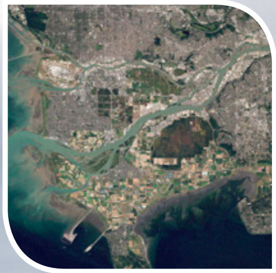


Flood Modelling and Mapping in BC's Lower Mainland: A Project Primer

Lower Mainland Flood Management Strategy

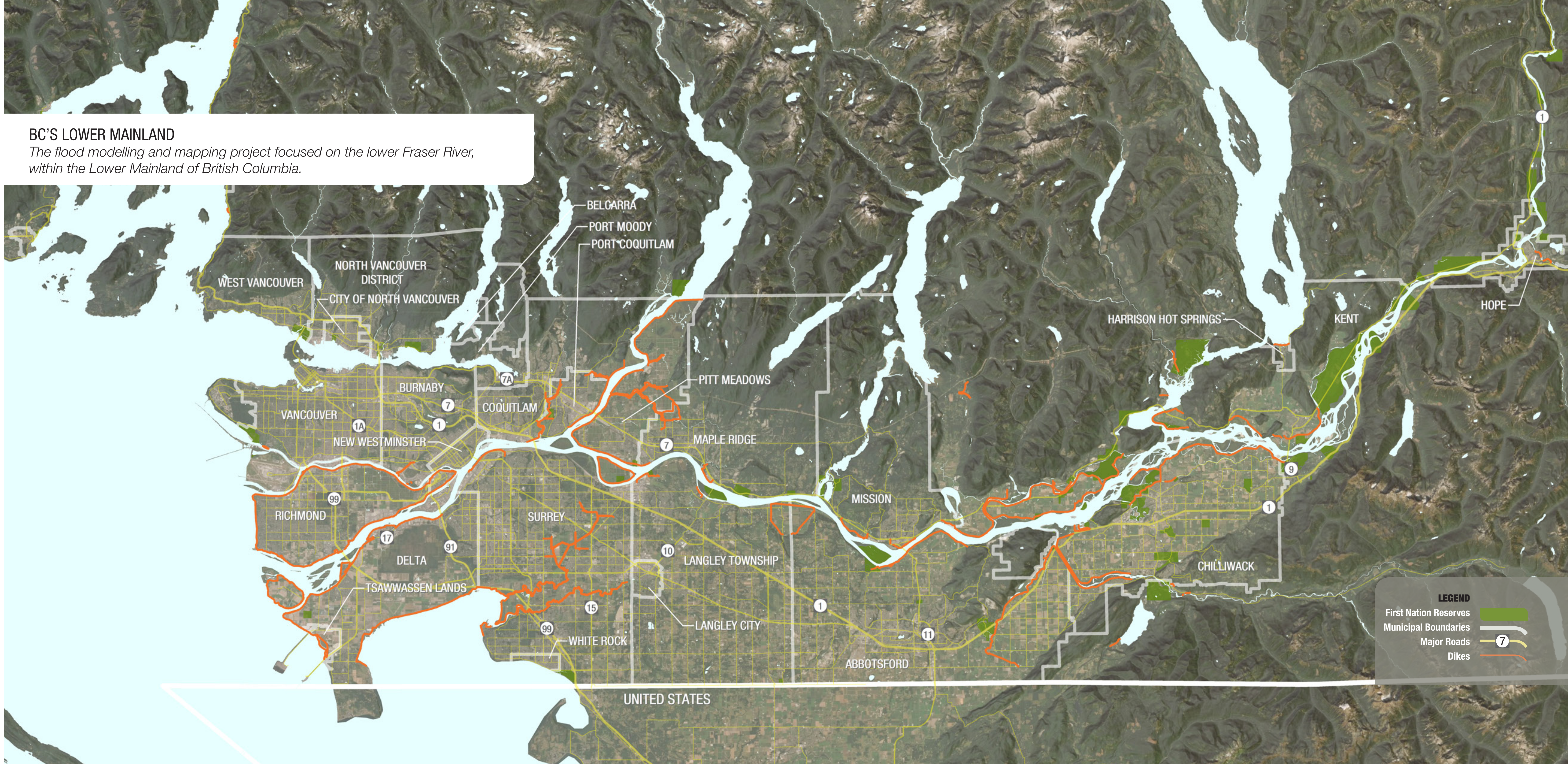
JULY 2019

Fraser Basin Council

Flooding and the Fraser River

The Fraser River is the largest river on the west coast of Canada, flowing over 1,300 km to the sea and draining about one-quarter of the Province of British Columbia. High water on the Fraser occurs seasonally, particularly during spring freshet when runoff from snowmelt swells river levels.

