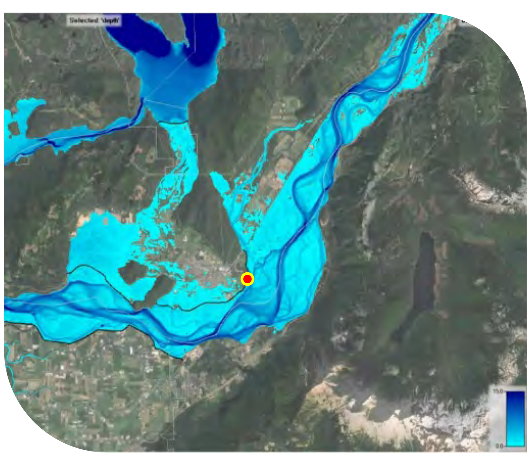
A series of key images have been captured from an animated file depicting a hypothetical breach of a Kent dike during a 500-year Fraser River flood scenario during the spring freshet. This hypothetical dike failure could potentially result from any number of dike failure mechanisms (see Section 4.2.1.)



On May 31, the upstream section of the Kent dike breaches (1). Water quickly begins filling the area that was previously protected by the dike. Water from the Fraser River has also back flowed up the Harrison River, with simulated flooding also beginning at Harrison Hot Springs (2).



On June 3, after several days of floodwaters entering the Kent and Harrison Hot Springs floodplains, floodwaters have reached their full extent. The extent and depth of floodwaters would vary based on the flood event and the area protected by the dike. This scenario illustrates the estimated extent of a 500-year flood, based on the data available.



On June 8, floodwaters begin receding. Prior to this, standing water from the flood has made it difficult to access properties safely and fully assess the scope of damage. It is likely that evacuees will remain displaced from their homes for some time in this type of scenario.

Figure 6. Flood Depths and Their Impacts

Depth (m)	Description of Typical Conditions
0–0.1	Most buildings are dry; underground infrastructure may be flooded
0.1–0.3	Most buildings are dry; walking in moving water or driving is potentially dangerous; underground infrastructure may be flooded
0.3–0.5	Most buildings are dry; walking in moving or still water or driving is dangerous; underground infrastructure may be flooded
0.5–1.0	Water on ground floor; underground infrastructure flooded; electricity failed; vehicles are commonly carried off roadways
1.0–2.0	Ground floor flooded; people evacuate
2.0–3.0	Ground floor flooded; first floor covered by water; people evacuate
> 3.0	First floor and often higher levels covered by water; people evacuate

The Effects of Climate Change on Fraser River Flood Hazards

> *Today's 500-year flood is projected to increase in likelihood, becoming a 50-year flood by 2100.*

Climate change is projected to increase the magnitude and frequency of floods along the lower Fraser River due to sea-level rise and larger peak flows on the Fraser River. Although warmer winters are expected to generate smaller snowpack, rapid snowmelt and increased spring rainfall in the Fraser Basin is currently projected to result in higher peak flows and potentially an earlier freshet. Climate change may also influence the magnitude of atmospheric river events and their impacts on the Fraser, however technical studies for the LMFMS to date have not examined this.

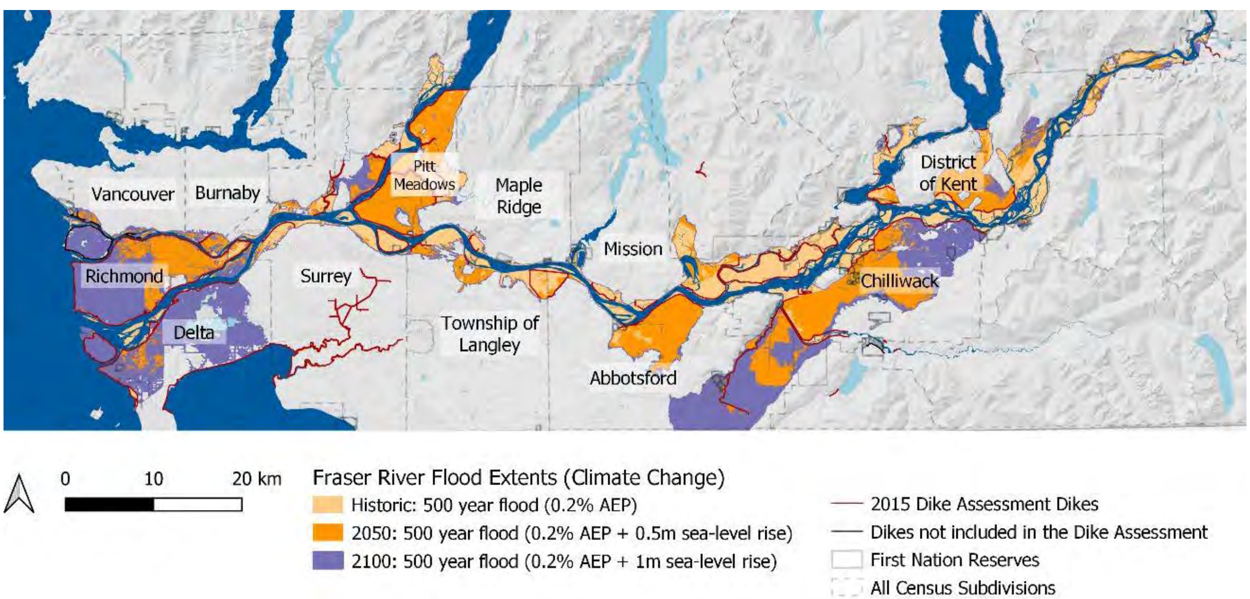
The *Analysis of Flood Scenarios* project found that a 500-year flood — one that currently has a 0.2% chance of occurring in any given year — would, by 2100, be 10 times more likely to occur (2% probability in a given year) due to the effects of climate change. Similarly, the *Hydraulic Modelling and Mapping Project* found that climate change is expected to increase both water levels and flood extents unless substantial dike upgrades prevent flooding. For a 500-year flood, the area flooded increases two- and three-fold by 2050 and 2100, respectively, because of significant additional dike overtopping, as shown in Table 4[10] and Figure 7 (Appendix D: Map 3) below. Deeper floodwaters would also result from climate change.

Since the *Analysis of Flood Scenarios* and the *Hydraulic Modelling and Mapping* projects were undertaken, projected climate change impacts on the Fraser River have changed. More recently, it has been projected that peak flows will be higher in 2050 than in 2100, predominately due to the loss of snowpack. Although 2100 flows are estimated to be lower than 2050 flows, they would still be higher than historic Fraser River flows. These projections have not yet been simulated by the HEC-RAS 2D model, making the climate change runs from the *2019 Hydraulic Modelling and Mapping Project* the best available mapped information at a regional scale.

Table 4. Differences in Modelled Flood Hazards Due to Climate Change for a 500-year Fraser River Flood

500-year flood	Water level at Mission	Area flooded	Diked areas
Present day	8.8 m	282 km^2	Approx. 20 dikes overtopped
2050	9.5 m	609 km^2	All dikes except 4 overtopped
2100	10.7 m	925 km^2	All river dikes are overtopped

Figure 7. Evolving Fraser River Flood Hazard Due to Climate Change



Note: Each flood extent illustrated is cumulative to previous flood extents.

[10] These results differ substantially from the Phase 1 scenario mapping, which indicated a smaller increase in the 500-year floodplain (from 993 km^2 today to 1103 km^2 in 2100). The Phase 1 work assumed all dikes fail in both scenarios, resulting in the maximum extent of flooding. On the other hand, the 2D modelling (which accounted for overtopping but not other dike failure mechanisms) indicated there would be some dike overtopping in the present-day 500-year flood but substantially more overtopping in the 2050 and 2100 scenarios. This resulted in a smaller present-day area of inundation and larger increases in the flooded area as the century progresses.

2.2.2 Coastal Flood Hazards

Coastal flooding in this region typically results from winter storm surge combined with extreme tides, and wind and wave effects. In BC, outside of the lower Fraser River, such as along the coast and other rivers, the design flood is the 200-year flood (0.5% AEP). However, a 500-year coastal flood was considered for equivalency with the lower Fraser River design flood.

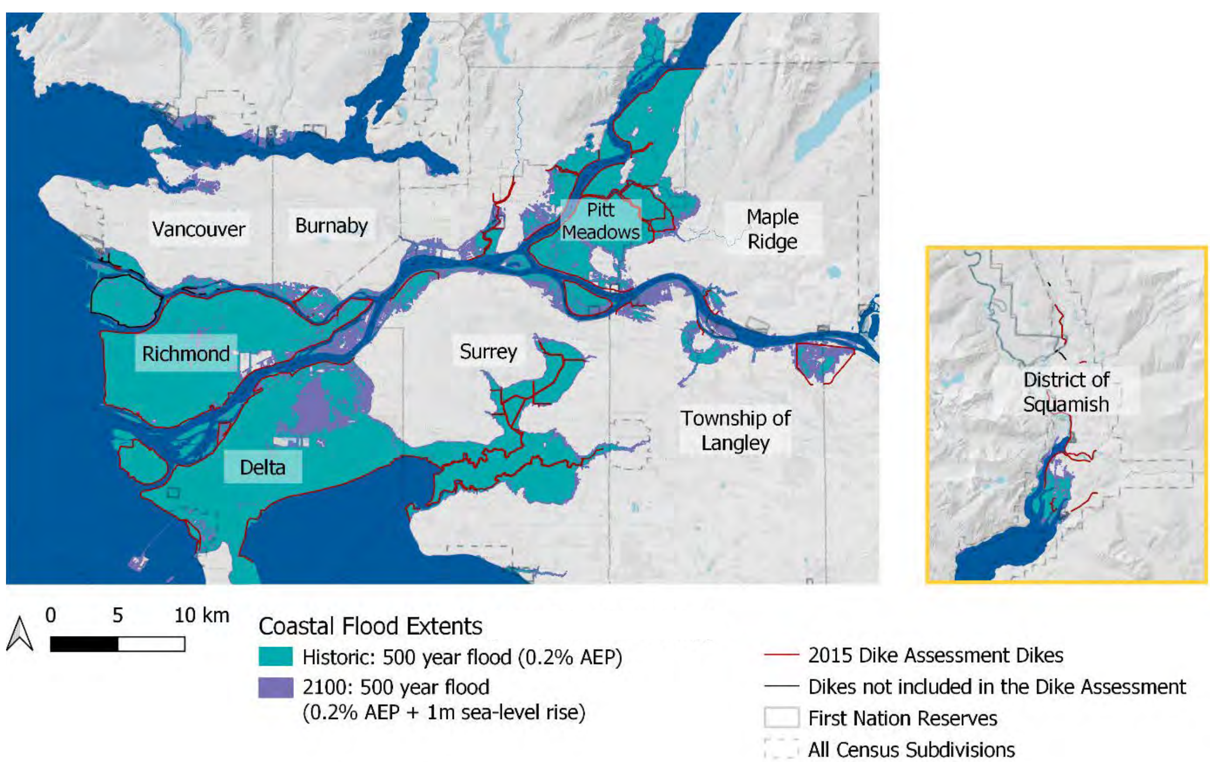
The *Analysis of Flood Scenarios* project found that a 500-year coastal flood would inundate 547 km^2. Areas unprotected by dikes can experience flooding in a smaller coastal flood, such as the 50-year (2% AEP) event, or as a result of king tides.

Compared with the Fraser River flood hazards, the coastal flood hazard information developed as part of the LMFMS has been more limited. Although the 2D model can simulate coastal flood scenarios, the extent of the 2D model is currently limited to the Fraser River floodplain. Many coastal communities in the region have performed their own detailed coastal flood hazard analyses, the results of which are not included in this document.

The Effects of Climate Change on Coastal Flood Hazards

Under climate change, major coastal floods in the Lower Mainland are expected to increase in magnitude and frequency due to sea-level rise. The *Analysis of Flood Scenarios* found that the 500-year coastal floodplain is anticipated to expand from 547 km^2 today to 611 km^2 in 2100, unless substantial dike upgrades prevented flooding. Figure 8 (Appendix D: Map 4) illustrates the difference in flood extent for a 500-year coastal flood today and in 2100 with 1 m of sea-level rise, based on mapping from *Analysis of Flood Scenarios.*

Figure 8. Evolving Coastal Flood Hazard Due to Climate Change



Note: The year 2100 flood extent is additional to the historic flood extent.

2.2.3 Other Flood Hazards

There are other flood hazards that communities in the Lower Mainland face in addition to Fraser River floods and coastal storm surge. First Nations participants in the LMFMS process have shared the following:

- Flood hazards from local streams, creeks, and tributaries (e.g., Pitt River, Squamish River, Harrison River, Chehalis River) are significant. During the spring freshet, the creeks on the mountain widen, and these rivers and creeks can also flood from heavy rainfall.
- Seepage flooding is a hazard in some communities. In several riverine floodplain areas, rising river levels correspond with rising groundwater levels, causing seepage even before riverbanks are overtopped (e.g., Kwantlen and Sts'ailes First Nations).
- Flooding caused by dam release is a hazard for communities located downstream of a dam (for example, Coquitlam River dam releases can affect the Kwikwetlem First Nation).
- Overland flooding during heavy rain events is experienced particularly in low-lying areas (e.g., Musqueam, where the golf course acts as a catch basin).
- Communities without erosion protection also experience heavy amounts of erosion, which has led and/or will lead to the loss of First Nations lands over time (e.g., Seabird Island, Kwantlen).
- Sea-level rise associated with climate change will contribute to loss of land or potentially constant flooding in some communities (e.g., Semiahmoo).

2.3 Gaps and Limitations

Despite significant improvements in the information available on flood hazards in this region, gaps in our understanding remain, including:

- **Coastal hazards:** The LMFMS has not yet developed an understanding of the regional coastal hazard equivalent to that of the Fraser River hazard. Howe Sound, English Bay, Boundary Bay, and White Rock are all exposed to coastal storm surge flooding, but these areas are not currently included within the 2D model, meaning that different levels of information are available for coastal and Fraser River flood risks, and for coastal flood hazards within and outside of the Fraser River floodplain.
- **Dike breaches:** So far, dike failure probability in LMFMS studies have accounted for dike crest heights, but not other information about dike conditions and vulnerability. More detailed understanding of dike failure probability would improve the accuracy of flood hazard information and could inform additional dike breach analyses. Additionally, a better understanding of the likely sequence of dike breaches and flooding that could occur as Fraser River flows or coastal water levels rise would be helpful.
- **Other flood hazards:** Analysis completed as part of the LMFMS has not yet included other types of flood hazards, including those associated with tributaries or smaller rivers, groundwater, dam breaks or releases, or severe rainfall events, such as atmospheric rivers.
- **Natural floodplain function:** At the time of this report's release, there is limited understanding about how the Fraser River and floodplains would function in their natural state, that is, without being constrained by 600 km of flood protection dikes and associated pumps and flood gates.
- **Impacts to Fraser Basin hydrology:** Forest pest outbreaks, forest harvesting, and wildfires may have significantly altered the runoff patterns and hydrology of the Fraser River Basin. Specific hydrological impacts of these activities are not currently well understood.

3. Flood Risk

Flood risk is a function of the likelihood of a given flood and the consequences of that flood. Consequences or impacts are based on:

- **Hazard** – location and characteristics of a flood event (e.g., extent, depth, velocity).
- **Exposure** – people and tangible assets exposed to, or physically reached by, a flood. Exposure does not necessarily mean that there will be a loss or even diminished function of the asset.
- **Vulnerability** – conditions of an individual, community, asset, or system exposed to a flood that increase its susceptibility to impacts and make damages from flood more likely.

Understanding not just the hazard but also exposure and vulnerability (the potential consequences of different flood scenarios) can support informed decisions about where and how to reduce flood risk.

Figure 9. Risk Graphic

Adapted from Ebbwater Consulting Inc. modified from Global Facility for Disaster Reduction and Recovery. (2016). The making of a riskier future: How our decisions are shaping future disaster risk, 1–166.

3.1 LMFMS Projects Related to Flood Risk

The following projects, completed as part of the LMFMS initiative, have contributed to knowledge on flood risk in the Lower Mainland.

The ***Regional Assessment of Flood Vulnerability (Flood Vulnerability Assessment)*** identified the potential impacts of flooding on people and assets in the region. It estimated direct losses[11] for buildings, agriculture, and essential facilities and critical infrastructure, as well as some indirect economic losses, for four major Fraser River and coastal flood scenarios in the present day and the year 2100, using hazard information from the *Analysis of Flood Scenarios* mapping. It identified exposed critical infrastructure in

[11] The *Flood Vulnerability Assessment* uses "vulnerability" to mean "potential for loss" and "sensitivity" to mean susceptibility to damage.

10 sub-regions, their vulnerabilities, and possible cascading effects from inundation of these assets. In general, the study assumed a flood duration of two days for the coastal scenarios and two weeks for the Fraser River flood scenarios. The year 2100 scenarios assumed more extensive flooding and deeper floodwaters but did not account for future population growth and development nor for economic inflation over time.

The ***Lower Mainland Flood Risk Assessment (Flood Risk Assessment)*** improved upon the *Flood Vulnerability Assessment* in several respects, including more accurate hazard information based on the 2D model, additional risk categories, more accurate methods to estimate dike failure probability and building losses, finer geographic resolution, and indexed risk scores to enable comparison among geographic areas. It used methods tailored to the Lower Mainland to assess a range of consequences for Fraser River and coastal flood scenarios. It also included estimated annualized damages (EAD) that account for the probabilities of 8 different Fraser River and coastal flood scenarios.[12]

The *Flood Vulnerability Assessment* and *Flood Risk Assessment* projects relied on different hazard information, datasets, assumptions, and approaches for estimating losses that led to different sets of results and under- or over-estimations of different consequences.

Notably, the *Flood Vulnerability Assessment* assumed that all dikes fail, and so the maximum extent of flooding was experienced, while the *Flood Risk Assessment* considered a probability of dike failure, resulting in reduced consequences.

While the *Flood Vulnerability Assessment*'s focus was estimating absolute losses, the *Flood Risk Assessment* aimed to enable comparisons of risk among different geographic areas, and across different flood scenarios, to help inform the prioritization of risk areas. Table 5 shows some of the key differences between the two projects. Due to these significant differences, the information provided from the two projects **should not** be referenced interchangeably.