Climate change is changing weather patterns. Changes in snowmelt and precipitation patterns in the Fraser Basin are expected to contribute to larger and more frequent floods on the Fraser River. Sea level rise will also impact water levels in the lower Fraser River during spring freshet.



BC'S LOWER MAINLAND
The flood modelling and mapping project focused on the lower Fraser River, within the Lower Mainland of British Columbia.

Lower Mainland Flood Management Strategy

The Lower Mainland Flood Management Strategy (LMFMS) is a collaborative initiative with the participation of 50 governmental and non-governmental agencies that are working together to reduce risk and strengthen resilience to river and coastal flooding in the Lower Mainland region. The Fraser Basin Council (FBC) manages and facilitates the initiative. The multi-year undertaking is divided into three phases.

Flood Modelling and Mapping Project

The Flood Modelling and Mapping Project is a major component of Phase 2 of the LMFMS. The Fraser Basin Council retained Northwest Hydraulic Consultants (NHC) for this project. NHC developed a comprehensive flood model to run a range of future flood scenarios for the Lower Mainland, based on different climate conditions, river flows and potential dike breaches.

▼ FIGURE: *Lower Mainland Flood Management Strategy process outline*

1 PHASE 1 (2014-2016)
Understanding Lower Mainland Flood Risks

Phase 1 reported on:

- Coastal and Fraser River flood scenarios (Present Day and Year 2100)
- Projected economic losses and impacts from a major flood
- Assessment of Lower Mainland dikes

Details are at **floodstrategy.ca**

2 PHASE 2 (2017-2020)
Building a Region-Wide Strategy

Phase 2 – now in progress – is aimed at developing a regional flood strategy.

The work includes:

- Assessment of flood hazards, flood risk and certain flood risk reduction options through modelling, mapping, risk assessment and analysis
- Identification of priorities for flood risk reduction in the region
- Assessment of governance and funding options
- Ongoing input from partner and participant entities on key issues
- Public and stakeholder engagement on key issues
- Completion of the Strategy

3 PHASE 3 (2020-)
Taking Action

Phase 3 will focus on implementation of the Flood Strategy, including opportunities for national, provincial, regional and local action

The Lower Fraser River 2D Flood Model generated updated flood hazard mapping and illustrated the regional effects of certain flood management options (e.g., dike raising, dike setbacks, upstream storage).

The key outputs of the flood modelling are summarized in this primer. Detailed maps generated by the model will be made available to partner organizations on request.

The flood model outputs are intended to help LMFMS partners and others with flood responsibilities in the Lower Mainland to:

- Better understand current and future flood hazards;
- Advance work on risk assessment, informed by updated flood hazard information, so as to prioritize high-risk areas;
- Evaluate flood risk reduction options; and
- Enhance emergency preparedness and response.

▸ PHOTO: EVACUATION OF RESIDENTS IN THE FRASER VALLEY FLOODPLAIN (1948)
There have been two large Fraser River floods in the Lower Mainland in the past 125 years. The larger (1894) flood is considered a .2% AEP (1 in 500-year) flood. The 1948 flood is considered a .5% AEP (1 in 200-year) flood (see page 8 for an explanation of AEP). Such large-scale floods are expected to occur more frequently as the climate changes. (photo: Vancouver Public Library Archives

Lower Fraser 2D River Flood Model

The Lower Fraser River 2D Flood Model can project the extent, depth and velocity of water in the Lower Fraser River channel and on the floodplain (which is normally dry land) for floods of different sizes. The model covers a 170 km stretch of the Fraser River from Hope to the Salish Sea (Strait of Georgia).

The size of a flood is impacted by the flow rate on the Fraser River and by changes in ocean levels. The model can also be used to show dike breach scenarios and the impact of possible flood mitigation options.

For this project in Phase 2 of the LMFMS, 27 flood scenarios were chosen for simulation by the flood model:

- 14 base run scenarios;
- Eight dike breach scenarios; and
- Five scenarios on the effects of different flood mitigation options (four of the five options were modelled).