[12] The value of using estimated annualized damages (EAD) is that it accounts for the probability of a wide range of events rather than an arbitrarily chosen one (e.g., 0.2% AEP or the Fraser design event). Risk reduction measures and investments that are focused on a single flood probability event could leave areas exposed to other events if unmitigated. Decisions optimized around EAD would install mitigation measures that balance the measures against floods of all magnitudes. Considering EAD can inform the appropriate level of investment in proactive flood mitigation.

Table 5. Key Characteristics of the *Flood Vulnerability Assessment* and *Flood Risk Assessment* Projects

	Flood Vulnerability Assessment (2016)	**Flood Risk Assessment** (2020)
Geographic extent and resolution	Lower Mainland region. Some finer-grained analysis split the region into 10 sub-regions. Descriptive results for First Nations reserves.	Lower Mainland region (excluding Squamish). Results available by census subdivision, census tract and dissemination area.
Flood hazard scenarios	Coastal storm surge: • Present-day 500-year return period (0.2% AEP) • Present-day 500-year return period plus 1 m sea-level rise Fraser River flood: • Present-day 500-year return period[13] • Year 2100 500-year return period with higher peak flow and 1 m of sea-level rise	• 8 coastal storm surge scenarios: 10%, 3.3%, 2%, 1%, 0.5%, 0.2%, 0.13%, 0.1% AEP (10- to 1000-year return periods) • 8 Fraser River flood scenarios: same probability events as for coastal • Estimated annualized damages (across 8 events each for coastal and Fraser River) • Assumes a probability of dike failure
Key strengths	• Includes two climate change scenarios • Includes detailed estimates and descriptive results for a wide range of impacts, including critical infrastructure	• Used modelled hazard information for Fraser River scenarios • Considers dike failure probability • Building loss estimation (depth-damage curves) tailored to region • Includes estimated annualized damages (EAD) • Developed and used flood damage modelling tool designed for Canada (CanFlood)
Key limitations	• Simplified Fraser River flood and coastal hazard information • Assumed all dikes fail • Uncertainties in loss estimation (used Hazus[14])	• Simplified coastal hazard information • Limited assessment of First Nations vulnerability due to a lack of data for reserves • Fewer critical infrastructure impacts assessed than the *Flood Vulnerability Assessment*

The ***Lower Mainland Flood and Environment Atlas*** is an online interactive mapping portal that includes environmental values and features and flood hazard mapping (from *Analysis of Flood Scenarios*) along the lower Fraser River and coastal foreshore areas. Datasets are organized under six main categories: base layers; communities; watercourses and wetlands; sensitive ecosystems; fish; and flood. While no analysis was undertaken as part of this project, the atlas allows a user to see where environmental features intersect with Fraser River and coastal flood hazards, and thus where the natural environment is exposed to flood hazards and risk.

[13] More accurately, it used the 1894 flood event, which is approximately equivalent to a 500-year/0.2% AEP flood; in this document, it will be referred to as the 500-year/0.2% AEP flood for simplicity.
[14] Originally developed for the US Federal Emergency Management Agency (FEMA) providing standardized tools and data for estimating risk from earthquakes, floods, tsunamis, and hurricanes; and later adapted for use in Canada.

Outside the LMFMS:

- The ***BC Dike Consequence Classification Study*** was a Government of BC study that classified 212 regulated dikes in BC based on the potential consequences associated with a dike failure. The study examined five categories of assets — people, economy: buildings, economy: critical infrastructure and agriculture, environment, and cultural heritage — in the 200-year protected floodplain for each dike. Dikes were classified based on their potential consequences using a scale ranging from insignificant to high consequence. Twenty-seven dikes in the Lower Mainland, including the District of Squamish, are considered high consequence.[15]
- The ***Mainland Coast Salish Flood Risk Assessment*** was a project led by Kwantlen First Nation (in partnership with the Emergency Planning Secretariat and Fraser Basin Council) that worked with 15 First Nations communities in the Lower Mainland to develop maps of flood and other hazards and exposed areas of high value to each community.

3.2 What We Have Learned about Flood Risk in the Lower Mainland

Results provided in this section are current to the date each project was completed, the datasets used, and the hazard information used.

3.2.1 Impacts of a Present-Day 500-Year Coastal or Fraser River Flood

As both projects examined the potential impacts of present-day 500-year (0.2% AEP) Fraser River and coastal flood scenarios, these two scenarios are used to highlight the findings from the two projects.

With a few exceptions, the *Flood Risk Assessment* found that a 500-year coastal flood would result in greater overall consequences than a 500-year Fraser River flood, both in terms of direct monetary losses and exposed assets. Both the *Flood Vulnerability Assessment* and *Flood Risk Assessment* found higher building-related losses in a major coastal flood than a Fraser flood. Notable areas in which the Fraser 500-year flood scenario results in higher consequences than a coastal scenario include:

- Hectares of sensitive areas.
- Interrupted cargo shipments (largely due to a longer duration of rail line interruption).
- Infrastructure losses (largely due to the high cost of bridge-related damages).
- Agricultural losses, where the *Flood Vulnerability Assessment* found a ten-fold difference in losses, however the *Flood Risk Assessment* found only a small difference.

Refer to the tables in Appendix B for more details.

[15] The BC Dike Classification Study separates out Lower Mainland dikes from Squamish dikes. For this report, Squamish dikes are included as Lower Mainland dikes.

Figure 10. *Flood Risk Assessment* Comparison of Dollar Losses from a 500-Year Coastal or Fraser River Flood

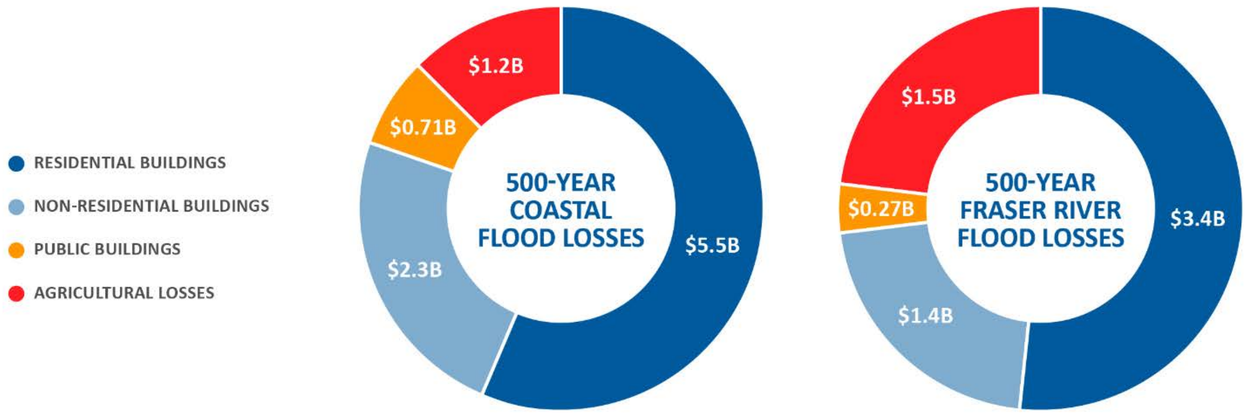
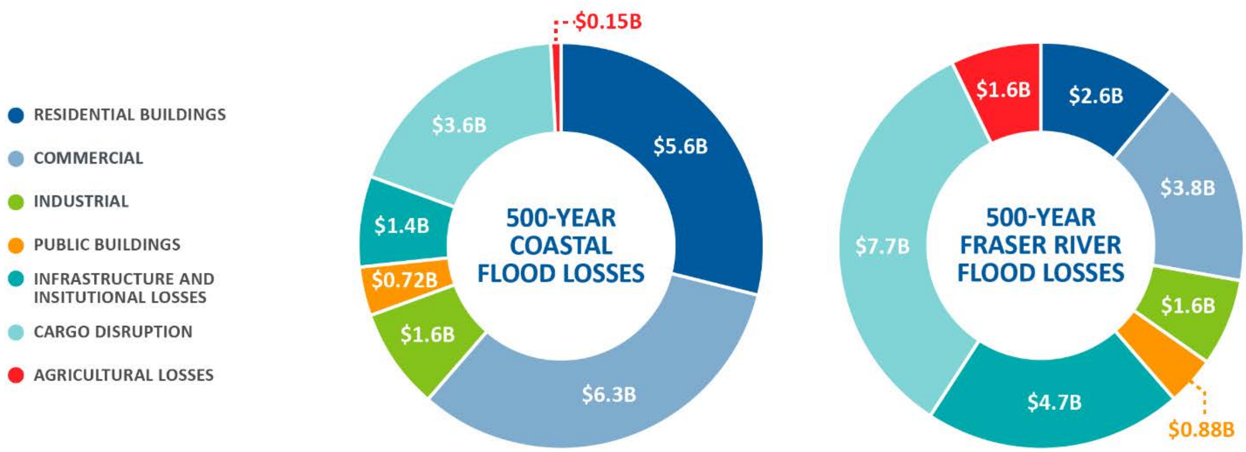


Figure 11. *Flood Vulnerability Assessment* Comparison of Dollar Losses from a 500-Year Coastal or Fraser River Flood



Quantified impacts from both the *Flood Vulnerability Assessment* and *Flood Risk Assessment* are summarized in Tables 6, 7 and 8.

Table 6. Dollar Losses from 500-year Coastal and Fraser River Floods

Dollar Losses (Billions)	500-year coastal flood		500-year Fraser River flood	
	Flood Vulnerability Assessment	Flood Risk Assessment[16]	Flood Vulnerability Assessment	Flood Risk Assessment
Combined residential, commercial, and industrial building-related losses	$14.2B	$7.8B	$9.0B	$4.8B
Residential buildings	$5.6B	$5.5B	$2.6B	$3.4B
Non-residential (commercial and industrial buildings, religious)	$6.3B (commercial) $1.6B (industrial)	$2.3B	$3.8B (commercial) $1.6B (industrial)	$1.4B
Public buildings and infrastructure	$720M[17]	$712M[18]	$880M	$269M
Infrastructure and institutional losses	$1.4B[19]	N/A[20]	$4.7B	N/A
Cargo disruption from disrupted rail lines[21]	$3.6B	N/A	$7.7B	N/A
Agricultural losses (production, buildings, equipment)	$151M	$1.2B	$1.6B	$1.5B

[16] The *Flood Risk Assessment* also assessed exposed socially vulnerable populations, potential hazardous material releases (from industrial buildings, landfill and transfer stations, and hazardous waste facilities), and sewage (sanitary lines, treatment plants), and electrical service disruption (transformers and substations), but due to the use of different units of measurement, these impacts are represented as a weighted "score", so are meaningful for relative rankings or comparisons only. Score values are therefore not provided in Table 6.

[17] Religious, non-profit, government buildings, emergency facilities, and educational institutions

[18] Libraries, hospitals, community centres, emergency facilities, educational facilities, pipes and parks

[19] Includes minor double-counting with the "Other buildings" category as this includes schools, municipal halls, hospitals, and policy/emergency services.

[20] N/A in this table means not available.

[21] Based on an estimate of $257M/day in losses of cargo/freight movement due to rail line disruption. A two-week duration is assumed for Fraser River flooding, while a two-day duration is assumed for coastal flooding.

Table 7. Assets Exposed in 500-Year Coastal and Fraser River Floods

Assets Exposed	500-year coastal flood		500-year Fraser River flood	
	Flood Vulnerability Assessment	Flood Risk Assessment	Flood Vulnerability Assessment	Flood Risk Assessment
Education and culture facilities exposed	80 (schools only)	43 (schools, libraries, museums)	116 (schools only)	29 (schools, libraries, museums)
Community centres exposed	N/A	50	N/A	45
Heritage buildings/sites exposed	N/A	57	N/A	19
Archaeological sites/cemeteries	N/A	109	N/A	58
Sensitive areas exposed	N/A	1,211 hectares	N/A	3,837 hectares
Road network exposed	N/A	722 km	N/A	879 km
Emergency facilities exposed	23 (police, fire, ambulance)	8 (fire, police, EOC, correctional facilities)	31 (police, fire, ambulance)	8 (police, fire, EOC, correctional facilities)
Health facilities exposed	1 (hospitals only)	13 (hospitals, ambulatory health, and nursing care)	2 (hospitals only)	16 (hospitals, ambulatory health, and nursing care)
First Nations reserves/treaty lands exposed	12 (1.5 completely inundated)	N/A	54 (27.5 completely inundated)	N/A
BC Hydro substations exposed	19	N/A	23	N/A

Table 8. Other Impacts from 500-Year Coastal and Fraser River Floods

Other Impacts	500-year coastal flood		500-year Fraser River flood	
	Flood Vulnerability Assessment	Flood Risk Assessment	Flood Vulnerability Assessment	Flood Risk Assessment
Population impacted	238,000 (seeking shelter[22])	146,000[23] (exposed)	266,000 (seeking shelter)	99,600 (exposed)
Trips disrupted per day	N/A	431,952	N/A	319,558
Debris generated[24]	656,000 US tons	N/A	656,000 US tons	N/A
Buildings damaged[25]	7200	N/A	3600	N/A
Buildings destroyed[26]	1100	N/A	690	N/A

The consequences for key critical infrastructure and essential services in the region, as informed by the *Flood Vulnerability Assessment* are summarized below.

CONSEQUENCES OF A 500-YEAR FRASER RIVER OR COASTAL FLOOD

CRITICAL INFRASTRUCTURE: Inundation of critical infrastructure and networks would be widespread in a major coastal or Fraser River flood and would cause cascading effects, including impacts on cargo and freight movement.

AIRPORTS: The Vancouver International Airport (YVR) is exposed to both coastal and Fraser River flooding, as are several smaller airports.

[23] The population exposed numbers for both the coastal and Fraser River flood are different than the ones found in the *Flood Risk Assessment.* After enquiry with the report preparer, there was a formula inconsistency in the *Flood Risk Assessment* report. The numbers in the *Synthesis of Technical Analysis* are the accurate ones.
[24] Refers to building debris only and omits agricultural building-related losses.
[25] Omits agricultural building-related losses.
[26] Omits agricultural building-related losses.

CONSEQUENCES OF A 500-YEAR FRASER RIVER OR COASTAL FLOOD

PORTS: Port facilities, ferry terminals, and other marine facilities are exposed to both coastal and Fraser River flooding, particularly with sea-level rise. Port infrastructure, particularly equipment, is vulnerable to damage by flood flows and debris; port function would also be affected by disrupted land transportation networks.

RAIL: CN Rail, CP Rail, BNSF, and SRBC assets — including several intermodal and marshalling yards — and rail passenger lines are exposed to both coastal and Fraser flooding. Mission Railway Bridge and CN Rail Bridge are potentially vulnerable to scour damage from a Fraser flood. Losses from cargo disruption due to inundated rail lines ($257M/day) are estimated to be significantly larger than from highway and YVR interruptions. Loss of freight services in and out of the Lower Mainland would impact supply chains.

HIGHWAYS: Key highways exposed to a Fraser River flood include Highway 1 (including all alternative accesses in Chilliwack and Abbotsford), Highway 7, and Highway 11 into Washington State. Key highways exposed to a coastal flood are Highway 99, and Highway 7. Many other critical routes and arterial roads are exposed to both Fraser River and coastal floods.

PUBLIC TRANSIT: Access to the Expo and Millennium SkyTrain and Canada Line rapid transit lines would be impacted by a coastal and/or Fraser River flood. At-grade sections and power sources/electrical equipment located below flood levels are particularly vulnerable.

ELECTRICAL INFRASTRUCTURE: Electrical substations vulnerable to coastal and Fraser flood impacts can be found in most parts of the region, but are concentrated in Richmond, Delta, Vancouver, Burnaby, and New Westminster. Service disruptions could be experienced in areas that are not inundated but are served by a substation that is flooded or taken offline as a precautionary measure. While many transmission towers are exposed, unless floodwaters undermine a tower’s structural integrity, the likelihood of damage or disruption is likely low as transmission lines are elevated. Loss of power would result in disruptions to many essential services, infrastructure, and buildings and facilities.

WASTEWATER FACILITIES: Nine major wastewater treatment facilities are exposed to flooding (six in a Fraser River flood, one in a coastal flood, and two in both flood scenarios), with regional impacts considered high as the facilities serve virtually the entire urban population base with significant potential for environmental contamination. Drinking water facilities were not found to be impacted by Fraser River or coastal flooding.

CONSEQUENCES OF A 500-YEAR FRASER RIVER OR COASTAL FLOOD

EMERGENCY FACILITIES: Of the region's approximately three dozen Emergency Operations Centres, three are exposed to coastal and/or Fraser River flooding. They are in Richmond, Delta, and Port Coquitlam. Police, fire, and ambulance emergency services exposed to flooding are primarily located in Richmond, Delta, Chilliwack, and Abbotsford.

HEALTH FACILITIES: The hospitals in Delta and Richmond, along with the Colony Farm Forensic Psychiatric Hospital, are exposed to both Fraser River and coastal floods, while the Chilliwack General Hospital is exposed in a Fraser River flood.

AGRICULTURE: Approximately 36% of the farmland in the Lower Mainland lies in the Fraser River floodplain. Agricultural losses primarily stem from direct crop losses, damage to buildings and equipment, and livestock feed crops (assuming that most livestock would be moved to higher ground). Flood duration is a significant factor in estimating crop losses. Damage to agricultural buildings constituted the highest losses in a coastal scenario (double that of lost farm gate sales because coastal floods typically occur in the winter with few, if any crops on the land), while lost farm gate sales constituted the largest type of agricultural loss in a Fraser flood scenario (double that of agricultural building damage).

SCHOOLS: Elementary, secondary, and post-secondary schools exposed to flooding are heavily concentrated in two sub-regions: Richmond/Delta (both coastal and Fraser River) and Chilliwack/Abbotsford (Fraser River flood only).

See Appendix D , maps 5 – 9 for selected regional and sub-regional infrastructure maps.

3.2.2 Flood Risk in First Nations Communities

*The Flood Vulnerability Assessment found that **four times** as many First Nations reserves are exposed to a 500-year Fraser River flood than a 500-year coastal flood.*

Over 60 First Nations' reserves and treaty lands in the Lower Mainland are vulnerable to coastal and/or Fraser River flooding. Most reserves and treaty lands that would be substantially or completely inundated in a coastal flood are developed (including with agricultural uses), while one-third of reserves/treaty lands that would be substantially or completely inundated in a Fraser River flood are described as uninhabited in the *Flood Vulnerability Assessment*. Despite being uninhabited by the community, consequences could still be significant due to the presence of culturally important sites, including burial grounds. Through a desktop and web-based review, the *Flood Vulnerability Assessment* report provides a high-level summary of the extent of inundation and exposed assets for each First Nation reserve.