Key model findings include:

- Many areas not currently protected by dikes will be flooded by even a relatively small flood event, and the potential extent and depth of flooding in these areas increases with climate change.
- The total area of floodplain flooded, and number of dikes overtopped increases significantly as the freshet flood scenarios become more severe. The total area impacted increases when end-of-the-century climate change impacts are considered.
- Based on assumptions about the potential for upstream flow storage – where river flows are temporarily held back in an existing impoundment area – it is estimated that flood levels in the lower Fraser River could be reduced to some degree. Setting back new dikes from their current location to create more “room for the river” in flood events may also reduce flood levels in some locations.
- For the 0.2% Annual Exceedance Probability flood (see text box), by 2050, climate change could raise water levels at Mission by approximately 0.8 m and by 2100 by approximately 1.9 m, compared to present conditions. The river channel of the lower Fraser River would undergo substantial change over time as it adjusts to the new, climate change-driven flow regime. There is uncertainty in projecting specific flood water levels, given evolving projections on climate change. That said, flood water levels are expected to increase substantially in the future.
- Downstream of the Alex Fraser Bridge, coastal flooding becomes dominant (i.e., storm surges generate higher water levels than the Fraser River freshet). Depending upon how quickly sea levels rise and the degree to which climate change affects Fraser River flows, the “transition point” between coastal- and river-dominated flooding will likely shift upstream towards the Alex Fraser Bridge.

FRASER RIVER BASE FLOOD SCENARIO (BASED ON 1894 FLOOD)

The map illustrates the extent and depth of flooding that could be expected in the “Base Flood Scenario,” a freshet flood in present day, based on the 1894 Fraser River flood, which is the largest on written record. This and other base run scenarios assume that dikes in different locations overtop, but that no dikes breach.

Base Flood Scenarios

The 14 base runs simulated in the flood model were selected to estimate flood levels corresponding to a range of Annual Exceedance Probabilities (see text box on page 8) for present and future climate conditions. Spring freshet and winter flood conditions (for the Fraser River and its floodplain) were modelled separately.

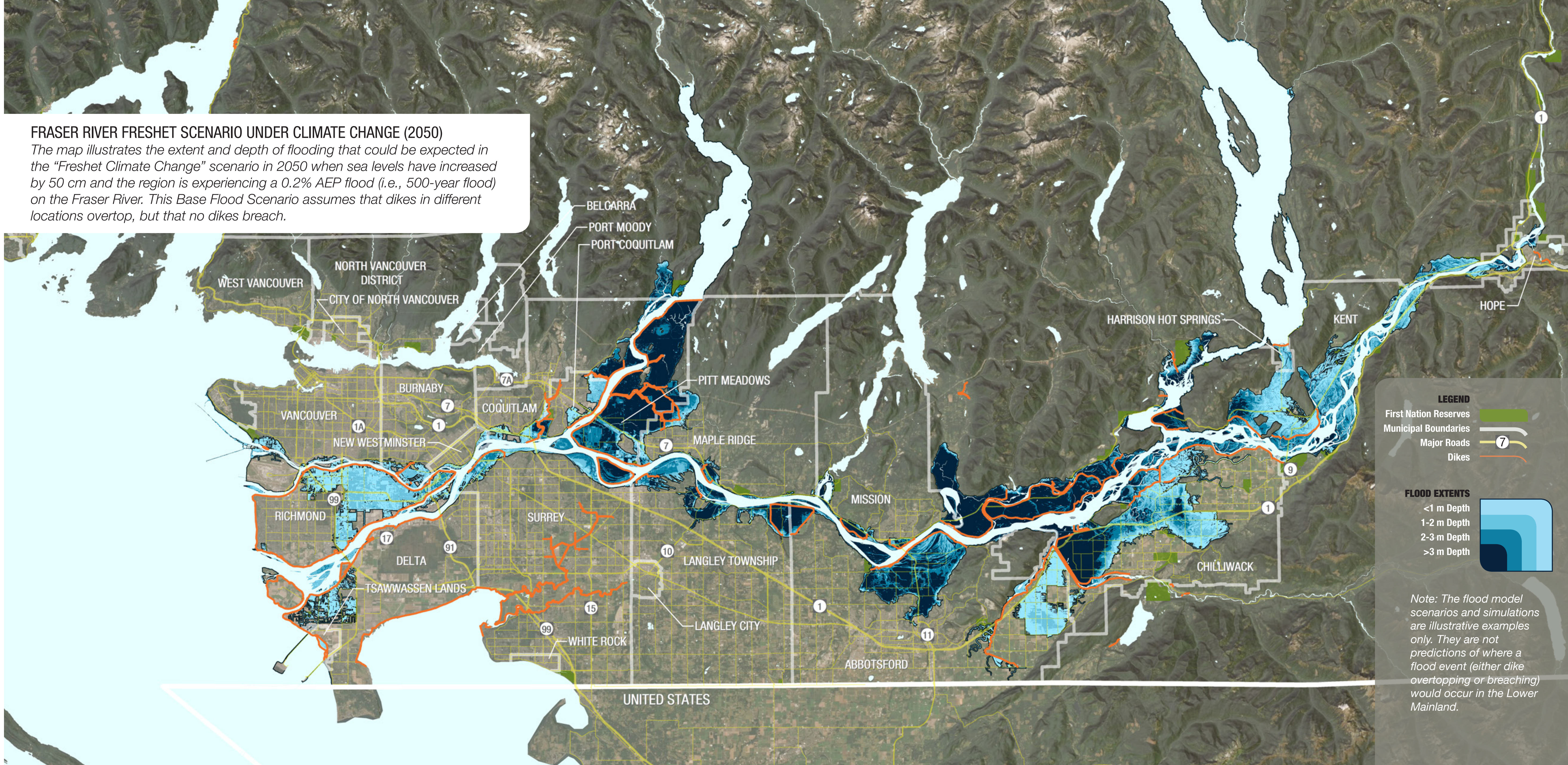
The extents and depths of flooding from different river flow and ocean level scenarios were estimated by the model.

The model results will help inform proactive flood risk reduction as well as emergency planning.

Annual Exceedance Probability (AEP)

Refers to the probability of a flood event occurring in any year. The probability is expressed as a percentage. For example, a large flood that may be calculated to have a 1% chance to occur in any one year is described as 1% AEP. The measure has replaced more traditional time-based expressions of probabilities (e.g., “100-year flood”).

AEP	Time-based probability
2%	50-year flood
1%	100-year flood
0.5%	200-year flood
0.2%	500-year flood



FRASER RIVER FRESHET SCENARIO UNDER CLIMATE CHANGE (2050)

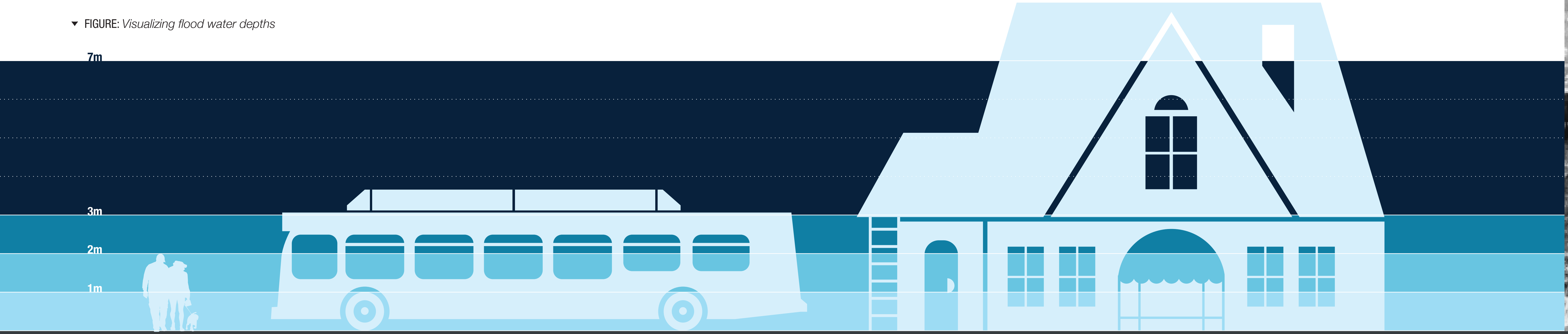
The map illustrates the extent and depth of flooding that could be expected in the “Freshet Climate Change” scenario in 2050 when sea levels have increased by 50 cm and the region is experiencing a 0.2% AEP flood (i.e., 500-year flood) on the Fraser River. This Base Flood Scenario assumes that dikes in different locations overtop, but that no dikes breach.