While First Nations and non-Indigenous values can overlap, First Nations have expressed that their priorities differ from those of non-Indigenous communities in many ways. Some of the values and assets identified by First Nations participants as being vulnerable to flood hazards are (in no specific order):

- Impacts on and loss of the environment and land, which is thought of as family and provides life to all. The river and its offerings are an integral part of Mainland Coast Salish culture. Several ceremonies and traditions focus on salmon, fishing, and the river.
- Cultural, sacred, archaeological, and traditional use sites. These sites, which include cemeteries and ancient village sites (especially along the river) both on reserve and in Traditional Territories, are important to First Nations' heritage and serve as a record of their historical presence.
- Safety and homes of people, particularly elders and those with disabilities.
- Cultural, health, and band administration buildings.
- Water and wastewater facilities. This includes vulnerability of septic fields that are used in many communities, as well as impacts of contaminated floodwaters on community wells and aquifers.
- Road and highway access and evacuation routes. These impacts are of particular importance to those communities that have only one road into and out of the community.
- Food security. Fisheries, fishing sites, and traditional harvesting sites are part of the sustenance, livelihood and cultural heritage of communities. A flood could cause wastewater and other contaminated waters to pollute aquifers and streams, impacting these areas and associated fish and fish habitat. Agricultural land is also an important asset regarding food security.
- Emotional and mental health impacts and stress, especially for communities impacted by frequent flood events.
- Other infrastructure, such as fire hydrants, utilities, and gas lines.

3.2.3 Areas with the Greatest Flood Risk

Determining the areas with the greatest flood risk can help prioritize areas for further study or risk reduction and resilience actions. This determination — and the results of any assessment of flood risk, in general — is sensitive to many factors, including:

- The geographic areas used for summarizing losses.
- The flood scenario(s) considered.
- The consequences considered, including what metrics are used and what data are available.
- Existing resilience measures (e.g., emergency measures, floodproofing) that may lower risk.[27]
- The assumptions used, for example, regarding dike failure or consideration of a community's capacity to withstand losses or to recover.

Tables 9 and 10 summarize the results from the *Flood Risk Assessment* and *Flood Vulnerability Assessment* on communities in the region with an emphasis on the greatest estimated consequences or losses, broken down by each type of consequence. While some communities dominate, the tables show that determining the areas with the greatest flood risk depends on what consequences are being considered.

[27] Both the *Flood Vulnerability Assessment* and *Flood Risk Assessment* did not account for existing resilience measures (other than diking in the *Flood Risk Assessment*) in their estimation of consequences**.** Although the *Flood Risk Assessment* undertook some preliminary analysis on other resilience measures, there was not enough information to incorporate the analysis into the risk modelling. Care **must** be taken in interpreting these results.

Table 9 illustrates that considering EAD (estimated annualized damages) — which combines the results from 8 flood scenarios into an annual average — changes the risk ranking in several cases. As EAD considers probabilities from the 10-year (10% AEP) to 1000-year (0.1% AEP) return period, further analysis is needed to verify whether, and in what cases, EAD results are more greatly influenced by the 1000-year event or by smaller events.

Table 9. Census Subdivisions with the Highest Consequences *(Flood Risk Assessment)*

<table>
<tr><th>Consequence type</th><th>500-year Coastal</th><th>Coastal EAD</th><th>500-year Fraser River</th><th>Fraser River EAD</th></tr>
<tr><td>Agricultural losses ($)</td><td colspan="2">Delta</td><td>Chilliwack</td><td>Delta</td></tr>
<tr><td>Non-residential building losses ($)</td><td colspan="2">Richmond</td><td>Chilliwack</td><td>Richmond</td></tr>
<tr><td>Public building/infrastructure losses ($)</td><td colspan="2">Richmond</td><td colspan="2">Richmond</td></tr>
<tr><td>Residential building losses ($)</td><td colspan="2">Richmond</td><td colspan="2">Richmond</td></tr>
<tr><td>Archaeological sites exposed (#)</td><td colspan="2">Delta</td><td>Richmond, Delta[28]</td><td>Delta</td></tr>
<tr><td>Heritage sites exposed (#)</td><td colspan="2">Delta</td><td colspan="2">Richmond</td></tr>
<tr><td>Community centres exposed (#)</td><td colspan="2">Richmond</td><td>Chilliwack</td><td>Richmond</td></tr>
<tr><td>Education/cultural facilities exposed (#)</td><td colspan="2">Richmond</td><td colspan="2">Richmond</td></tr>
<tr><td>Electrical service exposed (#)</td><td colspan="2">Richmond</td><td colspan="2">Richmond</td></tr>
<tr><td>Road network exposed (km)</td><td colspan="2">Richmond</td><td colspan="2">Richmond</td></tr>
<tr><td>Local trips disrupted (#)</td><td colspan="2">Richmond</td><td colspan="2">Richmond</td></tr>
<tr><td>Emergency services exposed (#)</td><td>Richmond</td><td>Richmond, Delta</td><td>Chilliwack</td><td>Richmond</td></tr>
<tr><td>Health service facilities exposed (#)</td><td colspan="2">Richmond</td><td>Chilliwack</td><td>Richmond</td></tr>
<tr><td>Population (general and socially vulnerable) exposed (#)</td><td colspan="2">Richmond</td><td colspan="2">Richmond</td></tr>
<tr><td>Sensitive areas exposed (ha)</td><td>Coquitlam, Delta</td><td>Coquitlam</td><td>Pitt Meadows</td><td>Coquitlam</td></tr>
<tr><td>Hazardous material facilities exposed (#)</td><td>Delta</td><td>Delta, Richmond</td><td colspan="2">Richmond</td></tr>
<tr><td>Sewage facilities exposed (#)</td><td colspan="2">Richmond</td><td colspan="2">Richmond</td></tr>
</table>

[28] A second census subdivision is included when its risk score is very close to the highest-ranking one (9+ out of 10).

The *Flood Vulnerability Assessment*, comparing custom-defined sub-regional areas, had similar findings with the *Flood Risk Assessment*.

Table 10. Sub-Regions with the Highest Consequences *(Flood Vulnerability Assessment)*

Consequence Type	500-year Coastal	500-year Fraser River Flood
Residential, commercial, and industrial building losses ($)	Richmond/Delta	Richmond/Delta
Other building losses ($)	Richmond/Delta	Abbotsford, Chilliwack, Hope, unincorporated areas of FVRD south of the Fraser
Buildings significantly damaged (% and #)	Richmond/Delta	Richmond/Delta
Buildings destroyed (#)	Richmond/Delta	Abbotsford, Chilliwack, Hope, unincorporated areas of FVRD south of the Fraser
Fire stations, hospitals, police stations, EOCs, and schools damaged (#)	Richmond/Delta	Richmond/Delta
Debris generated (tonnes)	Richmond/Delta	Abbotsford, Chilliwack, Hope, unincorporated areas of FVRD south of the Fraser
Households displaced (#)	Richmond/Delta	Richmond/Delta
Population seeking shelter (# and %)	Richmond/Delta	Richmond/Delta

3.2.4 Impacts of Climate Change on Flood Risk

The *Flood Vulnerability Assessment* found that, for a 500-year flood in 2100, compared to a 500-year flood today:

- **Total losses would increase from $19.3B today to $24.7B for a coastal flood, and from $23B to $32.7B for a Fraser River flood.** The year 2100 results are likely underestimates, as future increases in population, development, and inflation are not accounted for.
- Building losses would increase significantly, likely largely due to deeper floodwaters. For a coastal flood, industrial losses would increase 1.6-fold from present day to 2100. For a Fraser River flood, residential, commercial, and industrial losses would increase between 1.8- and 2.5-fold (i.e., total building losses would double).
- The number of BC Hydro substations exposed to a coastal flood would nearly double.
- The debris generated from both a Fraser River and coastal flood would more than double.
- The number of First Nations reserves and treaty lands inundated would not significantly increase, but deeper floodwaters would increase flood damages.
- Agricultural flood losses would increase slightly. This is due to the minor increases (12% increase for the coastal scenarios and 11% for the Fraser River scenarios[29]) in area flooded in the *Analysis*

[29] Note the difference in flood extent findings from the *Hydraulic Modelling and Mapping Project* (see Section 2).

of Flood Scenarios mapping. However, climate change impacts will likely increase the depth and duration of flooding; even if this does not additionally impact crops, damage to buildings and machinery would likely increase.

3.3 Gaps and Limitations

There remain limitations in current knowledge about flood risk at the regional scale. They include:

- **Hazard information.** Risk information depends heavily on the accuracy of hazard information. More accurate hazard information, including in the analysis of dike failure probability and coastal hazards, would improve the accuracy of our understanding of flood risk.
- **Resilience measures.** While the *Flood Risk Assessment* accounts for some level of dike performance, other flood resilience measures — for example, the prevalence of floodproofing — and emergency response capacity could be better integrated into knowledge of flood risk as these and other measures can influence the consequences of a flood.

Other vulnerabilities contributing to the region's flood risk that have not been thoroughly analyzed, include but are not limited to:

- **Impacts to First Nations:** A key gap in the regional understanding of flood risk is the lack of comparable data for First Nations reserves in the *Flood Risk Assessment's* risk modelling. While the *Flood Vulnerability Assessment* describes key assets in each reserve, it does not analyze the extent of inundation in relation to these assets. Aside from on-reserve assets, there are also important sites and values in First Nations' Traditional Territories that were not assessed in either project. As many communities are unprotected against smaller floods, similar analyses for smaller-magnitude events would be useful. The *Mainland Coast Salish Flood Risk Assessment* fills in some gaps for a number of communities, but this information is not accessible to inform the LMFMS, and a region-wide understanding of flood consequences for First Nations communities is not currently available.
- **Broader economic impacts:** While the *Flood Vulnerability Assessment* contains a discussion of economic losses from infrastructure inundation and disruption, indirect economic losses associated with disruption of infrastructure or businesses other than cargo shipment interruption were not quantified. Economic impacts at the provincial or national scale and net welfare (e.g., gains to businesses outside of the affected area, or benefits to the reconstruction industry) were not assessed.
- **Broader food security impacts:** Interruptions to cargo shipments (including food imports) and agricultural production were assessed in the *Flood Vulnerability Assessment*. However, longer-term (e.g., multi-year crop losses) or finer-grained (e.g., food processing facilities) impacts to food security were not. There could be broad regional-scale impacts, as well as food security impacts elsewhere in BC from those who source food from the Lower Mainland.
- **Critical infrastructure impacts and interdependencies:** Flood damages to YVR, port facilities, and some other critical infrastructure assets were assessed in a simplified way in the *Flood Vulnerability Assessment* and not at all in the *Flood Risk Assessment*, in part due to challenges acquiring the relevant vulnerability information. Cascading effects due to infrastructure interdependencies are discussed qualitatively in the *Flood Vulnerability Assessment* but are very challenging to quantify at a regional scale. For example, while emergency and health facilities

were considered, inundation of access roads to and from such facilities were not assessed, nor were the impacts of power outages on other infrastructure.

- **Environmental impacts:** While the potential for hazardous material release, the sewage network, and environmentally sensitive areas were assessed in the *Flood Risk Assessment*, and flood-related debris generation was estimated in the *Flood Vulnerability Assessment*, the extent of environmental damage resulting from a flood is challenging to quantify at a regional scale. There is potential for the *Flood and Environment Atlas* to illuminate more about exposed natural assets/ecosystem values.
- **Capacity to absorb losses**: Communities are impacted differently based on their size, resources, and proportion of the community exposed to flood hazards. Therefore, absolute numbers only tell part of the story. For example, the flooding of a single health care facility or access road would more severely impact a small community with only one facility or access road than a large community with multiple alternatives.

4. Flood Risk Reduction

Across the Lower Mainland, a variety of measures are used to reduce the consequences of a flood. Funding programs, provincial legislation, and changes in the distribution of authority over the years have influenced the choice of risk reduction measures in the region.

4.1 LMFMS Projects Related to Flood Risk Reduction

The following LMFMS projects were undertaken to improve knowledge about risk reduction and resilience measures in the region.

The ***Lower Mainland Dike Assessment (Dike Assessment)*** is a multi-criteria desktop evaluation of 74 registered dikes that make up approximately 500 km of roughly 600 km of dikes in the region. These dikes were assigned ratings on a scale of Good, Fair, Poor, and Unacceptable, based on 9 criteria relevant to dike integrity and performance, as shown in Table 11. The assessment was a desktop review that did not include field work or additional analysis to verify the accuracy of information from previous reports. Notably, little or no information was available for most dikes regarding seismic stability. "Orphan" dikes (dikes without a local authority to regularly inspect and maintain them) and some privately owned dikes were not included in this assessment.

Table 11. Rating Categories in the *Lower Mainland Dike Assessment*

1. Dike crest level compared with the design flood level
2. Dike geometry
3. General geotechnical stability
4. Seismic geotechnical stability
5. Erosion
6. Vegetation management and animal activities
7. Encroachment from buildings, roads, or other infrastructure
8. Presence of appurtenant structures
9. Administrative arrangements

The ***Analysis of Flood Protection Infrastructure, Practices and Policies*** report reviews a range of existing flood management infrastructure, practices, and policies and analyzes the associated gaps, limitations, successes, and opportunities. The analysis is largely based on a literature review, supplemented with interviews with 10 local governments and one other organization.

The ***FloodWise.ca*** website includes a high-level analysis of different types of structural and non-structural risk reduction measures and their strengths and limitations in the Lower Mainland context. While the information is not sufficient to recommend specific measures for specific locations, this resource offers a menu of options that may warrant further consideration by local and First Nations governments, and other decision makers regarding a suite of measures that may be suitable for their local circumstances.

The ***Hydraulic Modelling and Mapping Project***[30] simulated five flood mitigation scenarios to better understand the effects of mitigation measures on flood extents, depths, and Fraser River water levels. Four scenarios were modelled, and one used a simplified approach. The scenario locations and parameters were informed by the project advisory committee and consultant, accounting for where the mitigation measure may have the most impact. Two scenarios (dike raising and upstream storage) were

[30] The link provided is for the Primer on this project. It is an 11-page public-facing document that details key information from this work. A more thorough technical report is available via the Fraser Basin Council.

considered on a region-wide basis. The other three scenarios (dike setback, sediment removal, and land raising) were simulated at a local or sub-regional scale. The results are dependent to the areas they were simulated in, and different results should be expected if the scenarios are applied at other locations.

The ***Lower Mainland Flood Risk Assessment (Flood Risk Assessment)*** conducted some exploratory analysis of flood construction levels and emergency measures for a small number of municipalities based on interviews and questionnaires. Region-wide information was not available therefore, this analysis was not included in the regional assessment. This project also created dike influence areas to identify the area protected by each dike and used the rating criteria from the *Dike Assessment* to rate these areas based on the "weakest link" of the dike segments that protect them.

Outside the LMFMS: The ***Geotechnical Investigations and Seismic Assessment*** project assessed the seismic vulnerability of 27 high-consequence dikes in the Lower Mainland, including the District of Squamish. It used prediction models to estimate the damage levels caused by different magnitudes of earthquakes occurring within the next 50 years. A key objective of this project was to estimate the vertical displacement of the dikes, which can inform probabilistic analyses of seismic-induced flooding. Horizontal displacements can also be estimated using the results of this project. The evaluation of dike vulnerability is based on several variables including dike geometry, soil conditions and the earthquake return period. The project also included the results of drilling investigations, which assessed the dike fill material and foundation soils.

4.2 What We Have Learned about Flood Risk Reduction in the Lower Mainland

Prior to widespread European settlement, First Nations communities in the Lower Mainland lived with periodic flooding by leaving seasonal camps and villages during the flood season and returning when it was safe to do so. The Indian Act created reserves starting in the 1800s, limiting the ability of First Nations to continue this practice by restricting their movement. After a series of damaging floods in the late 1800s, including the 1894 Fraser River flood, European settlers began to invest heavily in defensive infrastructure, such as diking, to protect people and assets in the floodplain. The Fraser River Flood Control Program further expanded diking infrastructure by over 200 km in the 1970s and 80s. The region currently has approximately 600 km of dikes; however, not all inhabited lands are protected by dikes. Some First Nations communities are in floodplain areas that do not have dike protection. In the early 2000s, legislative changes delegated the authority for land use planning and regulation in floodplains to local governments. Today, funding for flood risk reduction and resilience in BC continues to focus predominantly on dikes.

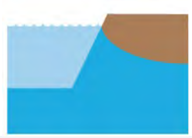
4.2.1 Structural Flood Risk Reduction Measures

Structural measures to reduce flood risk are aimed at controlling the movement of water in rivers or coastal areas to prevent floodwaters from entering floodplains. Structural measures in use by Lower Mainland communities include:

- *River and sea dikes*
- *Seawalls*
- *Sea dams*
- *Pump stations, flood boxes, and gates*
- *Tide gates*
- *Spillways*
- *Sediment basins*
- *Groynes*
- *Erosion protection (e.g., reuse of old concrete slab, vertical sheet piling, riprap, nature-based approaches)*
- *Dredging and sediment management*
- *Beach nourishment, subtidal reefing, non-contiguous rock gardens*
- *Raising land levels*
- *Maintenance of ditches and canals*
- *Retention ponds*
- *Wetland preservation and restoration*
- *Natural foreshore features*
- *Diversion pipes*
- *Revetment slopes*
- *Temporary measures such as Tiger Dams™ and sandbagging*

Regional analyses of structural measures to date have largely focused on diking because dikes are the primary structural measure for many communities in the Lower Mainland. The *Dike Assessment* found that **only 4% of dike segments**[31] **in the region are high enough to contain the 1894 design flood event with a standard freeboard allowance of 0.6 m.** Considering dike crest height *only* (allowing for reduced freeboard), 29% of assessed dikes could potentially contain the design event. This accounts for dikes that have full (0.6 m) or partial (0.3 m) freeboard. During the design event, 17% of dikes are expected to have no freeboard, and the remaining 54% of dike crests are below the design flood event. Considering only dike height versus the design flood level, 71% of the dikes could be expected to fail by overtopping during the design event (Table 12).

Table 12. Crest Heights of Lower Mainland Dikes

Dike Segments Meeting Provincial Standard	Dike Segments Below Provincial Standard		
			
Not expected to be overtopped by the design flood	**May or may not be overtopped by the design flood**	**Expected to be overtopped by the design flood**	
Design flood level + 0.6 m of freeboard	Design flood level + 0.3 m of freeboard	Design flood level + no freeboard	Below design flood level
4%	25%	17%	54%

[31] The 74 Lower Mainland dikes examined were further divided into 118 segments.

Generally, Fraser River dikes can contain the 100-year flood, with some containing the 200-year flood. However, some dikes are low enough to experience localized overtopping at the 20-year flood (5% AEP). In addition to dike overtopping, it is important to consider other potential factors for failure (Table 11).

Noted dikes with an overall rating of "poor to unacceptable" were located in Pitt Meadows, Maple Ridge, Barnston Island, Nicomen Island, and along the Squamish River. Coastal dikes that fall into this category include sections of sea dikes in Delta and Surrey.[32] Only 6% of the dikes assessed received a rating of "good to fair," with most dike segments deemed "fair to poor."

Table 13. Length of Diking Categorized by Overall Dike Rating

Overall Dike Rating Categories	Diking Length (km)
Good to Fair	31
Fair to Poor	377
Poor to Unacceptable	95

Close to 20%, of diking in the* Dike Assessment *has an overall rating of "poor to unacceptable"

(Table 13)

As an additional piece of exploratory analysis, the *Flood Risk Assessment* used the *Dike Assessment* rating criteria (omitting seismic geotechnical stability and dike crest level) to identify the most vulnerable dike-protected areas in the Lower Mainland, which included parts of Pitt Meadows and Mission, as well as Richmond, Delta, Surrey, Barnston Island, and Coquitlam. While these ratings were not incorporated into the *Flood Risk Assessment* hazard and risk analysis due to resource constraints (only dike crest heights were), these ratings can give local decision makers some comparison of the relative vulnerability of their jurisdictions to others in the Lower Mainland.

In addition to dike vulnerabilities from flooding, the Lower Mainland is a seismically active region. The dikes located along the Fraser River and the coast are vulnerable to earthquake damage due to their location on soils susceptible to liquefaction. Most dikes will experience deformation and/or displacement during a 2,475-year return period earthquake, which is the provincial seismic standard.

The BC *Seismic Design Guidelines for Dikes* apply to high-consequence dikes in southwestern BC and on Vancouver Island. One challenge that diking authorities have faced in building seismic resiliency into dike upgrades is the inadequate information available on geotechnical conditions and seismic vulnerability. The *Dike Assessment* did not assign ratings for seismic stability to nearly 30% of dike segments due to inadequate information. Of the remaining segments, 53% of the segments were found to be seismically unstable, and 18% almost meet seismic standards.

The *Geotechnical Investigations and Seismic Assessment* improved the information available on seismic vulnerability. Figure 12 (Appendix D: Map 10) and Table 14 provide key results from the study. Notably:

- **Two-thirds of high-consequence dikes in the region would experience subsidence of over 50 cm from a 2,475-year return period earthquake.** These dike segments do not comply with the provincial criteria for a 2,475-year return period earthquake (i.e., maximum allowable vertical displacement of 50 cm).

[32] A complete list of dike segments, their diking authorities, and the conditions of these segments are located in the *Lower Mainland Dike Assessment* report.

- **Almost half (48%) of the dike segments would not comply with the provincial criteria for a 475-year return period earthquake** (i.e., maximum allowable vertical displacement of 15 cm).

Figure 12. Vulnerability of High-Consequence Dikes in the Lower Mainland

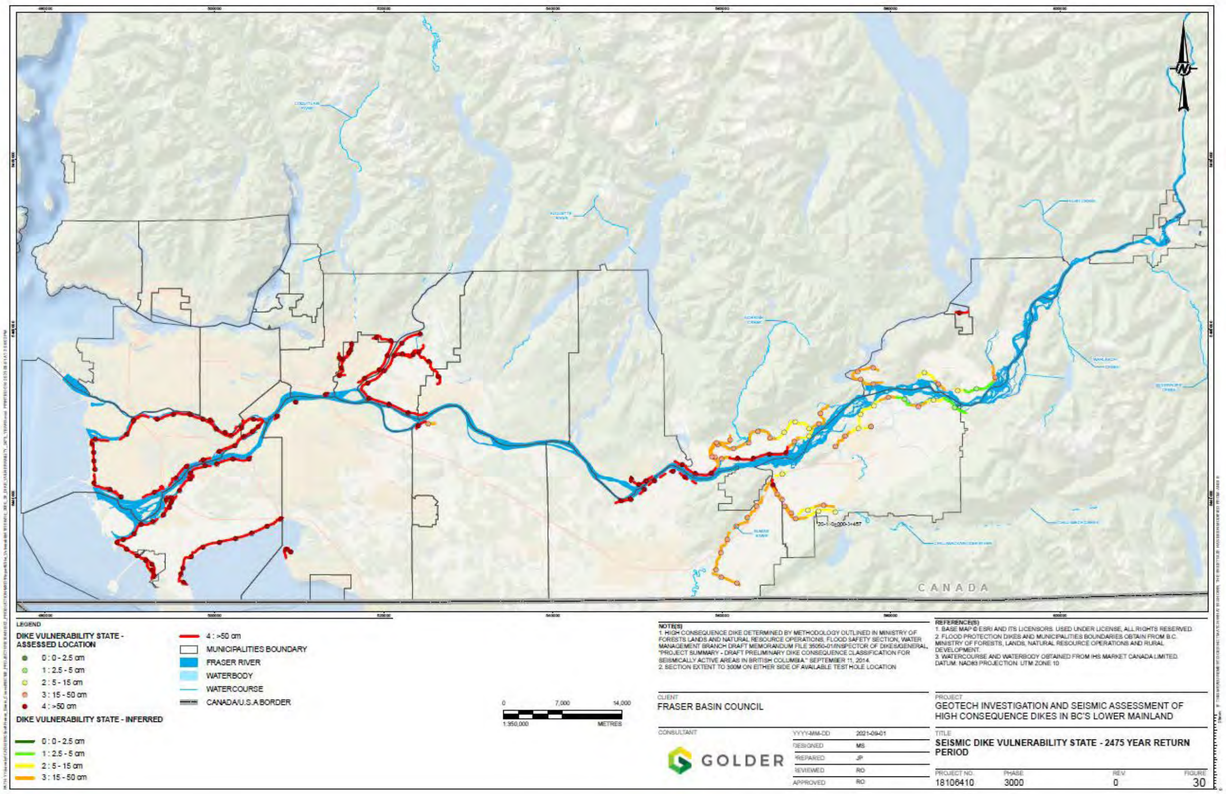


Table 14. Damage State and Dike Crest Subsidence for High-Consequence Dikes

Damage State Index	Dike Crest Subsidence (cm)	% of dikes in a 2,475-year return period earthquake	% of dikes in a 475-year return period earthquake
0	0–2.5	11% (<15 cm)	52% (<15 cm)
1	2.5–5		
2	5–15		
3	15–50	23%	21%
4	> 50	66%	27%

It should be noted that additional analysis is being undertaken on seismic dike vulnerability including an update of the seismic model version and a re-running of the previous analysis.

Challenges Associated with Structural Measures in the Region

Although dikes play a significant role in reducing flood risk to communities, they encourage the creation of risk by enabling building and development in the floodplain.

Many communities with assets behind dikes would be severely impacted if the dikes were to fail during a large flood event. The region has significant residual risk as many of the dikes do not meet provincial crest height standards, have general geotechnical (e.g., seepage and erosion) problems, are older, are not adapted for climate change, and have little to no seismic resilience in place.

It would be costly to upgrade all diking infrastructure in the Lower Mainland to meet current standards, although arguably, it may cost less than the avoided losses associated with significant dike failures. In addition to the often-prohibitive cost of land acquisition and seismic resilience, diking can be destructive to the natural environment, for example, by degrading vegetated riparian ecosystems and cutting off access to important salmon spawning and rearing habitat locations within floodplain areas. Many pumps associated with dikes can kill fish in addition to being a barrier to accessing fish habitat in the floodplain areas. Dikes that were built near or on top of sacred or traditional-use sites also negatively impact First Nations.

The *Analysis of Flood Protection Infrastructure, Practices and Policies* project also found challenges in the current regulatory environment. For example, the *Dike Maintenance Act* and the *Federal Fisheries Act* have conflicting approaches to vegetation management on flood protection infrastructure. If communities have fallen behind on a dike's vegetation management, Fisheries and Oceans Canada encourages local governments to keep the vegetation as it now provides riparian habitat. However, as vegetation can negatively affect the integrity of the dike, the *Dike Maintenance Act* encourages vegetation removal. When it comes to implementing nature-based approaches to flood risk reduction and resilience, communities and regulators lack knowledge and experience, which limits a willingness or ability to approve, permit, and implement such approaches.

4.2.2 Non-Structural Flood Risk Reduction Measures

Non-structural measures, such as managing land use and development in flood hazard areas, aim to reduce damages caused by exposure or vulnerability to flood hazards. Non-structural measures in use by Lower Mainland communities to reduce flood risk include:

- *Policies in regional growth strategies, official community plans, neighbourhood, or area plans*
- *Hazard-specific development permit areas*
- *Flood construction levels, setbacks, and other requirements within a zoning, floodplain, or other bylaw*
- *Coastal protection strategy/shoreline protection plan*
- *Subdivision regulation*
- *Restrictive covenants*
- *Stormwater management plans*
- *Building bylaws/requirements*
- *Parks planning*
- *Foreshore lease*
- *Risk tolerance criteria*
- *Requiring qualified professional reports (i.e., safe for use intended)*
- *Land acquisition*

Non-Structural Measures Used by Local Governments

There is variability in the use of non-structural measures across the region. In the *Analysis of Flood Protection Infrastructure, Practices and Policies*, Lower Mainland communities reported that floodplain bylaws — which are encouraged but not required of municipalities — have been difficult to adopt in built-up communities. The report cites a 2014 study of 159 BC municipalities that found that, ten years after land use and development decisions in floodplains were delegated by the provincial government to municipalities, only 55 municipalities had adopted a floodplain bylaw or incorporated relevant provisions into their zoning bylaw.[33] While BC's decentralized approach offers flexibility to local governments, it is unclear how effective these approaches are in significantly reducing or limiting future flood risk at a regional scale. Some challenges include varying capacity among different communities, conflicting incentives for development-related revenues (for local governments) versus disaster financial assistance (from provincial and federal governments), and common and varying exemptions across the region.

One of the more common tools used by municipalities is flood construction levels (FCLs). FCLs are the minimum height required for a development to protect habitable living space from flood damage. FCLs are usually specified in or required through floodplain bylaws, zoning bylaws, development permit area guidelines, or other policy or regulatory documents. Some jurisdictions do not enforce pre-calculated FCLs, but instead set flood water surface level criteria that allow development applicants to perform their own water surface level analysis, which may yield values that differ from a more conventional approach to setting FCLs. Others require the use of flood hazard assessments by qualified professionals to certify that a site is "safe" for the use intended and is in compliance with the jurisdiction's bylaw or policy. Many jurisdictions with floodplain regulations allow exemptions to their flood hazard bylaws, though the criteria for exemptions vary by jurisdiction. In addition, illegal conversion of non-habitable space to habitable space (e.g., converting a crawl space to a basement suite) after inspections sometimes occurs.

Existing regulations are not always updated with the most current flood hazard information available. No communities interviewed in the *Analysis of Flood Protection Infrastructure, Practices and Policies* project indicated that their floodplain bylaw had been adjusted to reflect a newer Fraser River flood profile that had been released in 2006 and updated in 2008, with the exception of Chilliwack. The *Flood Risk Assessment* found that many municipalities have FCL values that were developed more than 25 years ago, which likely do not reflect the current understanding of the flood hazard. Some communities rely on the 2008 Fraser River design flood profile, while others have more up-to-date information. The oldest FCL identified among the sample was in downtown New Westminster (1978), while the newest was Chilliwack (2018).

There are several communities with an increasing coastal hazard that have raised their FCLs based on 2016 provincial guidance of 1 m of sea-level rise by the year 2100. Some communities that used interim FCLs to prepare for higher FCLs resulting from sea-level rise projections reported experiencing challenges applying the interim FCL uniformly across the community.

[33] Stevens, M., and Hanschka S. (2014). "Multilevel Governance of Flood Hazards: Municipal Flood Bylaws in British Columbia, Canada." *Natural Hazards Review.* DOI:10.1061/(ASCE) NH.1527-6996.0000116.

Covenants were cited as the most in use policy/planning tool by interviewees of the Analysis of Flood Protection Infrastructure, Practices and Policies.

Some local governments use covenants to attach stipulations to the land titles of properties located in floodplains, such as requiring that a property be built to FCL standards, or that a property is exempt from the FCL. While covenants might help limit the liability of local governments associated with development in a floodplain, they are difficult to enforce, and residents can petition to have one removed. Bylaws are more enforceable than covenants.

Policy misunderstandings can discourage the use of some of the above measures. For example, anecdotally, restrictions on Disaster Financial Assistance eligibility based on the designation of floodplains have affected some local governments' decisions regarding the adoption of floodplain bylaws. Some local governments perceive that identifying floodplain areas may increase their liability. Also, as property taxes are the main source of local government revenues, this can drive communities located in the floodplain to support development in order to maintain services, including funding flood protection. For example, staff from New Westminster and Coquitlam estimated that approximately $100 million in building permits were issued per year in the floodplain within their respective jurisdictions in the *Analysis of Flood Protection Infrastructure, Practices and Policies*. Lack of understanding and buy-in by the development sector regarding floodproofing and flood resilient design was also found to be a challenge for the broad uptake of floodproofing practices.

Non-Structural Measures in First Nations Communities

Through engagement with First Nations on the LMFMS, the following insights were shared. Some First Nations governments are developing land use plans for their communities. One community was in the process of developing a land use plan that outlines floodplain areas where building is and is not recommended; in the meantime, it is advising that residents not build in areas with a high chance of flooding. Another community reported that their new wetland, built primarily to create habitat, served multiple uses, including water storage.

For some First Nations communities, commonly discussed non-structural measures — such as flood construction levels or building outside of the floodplain — are not viable due to limited available land outside the floodplain (due to the Indian Act reserve system) or challenges in raising buildings substantially. Due to reserve boundaries, options for relocation or managed retreat are presently limited. Other strategies, including "Add to Reserve" provisions, and/or access to additional and/or traditional lands, would need to be considered. In general, community comments to the LMFMS favoured a mix of risk reduction methods that would have lower negative impacts on the environment, including:

- Increasing water storage availability by naturalizing floodplain areas and/or building/restoring wetlands, streams, and sloughs
- Land use practices that increase water attenuation and decrease runoff
- Financial compensation mechanisms to flood lands with owners' consent
- Raising homes and critical infrastructure
- Floodproofing buildings
- Green infrastructure methods
- Fish-friendly grey infrastructure

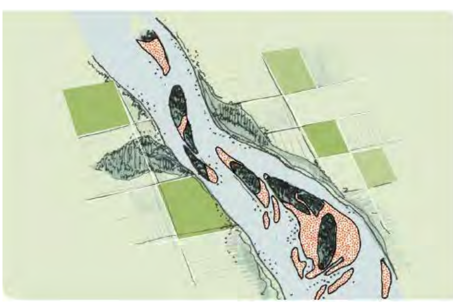
4.2.3 Potential Hydraulic Effects of Simulated Flood Risk Reduction Measures

The *Hydraulic Modelling and Mapping Project* found that the five mitigation scenarios assessed (dike raising, dike setback, sediment removal, land raising, and upstream storage) resulted in flood water level changes in the range of 10–40 cm. As a point of comparison, the same project found that flood water levels could increase by 0.5–2 m in 2050 and 2100 as a result of climate change.

The outcomes of these scenarios are described below. Effects on flood water level for mitigation measures outside of these specific scenarios will vary depending on the length and height of dike raising; location, length and amount of dike setback; locations and amount of sediment removed; location, extent and height of land raising; and capacity and timing of upstream storage.

Dike Raising: All lower Fraser River and sea dikes were raised to meet provincial design standards for dike crest elevation. This reduced the flood extent in multiple locations. It also increased the flood water level in the river channel for the 1894 freshet flood event from just downstream of the Harrison River confluence to the Port Mann Bridge by about 0.3 m in comparison to the base run. Upstream of the Agassiz-Rosedale Bridge, the impact on flood levels was limited, as there are few dikes.

Dike Setbacks: Approximately 15 km of existing diking in Chilliwack was set back by 400 m, which resulted in a 0.15 m reduction in flood water levels in that section of the river. Additional large setbacks would be required to accomplish more significant flood level reductions. In the low gradient, tidally influenced reaches of the Fraser, dike setbacks have limited effects on water levels.



Sediment Removal: Approximately 2 million cubic metres of sediment was removed from the tops of gravel bars between the Agassiz-Rosedale Bridge and the Harrison River, resulting in a 0.2 m reduction of local water levels. Localized sediment removal areas would be expected to fill over time, not providing a long-term lowering of the flood water level. Two million cubic metres is significantly more than previous approvals by regulators and has limited potential to lower flood water levels.

Land Raising: About 80 hectares of land at a site along the Fraser River was raised to exceed a flood construction level equivalent to the 1894 flood level plus 0.6 m of freeboard. For the scenario (largely inside a dike), there were negligible impacts on water levels in the river (less than 0.01 m). Raising land in the floodplain can negatively impact surrounding lands, unless these are also raised or otherwise managed for flood, particularly if the raised area is outside present diking.

Upstream Storage (not modelled): Based on a literature review of the use of the Nechako and Bridge-Seton reservoirs for storage during the 1972 flood, it was estimated that a 200-year flood could potentially be reduced to the water levels of a 100-year flood. The modelled 100-year flood was used to illustrate the effects of upstream storage, whereby the flood level at Mission was estimated to drop by 0.4 m, at the Agassiz-Rosedale Bridge by 0.3 m, and at Hope by 0.4 m. A similar scale of reduction would be unlikely at larger flood magnitude (e.g., the 500-year flood) due to the large amount of storage needed.