Dike Breach Modelling

In the base runs, the model allows for dike overtopping in scenarios where the flood level is higher than the dike crest. However, dikes can fail through other processes prior to overtopping, such as erosion and seepage. Therefore, eight scenarios were selected to simulate the failure – or breaching – of one or more of the dikes. Dike breach modelling focused on determining the extent (area) of potential flooding, maximum water depths, flow paths, water velocities and other relevant information to better understand overall flood hazards. Dike breach locations and other parameters were selected based on historical information (with a focus on breaches that occurred during the 1948 flood), previous dike breach studies in the area, floodplain mapping guidelines for BC, and practices in other jurisdictions. Some of the key points from this modelling are highlighted here.

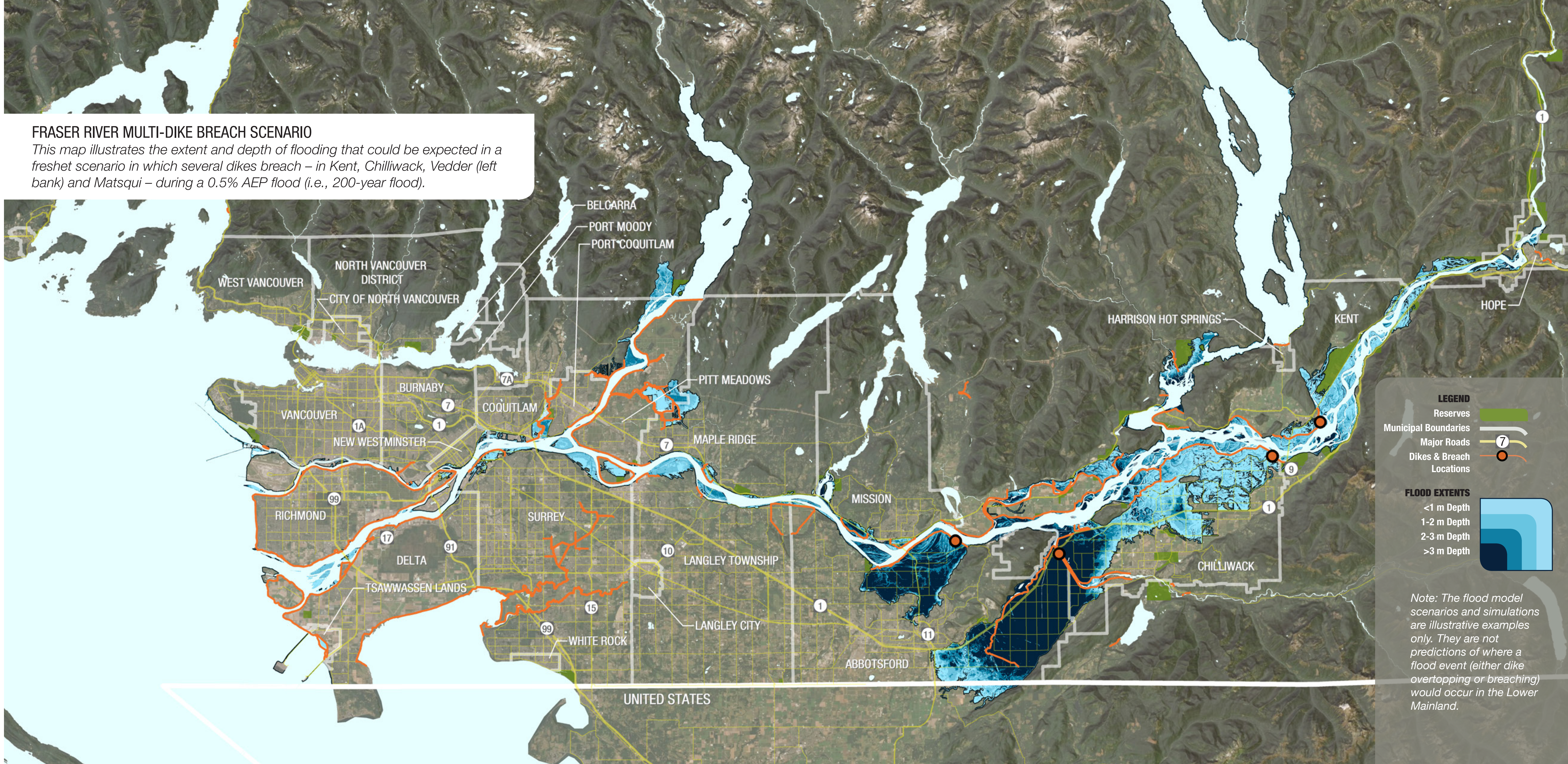
- **Flood Hazard in the Floodplain:** The dike breach scenarios can help those with responsibilities for flood management understand flood hazards in the floodplain. Flow velocity and water depth contribute to the hazard. For most of the Fraser floodplain, the most critical safety hazard is deep water, both in areas unprotected by dikes and diked areas following a breach. Water depths would exceed 1.0 m in the majority of the floodplain areas flooded in the dike breach scenarios. In many areas, water depths exceed 3.0 m, with depths reaching 7.0 m in some locations, such as the Greendale area of Chilliwack and Sumas Prairie in Abbotsford. Even with low velocities (0.5 to 1.0 m/s), flood depths exceeding 1 m are considered a significant hazard.
- **Flood Mitigation Planning:** A better understanding of flood hazards in the floodplain will inform flood hazard managers, planners and decision makers about the potential consequences of dike failures. The information will also help identify what flood risk reduction measures that may be effective and those unlikely to be effective, given the nature of the hazard in specific locations.
- **Emergency Planning and Response:** The dike breach scenarios are also informative for emergency planning and response in the modelled areas. Flooding from a dike breach progresses rapidly. Major evacuation routes can be cut off, and vulnerable residents, livestock and infrastructure can be impacted within a few hours. The flood modelling shows the severity of flooding, and how quickly it can occur, and why early evacuations prior to potential dike breaches are important. It is helpful for emergency planners to see, for a specific scenario, the timing and extent of flooding, water velocity and flow direction when refining emergency plans.