4.3 Gaps and Limitations

An improved understanding of flood risk reduction approaches would help inform the selection and design of risk reduction measures in the Lower Mainland. The following are identified as key gaps in the regional understanding of flood risk reduction:

- **Non-structural measures:** Analyses of non-structural risk reduction measures have not been as thorough as the analyses of dikes in the region. Although interviews, surveys and a literature review have provided partial, qualitative, and anecdotal information; a regional-scale assessment has not been completed. A more thorough evaluation of the effectiveness of existing measures, such as floodplain regulations, development permit areas, and covenants, in reducing the region's flood risk could lead to more effective and widespread use of non-structural measures for risk reduction.
- **Mitigation scenarios:** The five mitigation scenarios simulated in the Fraser River flood model provided helpful information, but more analysis is needed to understand how a wider range of measures, and combinations of measures — both structural and non-structural — would affect flood hazards and flood consequences (including risk transfer). Modelling measures in other locations and under different flood scenarios would provide additional insights. The *Hydraulic Modelling and Mapping Project's* report contains some recommendations for further analysis.
- **Environmental impacts:** Both the positive and negative environmental impacts of structural and non-structural measures have not been assessed. A comparison of these impacts would be useful information to assist with the selection and design of risk reduction measures.
- **Critical infrastructure resiliency:** There is little available information on what critical infrastructure providers are currently doing to reduce risk/make their assets flood resilient.
- **Community resilience measures:** Community resilience actions, such as plans to manage and maintain municipal infrastructure and dikes and emergency management plans, have not been accounted for in the analyses to date.
- **Risk transfer:** The extent to which risk transfer is occurring as a result of flood hazard management measures in the Lower Mainland is currently unknown; however, at least one dike alignment project has modelled the effects of different dike alignments on flood levels upstream and downstream of the project area.
- **Context-specific analyses:** Technical analyses for the LMFMS have focused on regional measures to build a regional understanding. However, detailed local analyses are important to better understand the suitability and impacts of risk reduction measures for individual communities. For

example, dikes and sandbags would not be effective to protect communities that experience seepage during high water events. Communities like this would be better served by sewage system upgrades and building to higher FCLs. A multi-criteria evaluation of various risk reduction measures applied to different contexts would help communities identify optimal measures for their particular contexts. Such a framework was recommended and illustrated in Draft 1 of the LMFMS.

- **Nature-based approaches:** While nature-based approaches to reducing flood risk are of interest to many communities, there is limited knowledge and guidance to support their design, authorization, implementation and maintenance. The Lower Mainland is home to some pilot projects, but additional analysis and expertise are needed to support and build momentum in this emergent area.

5. Relevance of the Analyses to the LMFMS

This section discusses how the information produced has informed the strategy to date and discusses opportunities to further use or build on available information to support strategy development. It is based on assumptions about the strategy's approach, scope, and recommended actions, as well as draft frameworks presented in Draft 1, with consideration of the diverse feedback received on Draft 1. Input from participating organizations has also been, and will continue to be, a key input into the strategy.

The use and usefulness of the flood hazard, risk, and risk reduction information and tools developed through the LMFMS ultimately depend on the direction being taken for the strategy.

5.1 How Information Developed Has Informed the Strategy to Date

Process: Flood hazard information is foundational to understanding flood risk. The hazard analyses from *Analysis of Flood Scenarios* and the *Hydraulic Modelling and Mapping* projects provided the information about Fraser River and coastal flood hazards required to assess flood consequences and risk through the *Flood Vulnerability Assessment* and *Flood Risk Assessment* studies, respectively. Knowing that most dikes do not meet current standards for the design flood also helped inform decisions/assumptions regarding the flood scenarios used for the *Flood Vulnerability Assessment*. Information developed on hazard, risk, and risk reduction has been incorporated into FloodWise.ca for educational purposes.

Scope: The results from the *Flood Vulnerability Assessment* that highlighted the significant direct and indirect costs of a major flood in the region helped participating organizations confirm the need for a regional flood strategy and an initial focus of the strategy on coastal and Fraser River flooding as regionally significant flood hazards.

Draft strategy content: Findings and lessons learned from the analyses have, in conjunction with participant input, helped inform recommended actions in Draft 1. For example:

- Experience developing the hydraulic model, and confirming significant demand to use the model, has led to the recommended action of developing a long-term regional program for flood hazard modelling and mapping. Communities and other organizations in the region want and need this type of information and this type of tool.
- The *Flood Risk Assessment* process and results have helped shape the proposed development of a regional prioritization framework. Additional considerations were also presented in Draft 1 to help overcome some of the limitations of the *Flood Risk Assessment*.
- Understanding the increases in flood magnitude and frequency, and associated consequences, due to climate change informed several recommended actions.
- Findings from the *Analysis of Flood Protection Infrastructure, Practices and Policies* and the *Dike Assessment* have supported some of the recommended actions that aim to support and strengthen risk reduction and resilience actions.

5.2 How Information Developed Can Further Support Strategy Development

5.2.1 Strategy Actions for Improving Flood Information

Section 2.3 and Section 3.3 summarize some of the key gaps and limitations in the knowledge developed on flood hazard and risk in the region. Understanding the limitations and challenges of the completed analyses and understanding the need for improved information informed recommended actions in the strategy on improving understanding of flood risk (Section 2.1 in Draft 1 of the LMFMS).

5.2.2 Prioritization of Risk Areas

To have these Technical Analyses meaningfully inform further deliberations and decision-making, there needs to be a common understanding about what they do and do not include, and what assumptions were made to develop them.

Regional-scale prioritization of flood risk areas is a key concept in the LMFMS. Draft 1 proposed a set of risk-based criteria to support a framework for the prioritization of regionally significant areas for risk reduction actions and investments. The *Flood Vulnerability Assessment* and *Flood Risk Assessment* sought to understand the potential impacts of flooding in the region and serve as a basis for the prioritization of risk reduction actions and investments in the region through the LMFMS. In different ways, both studies provide information about where different types of consequences could be greatest in a given flood scenario. The *Flood Risk Assessment* online portal was designed to support prioritization of flood risk areas by enabling the weighting of consequences and comparing/ranking areas based on the overall consequences of a flood scenario.

Assessments and discussion of flood risk are sensitive to the variables being considered. To have this information meaningfully inform further deliberations and decision-making, there should be a common understanding about what is and is not included and what assumptions have been made. Section 3.2 focuses largely on 500-year flood scenarios, as this is the information available from both the *Flood Vulnerability Assessment* and *Flood Risk Assessment* (and this aligns with the Fraser River design flood). Other flood scenarios can and should be considered to inform regional prioritization.

If flood risk is used as a basis for prioritization, prioritization criteria will have to be sensitive to the limitations of these studies, and consideration of other factors, for example, by accounting for proportional impacts to a community, applying the appropriate geographic area for different types of impacts (e.g., census-based geographies might not be appropriate to assess linear infrastructure impacts), considering the existing resilience measures a community has (which would reduce its risk), and considering the capacity of a community to respond to or recover from a flood.

If the prioritization of areas for risk reduction through a regional strategy is based on flood risk, as proposed in Draft 1, certain information gaps will likely need to be addressed (summarized in Draft 1).

Key among them are:

- **Improved coastal hazard information.** By expanding the geographic extent of the current flood model to include Boundary Bay and English Bay (see Section 2.3).
- **Improved knowledge of flood risk for First Nations communities and Traditional Territories**. Information on exposed/vulnerable assets in First Nations communities (summarized in the *Flood*

Vulnerability Assessment report) is outdated and incomplete. While the knowledge provided through engagement is valuable, it does not provide complete information, nor comparisons between areas within and outside of reserves. As an interim approach, using hazard information and reserve boundaries to estimate the area or proportion of each reserve inundated with flood depths over a certain amount could provide a proxy for impacts to a community.

- **Environmental impacts**. While the *Flood and Environment Atlas* has not been used for analysis, if updated, some of the datasets used in the *Atlas*, such as fish presence, fish habitat, and species and ecosystems at risk, could be applied to the *Flood Risk Assessment* to understand the exposure of certain natural features to impacts from a given flood event.
- **Critical infrastructure impacts and interdependencies.** Despite the finding that building losses make up the highest proportion of monetary losses, it is anticipated that the disruption of certain infrastructure can cause cascading effects that result in significant indirect and harder-to-measure losses. If this is agreed upon as a criterion for prioritization (as proposed in Draft 1), additional analysis may have to be undertaken to better understand interdependencies and support decision-making on improving critical infrastructure resilience. Although the *Flood Vulnerability Assessment* provides information on the exposure of critical infrastructure assets, its use of highly simplified hazard mapping makes the results less reliable, and the analysis may have to be updated using more accurate modelling and mapping (e.g., that used for the *Flood Risk Assessment*).

The *Flood Risk Assessment*'s flood consequence results took into account the variability in crest elevations of dikes throughout the region, but it did not consider differences in other vulnerability characteristics of the dikes. Dike ratings from the *Dike Assessment* could be considered alongside existing consequence information from the *Flood Risk Assessment* or *Flood Vulnerability Assessment* — or BC's *Dike Consequence Classification* — to identify areas with the highest consequences associated with dike failure, and where existing dikes are also the most vulnerable to failure or are in poorest condition. This could inform decision-making on further study, prioritization, and ultimately, dike upgrades. For example, of the 27 dikes in the Lower Mainland (including the District of Squamish) rated as high consequence in the *Dike Consequence Classification Study*, over 20 were rated as "fair to poor" in the *Dike Assessment*. Among the region's dikes rated "poor to unacceptable," the Barnston Island, Surrey Mud Bay, and Maple Ridge Albion dikes were rated as "moderate" consequence; the Pitt Meadows and Nicomen Island dikes were rated as "major" consequence; and the Squamish River and Delta Sea Dike were rated as "high" consequence.[34]

Although the focus in this initiative to date has been on addressing major flood events, smaller, more frequent floods affect many areas that lack diking infrastructure, which are disproportionately First Nations communities. Understanding which areas would experience flooding in a relatively small flood (e.g., 50-year event) can also help identify those areas for prioritization, including implementation of preventative measures, and the provision of emergency response capacity.

[34] The *Dike Assessment* rated dikes based on the 1894 flood event while the *Dike Consequence Classification Study* uses the 200-year floodplain, so results are not directly comparable.

The above considerations underscore the need for further discussion to develop a defensible framework for regional prioritization of risk areas. Some key elements to resolve/decide on are:

- **Risk tolerance, or the flood scenario(s) to be used as a basis for decision-making in the strategy.** (Note that the flood scenarios and hazard information used, differ from project to project. If information from multiple studies is combined to inform prioritization, there will be a need to fully understand and reconcile the differences in scope, approach, and assumptions.)
- **Weighting of consequence factors**. The *Flood Risk Assessment* shows how the weighting of consequence types can affect the relative risk score of an area. While communities can and may wish to apply their own weights specific to their community for their own planning, developing and agreeing upon a standard regional weighting will be required for regional-scale prioritization of risk areas as is proposed in Draft 1 of the LMFMS.

5.2.3 Risk Reduction Actions in the Strategy

Draft 1 of the LMFMS recommended actions to support understanding about and use of a range of risk reduction measures, but it did not recommend the use of specific measures in specific areas. Although initial guidance from participating organizations was that the LMFMS should not prescribe specific measures in specific areas, feedback on Draft 1 from some participating organizations indicated a desire for the strategy to provide stronger direction about specific actions.

The mitigation scenarios described in Section 4.2.3 provide helpful insights on the effectiveness of several measures in affecting flood extent and depth along the lower Fraser River. However, these simulations did not analyze alternative designs, locations, etc. of these types of measures. For example, what the outcomes and trade-offs would be with larger-scale dike setbacks, widespread land-raising scenarios, different sediment removal scenarios, or different dike raising scenarios. The simulations also did not analyze the measures' effectiveness in reducing risk (or the consequences of a flood). If the strategy development process is to support discussions and decisions on risk reduction measures, or be more prescriptive in recommending actions, more significant analyses of risk reduction measures are required across a wide range of criteria (as recommended in Draft 1).

For any location-specific analyses of certain measures, flood hazard and/or risk information would be required. The existing flood model could continue to provide insights on the extent and depth of floodwaters, within the river corridor and within other floodplain areas, including impacts upstream and downstream. Additional risk data and analyses would be required to understand how different measures affected flood exposure and/or vulnerability, including potential risk transfer.

Both the *Flood Vulnerability Assessment* and *Flood Risk Assessment* identified vulnerable assets located in the floodplain. Combining this with knowledge of the region's dikes and non-structural flood management measures, new or improved risk reduction measures can be assessed, designed and implemented to minimize future flood damages and losses.

In Draft 1, it was assumed that any dike upgrades undertaken as part of implementing the LMFMS would meet current standards and guidelines. This would include provincial guidelines on dike crest elevation and seismic resilience. The information developed through the *Geotechnical Investigations and Seismic Assessment* is available to help local diking authorities and statutory decision makers (i.e., the Inspector of Dikes office) understand the seismic vulnerability of various high-consequence dikes across the Lower Mainland. Current policies and practices are evolving. Provincial policy initiatives including the BC Flood

Strategy, *Emergency Program Act* modernization, and the *Declaration on the Rights of Indigenous Peoples Act* will all inform the planning, governance, and implementation of flood risk reduction across BC, including the Lower Mainland and the LMFMS.

6. How Organizations Can Use These Information Resources

The following tools and outputs are available for participating organizations to use in their flood planning and management activities. If your organization would like to access any of these materials, please contact floodstrategy@fraserbasin.ca.

Hydraulic Modelling and Mapping Project

Lower Fraser 2D Hydraulic Model: The 2D model is based on a digital elevation model that encompasses both the river channel and the floodplain. Developed using open-source HEC-RAS software, the model can be used to understand how water moves down the river and across the floodplain under various flow and ocean level scenarios; analyze the effects of simulated dike breaches; create flood hazard maps that show the extent and depth of floodwaters; and evaluate the effects of some flood mitigation measures. Although the regional-scale model is not accurate enough to determine infrastructure design or flood construction levels, it can be used to inform these measures and support more detailed local-scale modelling and assessment. The model (not including model outputs) has been shared with more than 18 organizations to date. At least one municipality has used the model as a starting point for updating its floodplain bylaw.

Model Outputs (Mapping and Animations): Outputs include flood extent/depth maps in PDF and GIS formats as well as animation videos, that illustrate the areas that would be flooded under given conditions and where and when flooding might be most severe. PDF maps are helpful for communication, engagement and high-level analysis, while GIS files allow flood managers to conduct more in-depth analysis that informs planning and decision-making. Model outputs have been shared with 26 organizations to date. Most of the PDF maps are available on FloodWise.ca.

Lower Mainland Flood Risk Assessment

Depth-Damage Functions: New depth-damage functions were developed for a wide range of building/infrastructure types. This was informed by a survey (conducted by BC Statistics) of businesses and organizations in the Lower Mainland, a set of hypothetical building repair and contents replacement estimates, and a small number of depth-damage functions originally developed for Calgary and adjusted for use in the Lower Mainland. This has been formatted and integrated for use in CanFlood (an open-source flood risk modelling toolbox funded by Natural Resources Canada) and can be adapted for use in any flood damage model that uses object-level depth-damage functions.

Risk Profiling Portal: A web-based portal was created to enable a dynamic risk scoring process based on a chosen flood scenario, geographic scale, and adjustable weightings for 20 different consequence types. This allows a user to set their own weights for impact metrics based on what is appropriate for their community and provides decision makers with a tool to spatially explore the calculated flood risk metrics. Data from the project are also available for organizations to extract risk assessment results not shown on the portal or to undertake additional analysis. Portal access has expired; however, FBC is exploring opportunities to extend the availability and potential enhancement of this tool.

Lower Mainland Flood and Environment Atlas

The online atlas can be used to identify environmental features that could be exposed or vulnerable to Fraser River or coastal flood hazards, as well as those features that are in proximity to, and potentially impacted by current alignment of flood protection infrastructure. This tool can also inform flood risk reduction planning and decision-making by helping to identify environmental features that would need to be addressed in the selection, design, and siting of different flood mitigation projects. It could suggest the kinds of environmental issues to be addressed through regulatory process and potentially help identify candidate sites for protection, conservation, restoration, or habitat compensation.

FloodWise.ca

Most LMFMS project reports are available for download on FloodWise.ca. Additional resources can be requested directly through the FBC Flood Program. The website communicates key findings from the aforementioned projects, as well as links to other relevant resources from across BC and Canada. The website can be used by organizations for education and engagement purposes, particularly to help enhance flood understanding among decision makers, stakeholders and the public.

Appendix A. Lower Mainland Communities Exposed to Fraser River Flood and Coastal Flood Hazards

Tables 15 and 16 show which First Nations reserves and municipalities/electoral areas, respectively, face Fraser River and coastal flood hazards, based on flood extent mapping from the *Hydraulic Modelling and Mapping Project*. These tables are limited to the project area boundary of the model.

Municipalities and First Nations reserve lands in the Lower Mainland that are located outside of the coastal and Fraser River study area are not included in the tables below. Reserve lands that were included in the study area but did not have flood exposure to coastal or Fraser River hazards are also not included in this list.

Table 15. First Nations Reserves or Treaty Lands Exposed to Fraser River and/or Coastal Flooding

First Nation Communities		Coastal		Fraser River					
First Nation	Reserve or Treaty Lands	0.2% AEP	0.2% AEP 1m SLR *	1894 flood	1% AEP	0.5% AEP	0.2% AEP	0.2% AEP (year 2050)	0.2% AEP (year 2100)
Aitchelitz	Aitchelitch 9	N	N	Y	N	N	N	Y	Y
Chawathil	Hope 1	N	N	Y	Y	Y	Y	Y	Y
	Schkam 2	N	N	Y	Y	Y	Y	Y	Y
	Tunnel 6	N	N	Y	Y	Y	Y	Y	Y
	Chawathil 4	N	N	Y	Y	Y	Y	Y	Y
	Greenwood Island 3	N	N	Y	Y	Y	Y	Y	Y
Cheam	Cheam 1	N	N	Y	Y	Y	Y	Y	Y
	Tseatah 2	N	N	Y	Y	Y	Y	Y	Y
Katzie	Barnston Island 3	Y	Y	Y	Y	Y	Y	Y	Y
	Katzie 1	Y	Y	Y	Y	Y	Y	Y	Y
	Katzie 2	Y	Y	Y	Y	Y	Y	Y	Y
	Pitt lake 4	Y	Y	Y	Y	Y	Y	Y	Y
Kwantlen	Langley 2	N	N	Y	Y	Y	Y	Y	Y
	Langley 3	N	N	Y	Y	Y	Y	Y	Y
	Langley 4	N	N	Y	Y	Y	Y	Y	Y
	Langley 5	Y	Y	Y	Y	Y	Y	Y	Y
	McMillan Island 6	Y	Y	Y	Y	Y	Y	Y	Y
	Whonnock 1	Y	Y	Y	Y	Y	Y	Y	Y
Kwaw-kwaw-a-pilt	Kwawkwawapilt 6	N	N	N	N	N	N	Y	Y

First Nation Communities		Coastal		Fraser River					
First Nation	Reserve or Treaty Lands	0.2% AEP	0.2% AEP 1m SLR *	1894 flood	1% AEP	0.5% AEP	0.2% AEP	0.2% AEP (year 2050)	0.2% AEP (year 2100)
Kwikwetlem	Coquitlam 1	Y	Y	Y	Y	Y	Y	Y	Y
	Coquitlam 2	Y	Y	Y	Y	Y	Y	Y	Y
Leq'a:mel	Zaitscullachan 9	N	N	Y	N	N	Y	Y	Y
	Sumas Cemetery 12	N	N	Y	Y	Y	Y	Y	Y
	Aylechootlook 5	N	N	N	N	N	N	Y	Y
	Holachten 8	N	N	Y	Y	Y	Y	Y	Y
	Lackaway 2	N	N	Y	Y	Y	Y	Y	Y
	Lakahahmen 11	N	N	Y	Y	Y	Y	Y	Y
	Papekwatchin 4	N	N	Y	Y	Y	Y	Y	Y
	Skweahm 10	N	N	Y	Y	Y	Y	Y	Y
	Yaalstrick 1	N	N	Y	Y	Y	Y	Y	Y
Matsqui	Matsqui Main 2	N	N	Y	Y	Y	Y	Y	Y
	Sahhacum 1	N	N	N	N	N	N	Y	Y
	Three Islands 3	N	N	Y	Y	Y	Y	Y	Y
Musqueam	Musqueam 2	Y	Y	Y	Y	Y	Y	Y	Y
	Musqueam 4	Y	Y	N	N	N	N	Y	Y
	Sea Island 3	Y	Y	Y	Y	Y	Y	Y	Y
Peters	Peters 1	N	N	Y	Y	Y	Y	Y	Y
	Peters 2	N	N	Y	Y	Y	Y	Y	Y
Popkum	Popkum 1	N	N	Y	Y	Y	Y	Y	Y
Seabird Island	Seabird Island	N	N	Y	Y	Y	Y	Y	Y
Semiahmoo	Semiahmoo	Y	Y	N	N	N	N	N	N
Shared Reserve: Aitchelitz / Kwaw-kwaw-a-pilt / Squiala / Shxwhá:y Village / Skowkale / Skwah / Soowahlie / Tzeachten / Yakweakwioose	Grass 15	N	N	N	N	N	N	Y	Y

First Nation Communities		Coastal		Fraser River					
First Nation	Reserve or Treaty Lands	0.2% AEP	0.2% AEP 1m SLR *	1894 flood	1% AEP	0.5% AEP	0.2% AEP	0.2% AEP (year 2050)	0.2% AEP (year 2100)
Shared Reserve: Aitchelitz / Kwaw-kwaw-a-pilt / Shxwhá:y Village/ Skwah / Squiala	Skumalasph 16	N	N	Y	Y	Y	Y	Y	Y
Shxwhá:y Village	Skway 5	N	N	Y	Y	Y	Y	Y	Y
Shxw'ow'hamel	Wahleach Island 2	N	N	Y	Y	Y	Y	Y	Y
	Ohamil 1	N	N	Y	Y	Y	Y	Y	Y
Skawahlook	Ruby Creek 2	N	N	Y	Y	Y	Y	Y	Y
	Skawahlook 1	N	N	Y	Y	Y	Y	Y	Y
Skowkale	Skowkale 10	N	N	N	N	N	N	Y	Y
	Skowkale 11	N	N	N	N	N	N	N	Y
Skwah	Schelowat 1	N	N	N	N	N	N	N	Y
	Skwah 4	N	N	Y	Y	Y	Y	Y	Y
	Skwahla 2	N	N	Y	Y	Y	Y	Y	Y
	Skwali 3	N	N	Y	Y	Y	Y	Y	Y
Sq'éwlets	Scowlitz 1	N	N	Y	Y	Y	Y	Y	Y
	Squawkum Creek 3	N	N	Y	Y	Y	Y	Y	Y
	Williams 2	N	N	Y	Y	Y	Y	Y	Y
Squamish	Capilano 5	Y	Y	N	N	N	N	N	N
	Kitsilano 6	Y	Y	N	N	N	N	N	N
	Mission 1	Y	Y	N	N	N	N	N	N
	Seymour Creek 2	Y	Y	N	N	N	N	N	N
	Stawamus No. 24	Y	Y	N	N	N	N	N	N
	Yekwaupsum 18	N	Y	N	N	N	N	N	N
	Yekwaupsum 19	N	Y	N	N	N	N	N	N
Squiala	Squiaala 7	N	N	Y	N	N	N	Y	Y
	Squiaala 8	N	N	Y	Y	Y	Y	Y	Y
Sts'ailes	Chehalis 5	N	N	Y	Y	Y	Y	Y	Y
	Chehalis 6	N	N	Y	Y	Y	Y	Y	Y
Sumas	Upper Sumas 6	N	N	N	N	N	N	Y	Y

First Nation Communities		Coastal		Fraser River					
First Nation	Reserve or Treaty Lands	0.2% AEP	0.2% AEP 1m SLR *	1894 flood	1% AEP	0.5% AEP	0.2% AEP	0.2% AEP (year 2050)	0.2% AEP (year 2100)
Tsawwassen	Tsawwassen (Treaty Lands)	Y	Y	N	N	N	N	N	Y
Tsleil-Waututh	Burrard Inlet 3	Y	Y	N	N	N	N	N	N
Union Bar	Aywawwis 15	N	N	Y	Y	Y	Y	Y	Y
Yakweakwioose	Yakweakwioose 12	N	N	N	N	N	N	Y	Y
Yale	Lukseetsissum 9	N	N	Y	Y	Y	Y	Y	Y

* SLR is sea-level rise

Table 16. Census Subdivisions Exposed to Fraser River and/or Coastal Flooding

Census Subdivisions	Coastal		Fraser River					
Municipality / Electoral Area	0.2% AEP	0.2% AEP 1m SLR*	1894 flood	1% AEP	0.5% AEP	0.2% AEP	0.2% AEP (year 2050)	0.2% AEP (year 2100)
Abbotsford (Glen Valley)	Y	Y	Y	Y	Y	Y	Y	Y
Bowen Island[35]	Y	Y	N	N	N	N	N	N
Burnaby	Y	Y	Y	Y	Y	Y	Y	Y
Chilliwack	N	N	Y	Y	Y	Y	Y	Y
City of North Vancouver	Y	Y	N	N	N	N	N	N
Coquitlam	Y	Y	Y	Y	Y	Y	Y	Y
Delta	Y	Y	Y	Y	Y	Y	Y	Y
District of North Vancouver	Y	Y	N	N	N	N	N	N
Fraser Valley Electoral Area B	N	N	Y	Y	Y	Y	Y	Y
Fraser Valley Electoral Area C	N	N	Y	Y	Y	Y	Y	Y
Fraser Valley Electoral Area D	N	N	Y	Y	Y	Y	Y	Y
Fraser Valley Electoral Area F	N	N	Y	N	N	Y	Y	Y
Fraser Valley Electoral Area G	N	N	Y	Y	Y	Y	Y	Y
Fraser Valley Electoral Area H	N	N	N	N	N	N	N	Y
Harrison Hot Springs	N	N	Y	Y	Y	Y	Y	Y
Hope	N	N	Y	Y	Y	Y	Y	Y
Kent	N	N	Y	Y	Y	Y	Y	Y
City of Langley	Y	Y	N	N	N	N	N	N
Township of Langley	Y	Y	Y	Y	Y	Y	Y	Y
Lions Bay	Y	Y	N	N	N	N	N	N
Maple Ridge	Y	Y	Y	Y	Y	Y	Y	Y
Metro Vancouver A	Y	Y	Y	Y	Y	Y	Y	Y
Mission	N	N	Y	Y	Y	Y	Y	Y
New Westminster	Y	Y	Y	Y	Y	Y	Y	Y
Pitt Meadows	Y	Y	Y	Y	Y	Y	Y	Y
Port Coquitlam	Y	Y	Y	Y	Y	Y	Y	Y
Port Moody	Y	Y	N	N	N	N	N	N
Richmond	Y	Y	Y	Y	Y	Y	Y	Y
Squamish	Y	Y	N	N	N	N	N	N
Surrey	Y	Y	Y	Y	Y	Y	Y	Y
Vancouver	Y	Y	Y	Y	Y	Y	Y	Y
West Vancouver	Y	Y	N	N	N	N	N	N
White Rock	Y	Y	N	N	N	N	N	N

[35] Although Bowen Island was not included in the coastal modelling and mapping analysis, it is expected that low-lying areas on the shoreline could be inundated, especially when accounting for sea level rise.

Appendix B. Comparing Consequences from the Fraser River and Coastal Flood Scenarios

The following tables compare the consequences of the 500-year coastal flood and 500-year Fraser River flood based on the results of the *Flood Risk Assessment* and the *Flood Vulnerability Assessment*.

Table 17. 500-year Coastal and Fraser River Flood Consequences (*Flood Risk Assessment*)

Estimated Dollar Damages:	500-year coastal	500-year Fraser River
Residential ($)	**$5.5B**	$3.4B
Non-residential ($)	**$2.3B**	$1.4B
Public ($)	**$713M**	$269M
Agricultural ($)	$1.2B	**$1.5B**
Total direct damage ($)	**9.7B**	$6.5B
Additional Consequences:	**500-year coastal**	**500-year Fraser River**
Education and Culture (exposure count[36])	**43**	29
Community Centres (exposure count)	**50**	45
Heritage (exposure count)	**57**	19
Archaeological (exposure count)	**109**	58
Shelter (exposure score[37]: number of people with difficulty acquiring emergency and permanent shelter)	**987,028**	526,748
Financial Capacity (exposure score: number of exposed people with lower financial capacity)	**1,123,108**	606,140
Social Services (exposure score: number of people with greater dependence on social services)	**142,964**	86,166
Exposed Population (people exposed)	**146,000**	99,600
Hazardous Material (exposure score: number of locations with potential material release)	**720**	335
Sewage (exposure score: meters of pipe)	**508,189**	432,701
Sensitive Areas (ha of land exposed)	1,211	**3,837**
Trips (local trips)	**431,952**	319,558
Road Network (km exposed)	722	**879**
Emergency Services (exposure count)	8	8
Health Services (exposure count)	13	**16**
Electrical Service (exposure score, number of substations and transformers)	**8,650**	4,085

[36] Exposure count is the number of respective sites exposed to a flood of a certain magnitude.

[37] Exposure score has used weighted proxies for potential loss. It does not estimate actual numbers, like exposure count does.

Table 18. 500-year Coastal and Fraser River Flood Consequences *(Flood Vulnerability Assessment)*

Estimated Dollar Damages:	500-year coastal	500-year Fraser River
Building Losses	**$14.2B**	$9B
Agricultural Losses	$150M	**$1.6B**
Interrupted Cargo Shipments	$3.6B	**$7.7B**
Infrastructure/Institutional Losses	$1.4B	**$4.7B**
Total direct damage ($)	$19.3B	**$23B**

Appendix C. Glossary

Term	Definition
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.
Annual Exceedance Probability (AEP)	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 0.01 (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 (0.2% AEP).
Atmospheric Rivers	Long, narrow flows of moisture-laden air that can carry large amounts of water in short periods of time and release this moisture as either snow or rain. Atmospheric rivers can be hundreds of kilometres long and extend from tropical ocean areas to mid-latitude coastal locations, such as the BC coast.
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.
Restrictive or "Save Harmless" Covenants	Used to attach stipulations to land titles. In the context of flood, specific items in covenants can include: FCLs, exemptions to FCLs, design requirements, "right to flood" in areas where it is acknowledged that land cannot be protected (mostly agricultural land), no-build areas on a property, maintaining flood path routing and conveyance
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.
Design Flood	In BC, a given flood magnitude that is used as a standard for designating flood levels (e.g., for use in the calculation of flood construction levels) or dike design and construction. In most parts of the province, it refers to a 200-year (or 0.5% AEP) flood. Along the Lower Fraser, the design flood for dike construction is the estimated flow during the 1894 Fraser River flood. In select areas elsewhere, it is set on a site-specific basis.
Development Permit Areas (DPAs)	Local governments designate these for areas that need special treatment for certain purposes. DPAs can include protection of development from hazards, like flood.
Dike	An embankment designed and constructed to prevent the flooding of land. A dike is supported by related works, such as flood boxes, gates and pumps, that serve to hold back floodwaters while continuing to discharge water from behind the dike.

Term	Definition
Direct Damage	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 hazard events interacting with conditions of exposure, vulnerability and capacity, leading to human, material, economic and environmental losses and impacts.
Exposure	The presence of people, infrastructure, housing, or other assets-at-risk in places that could be adversely affected by hazards.
Flood	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.
Floodplain	A floodplain is flat or nearly flat land that is susceptible to flooding from a watercourse, lake or other body of water.
Floodproofing	In reference to development, actions taken at the site or property level that reduce the vulnerability of buildings and their contents to flood damage.
Flood Construction Level (FCL)	The minimum height required for a development to protect habitable living space from flood damage.
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 Maps	Maps that display information related to a flood, such as the estimated extent of flooding, water depths, water velocities, flood duration or other information.
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.
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.
Hazard Assessment	A process to acquire information about the nature, extent, intensity, frequency and probability of a hazard.
Peak Flow	The maximum rate of water discharge during a flood at a given location on a river or other watercourse.
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.
Storm Surge	The increase in still water level at a coastal site due to meteorological conditions.
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 D. Detailed Mapping Figures

Lower Mainland Flood Management Strategy

Synthesis of Technical Analysis

May 2023

Fraser Basin Council

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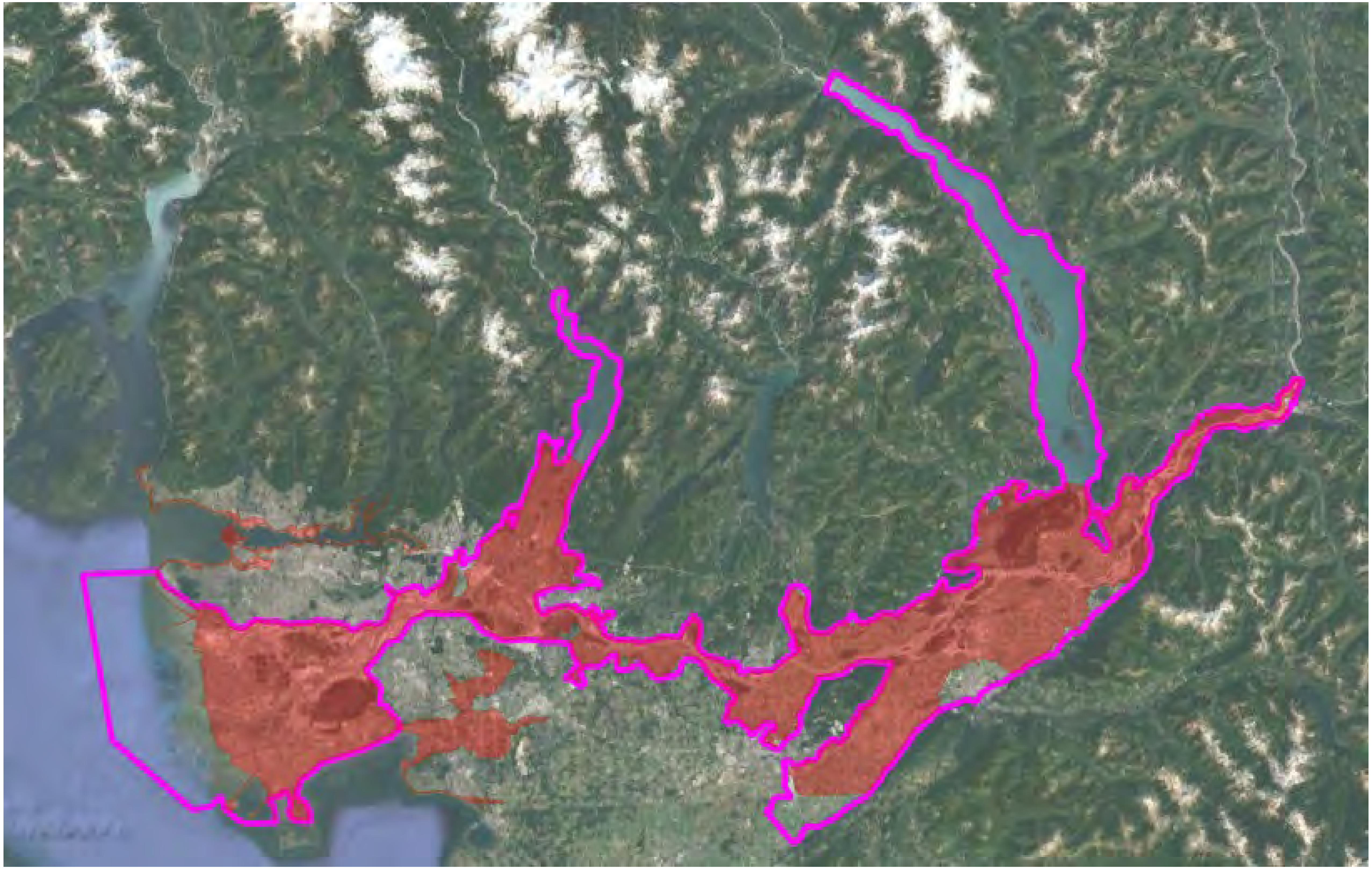
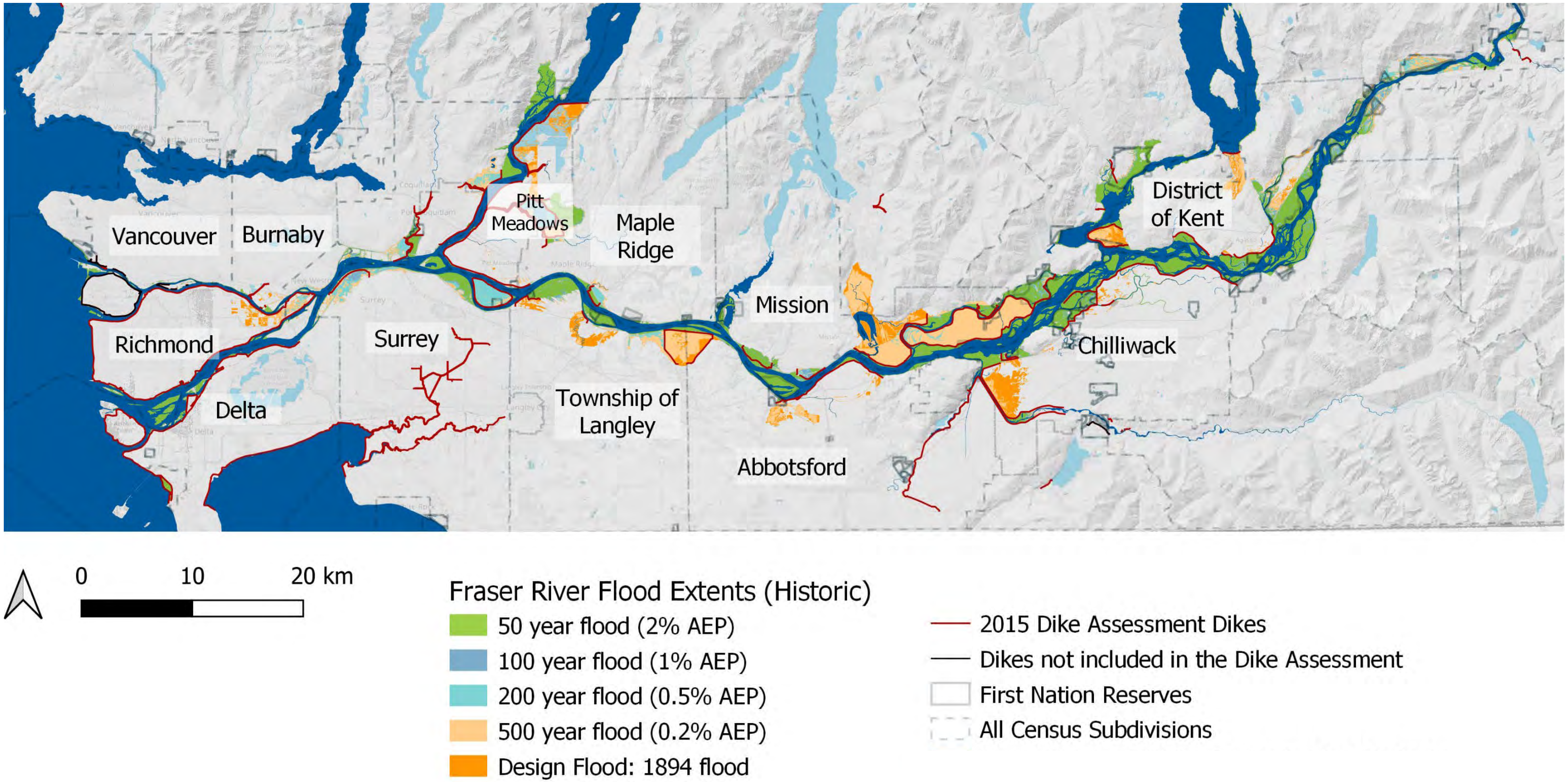
Map 1. Lower Fraser 2D Model Boundaries in the Hydraulic Mapping and Modelling project *(Figure 3 in the Technical Synthesis)*

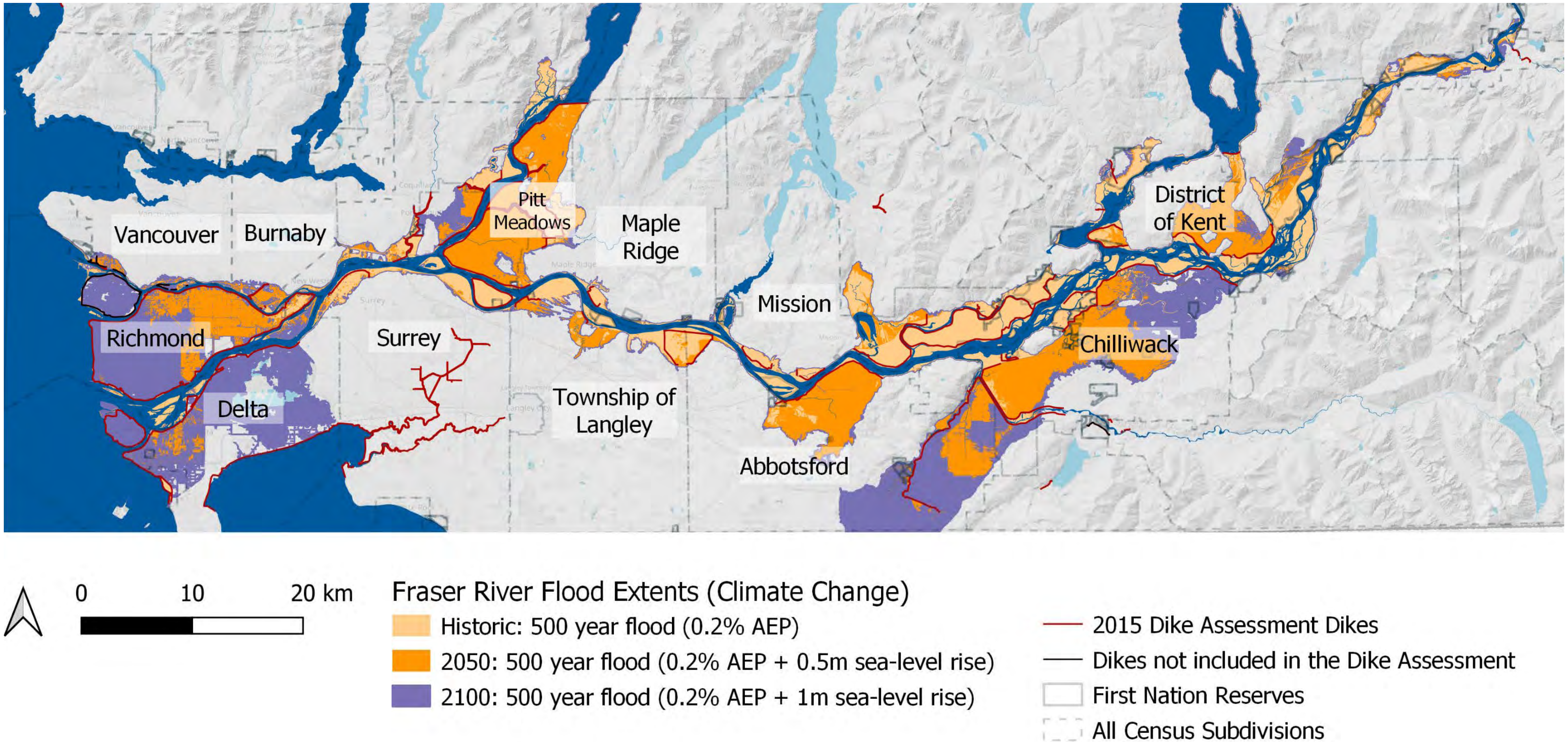


Map 2. Overlay of historic Fraser River flood extents for multiple floods using 2D HEC RAS modelling in the Hydraulic Mapping and Modelling project. Flood extents include dike overtopping but not other dike failures. *(Figure 5)*



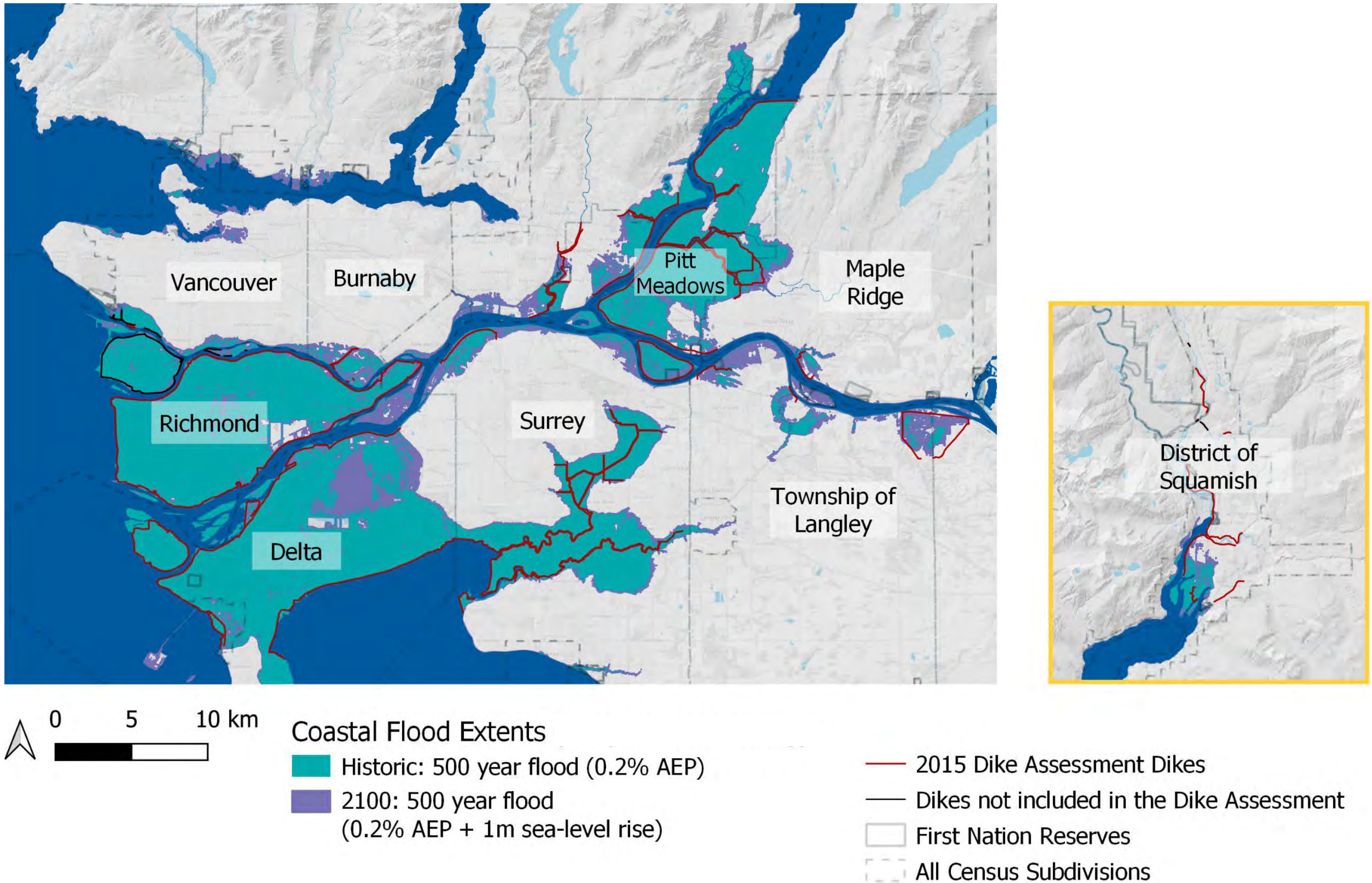
***Note:** Flood extents are additive. For example, the 100-year flood will flood the land represented in both the 100-year dark blue color, and the 50-year green color.*

Map 3. Overlay of climate change Fraser River flood extents for multiple floods using 2D HEC RAS modelling in the Hydraulic Mapping and Modelling project. Flood extents include dike overtopping but not other dike failures. *(Figure 7)*



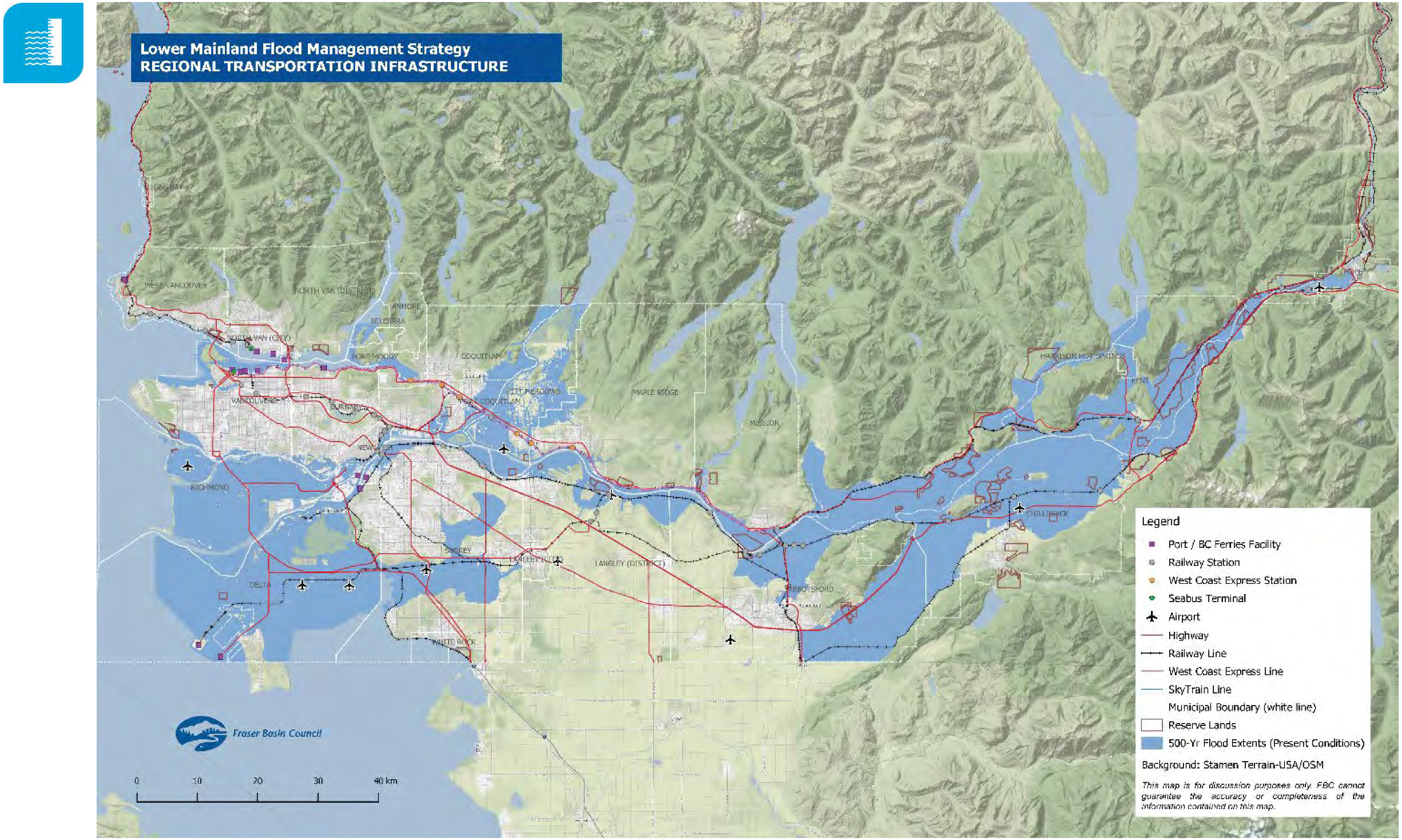
Note: *Flood extents are additive. For example, the year 2050 500-year flood will flood the land represented in both the Historic: 500-year light orange color, and the 2050 500-year dark orange color.*

Map 4. Overlay of the historic 500-year coastal floodplain extents and year 2100 500-year coastal floodplain extents using a simplified approach to illustrate how lower-lying lands may be inundated by ocean levels in the *Analysis of Flood Scenarios (Phase 1)*. *(Figure 8)*

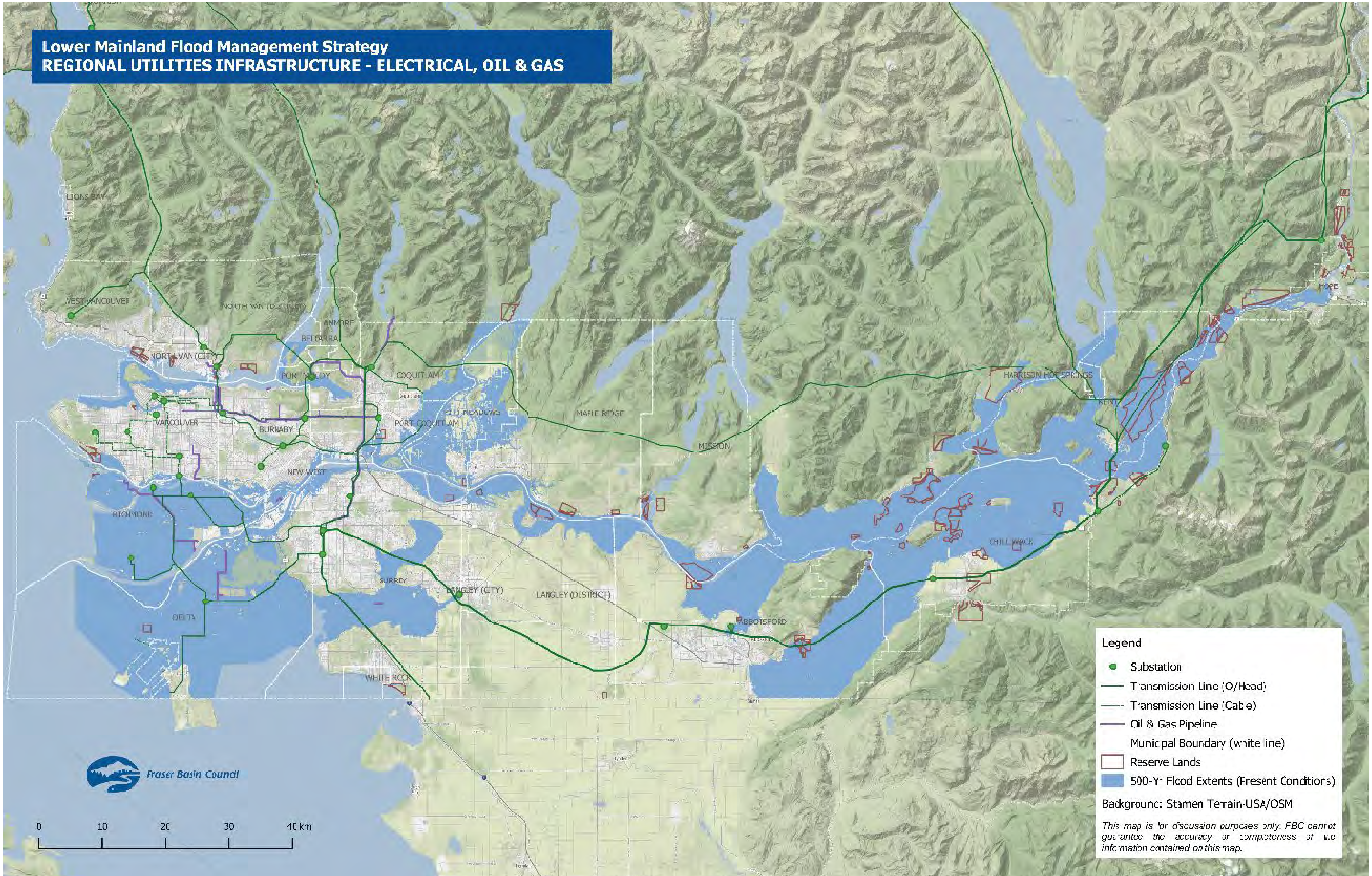


Note*: Flood extents are additive. For example, the year 2100 500-year flood will flood the land represented in both the Historic: 500-year dark teal color, and the 2100 500-year purple color.*

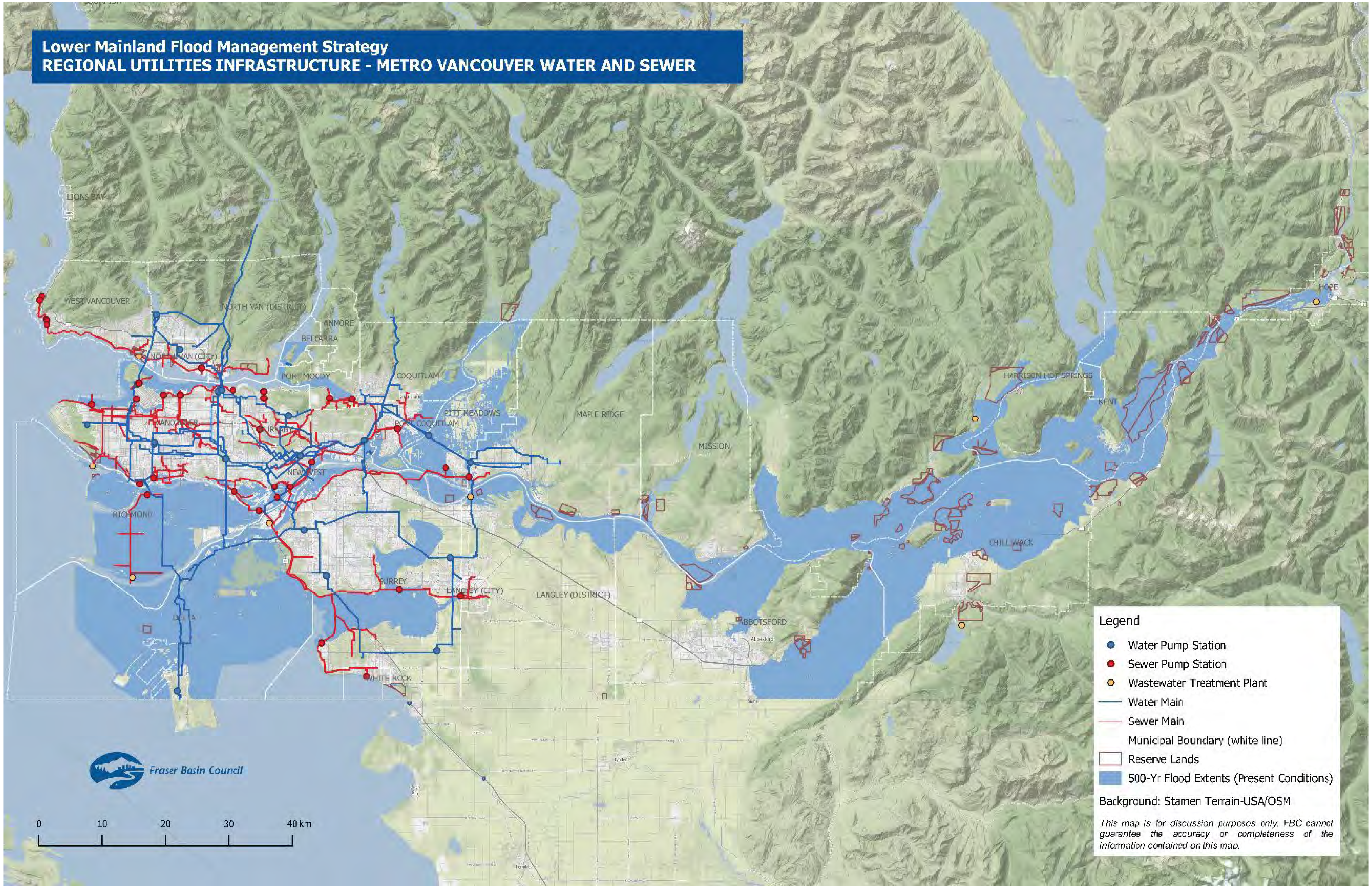
Map 5. Transportation Infrastructure Exposure to Fraser River and Coastal Flooding (Generated using the *Analysis of Flood Scenarios (Phase 1)*)



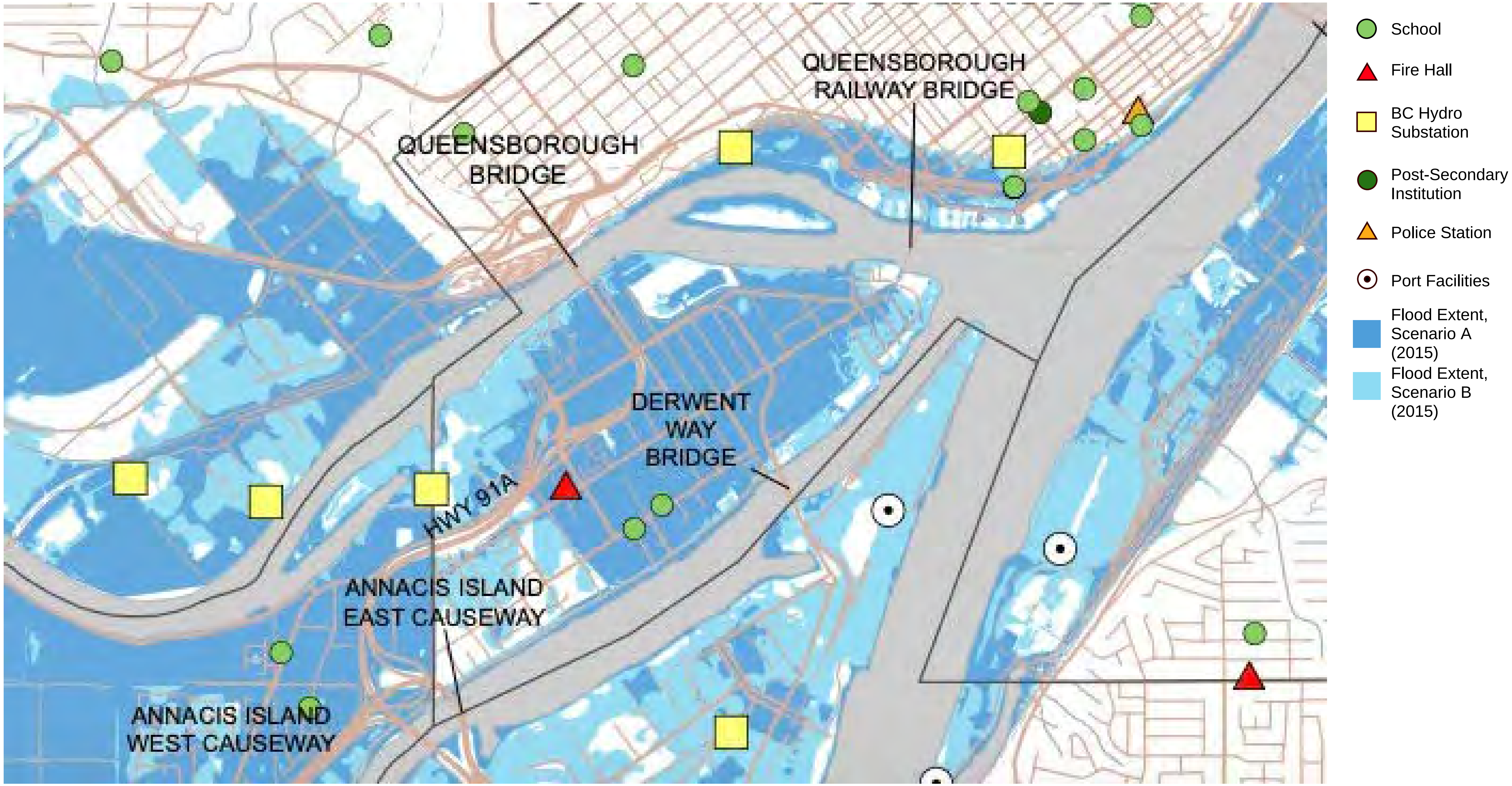
Map 6. Energy Infrastructure Exposure to Fraser River and Coastal Flooding (Generated using the *Analysis of Flood Scenarios (Phase 1)*)



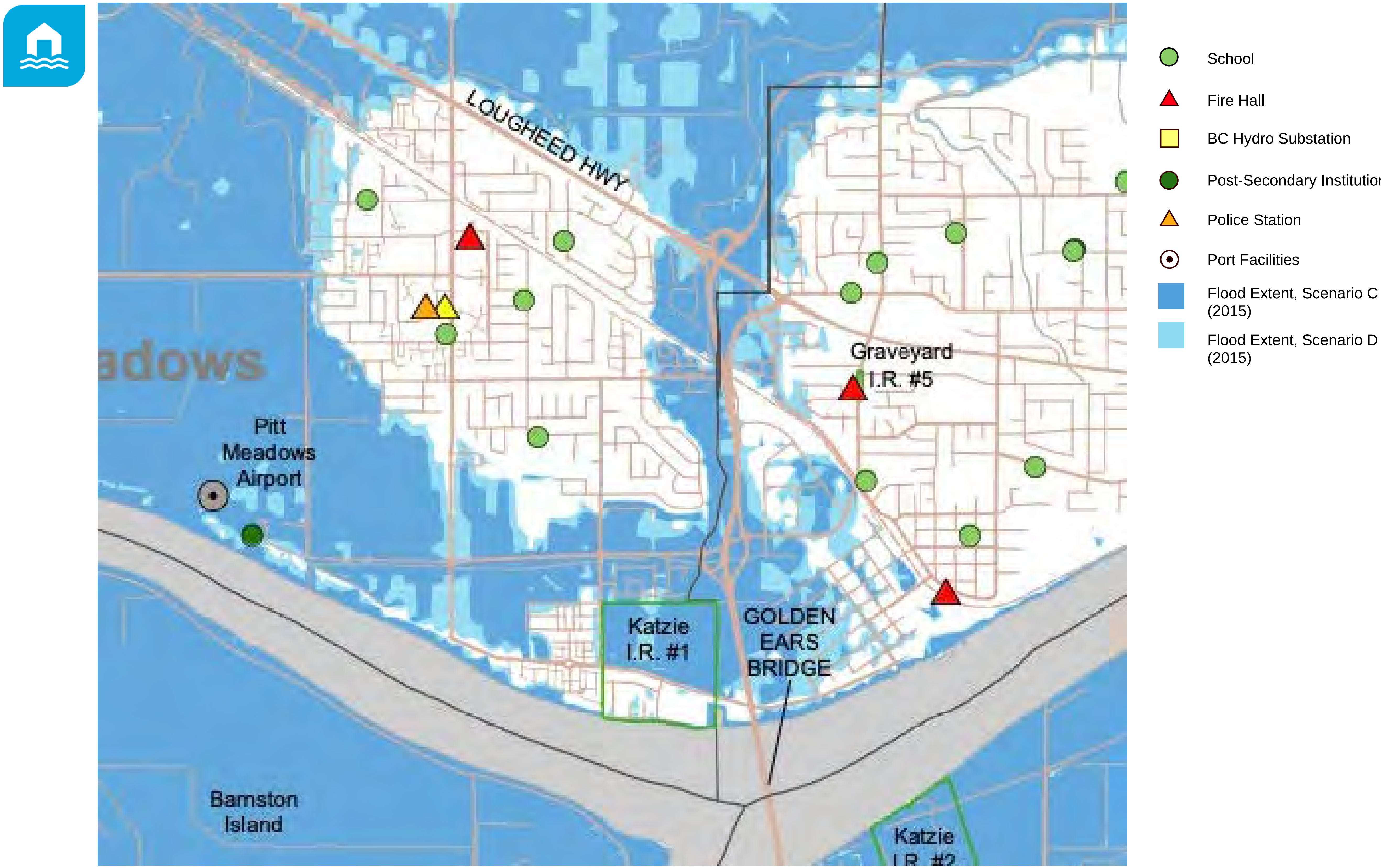
Map 7. Water and Wastewater Infrastructure Exposure to Fraser River and Coastal Flooding (Generated using the *Analysis of Flood Scenarios (Phase 1)*)



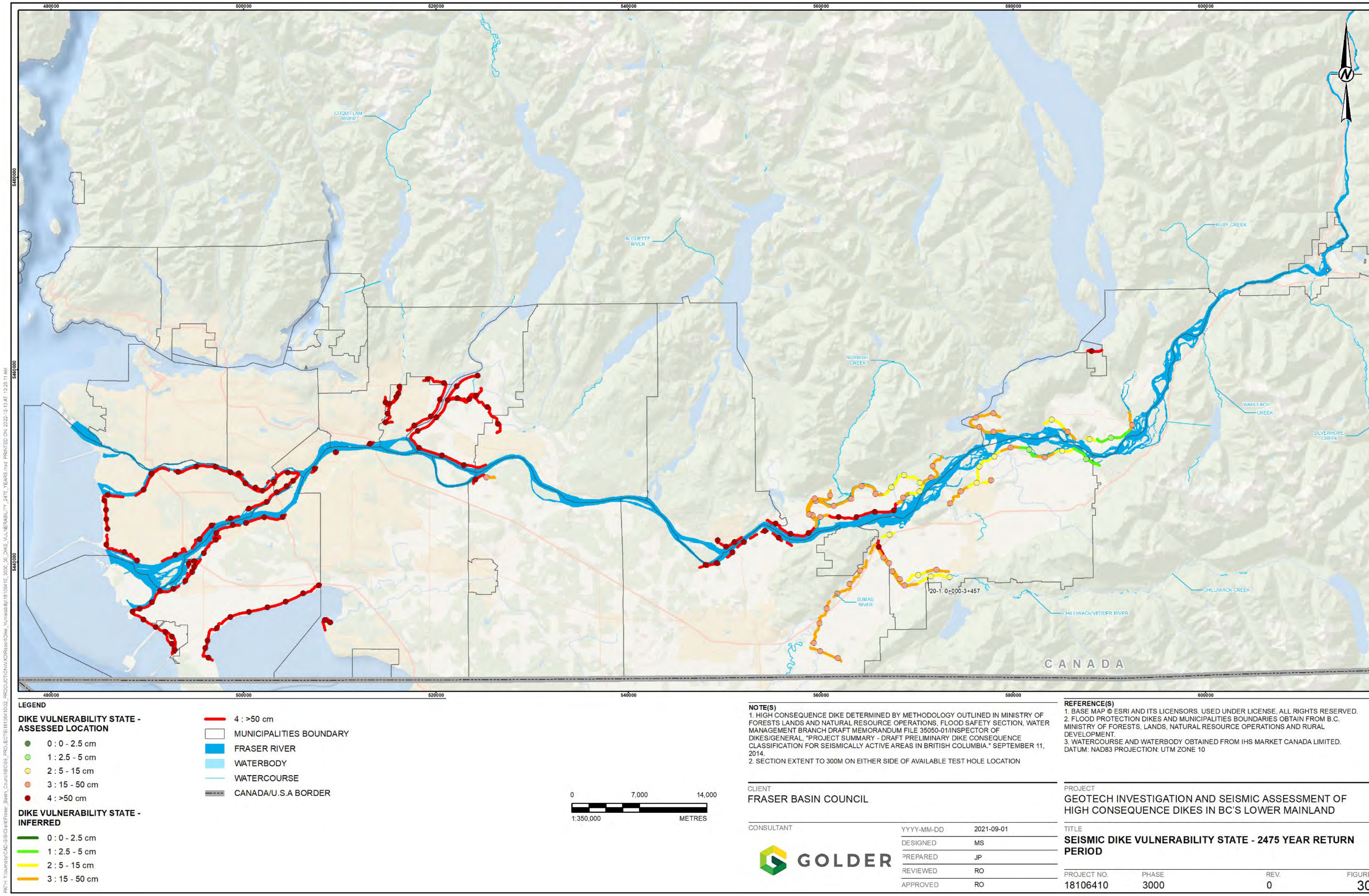
Map 8. Sample of Critical Facility Exposure to Coastal Flooding (Detail of New Westminster and Surrey, *"Flood Extents, Scenarios A & B" (Flood Vulnerability Assessment,* page 85))



Map 9. Sample of Critical Facility Exposure to Fraser River Flooding (Detail of Golden Ears Bridge, *"Flood Extents, Scenarios C & D" (Flood Vulnerability Assessment,* page 86))



Map 10. Seismic dike vulnerability map for the 2,475-return earthquake return period from Geotechnical Investigations and Seismic Assessment of High Consequence Dikes in BC's Lower Mainland, page 57. *(Figure 12)*



The maps presented in Appendix D were designed using a variety of techniques, source data, and assumptions. Please refer to their original reports to understand the full assumptions and limitations.