▼ FIGURE: *Visualizing flood water depths*



▲ PHOTO: *Dike breach at Hatzic, Fraser River Flood, 1948 (photo: Vancouver Public Library Archives)*

- **Potential for Dike Breach Repairs:** If equipment and materials can access the breach sites, low tide may present an opportunity to close a dike breach or at least prevent further widening. However, the tidal relief diminishes quickly upstream of the Alex Fraser Bridge, and this should be considered carefully in emergency response planning. Dike breaching from coastal storm surge floods was not modelled in this project. It is important, however, and merits separate consideration.
- **Effects of Dike Breaches on Fraser River Water Levels:** Given the very large flow rates of the Fraser River and comparatively limited storage in the lower Fraser River floodplain, multi-dike breaches do not significantly reduce peak flood levels. For example, the simulation of four major sequential dike breaches (that would result in massive flood damage and impacts) into the Kent, Chilliwack, Sumas, and Matsqui floodplains provided only temporary (2-3 day) water level reductions at Mission and other communities downriver. For this scenario, the 0.5% AEP (200-year) flood was simulated. Although the water level reduction at Mission was as much as 0.7 m and 0.4 m at the Port Mann Bridge, the maximum flood level at these two locations was lowered by only approximately 0.1 m. The timing of the breaches compared to the timing of the river's highest flow is critical. Should dike breaches occur well in advance of the river reaching its highest flow, there may be almost no reduction in downstream flood levels.



FRASER RIVER MULTI-DIKE BREACH SCENARIO

This map illustrates the extent and depth of flooding that could be expected in a freshet scenario in which several dikes breach – in Kent, Chilliwack, Vedder (left bank) and Matsqui – during a 0.5% AEP flood (i.e., 200-year flood).

Mitigation Options Modelling

The Fraser River is a large river with extremely high flood flows. Diking has been the primary tool of flood hazard management for the past century. While there have been some upgrades to Fraser River diking, including the installation new pump stations, most diking does not meet Provincial standards, is susceptible to seismic hazards, and has not truly been tested by a large flood since 1948.

One of the primary objectives of the LMFMS flood modelling and mapping project is to support planning and decision-making related to various flood mitigation options. By simulating mitigation options in the model, their effectiveness can be assessed, and promising options selected for further investigation. Five mitigation options were explored (four were modelled): dike raising, dike setbacks, sediment removal, land raising and upstream flow storage. These options and their effects on flood depth and extent are described in more detail below.

All flood mitigation options come with a variety of potential challenges, benefits and trade-offs that must be considered when deciding on appropriate options for a given community or region. Land use, land tenure and associated jurisdictional and regulatory requirements are very significant considerations when it comes to designing and implementing flood mitigation options.

First Nations title, rights, consultation and accommodation are also key to flood mitigation planning and implementation. This is particularly important in this region where there are over 30 First Nation communities with varying degrees of flood protection – from high to none – and where there are significant traditional and present day uses of the Fraser River and its floodplain.

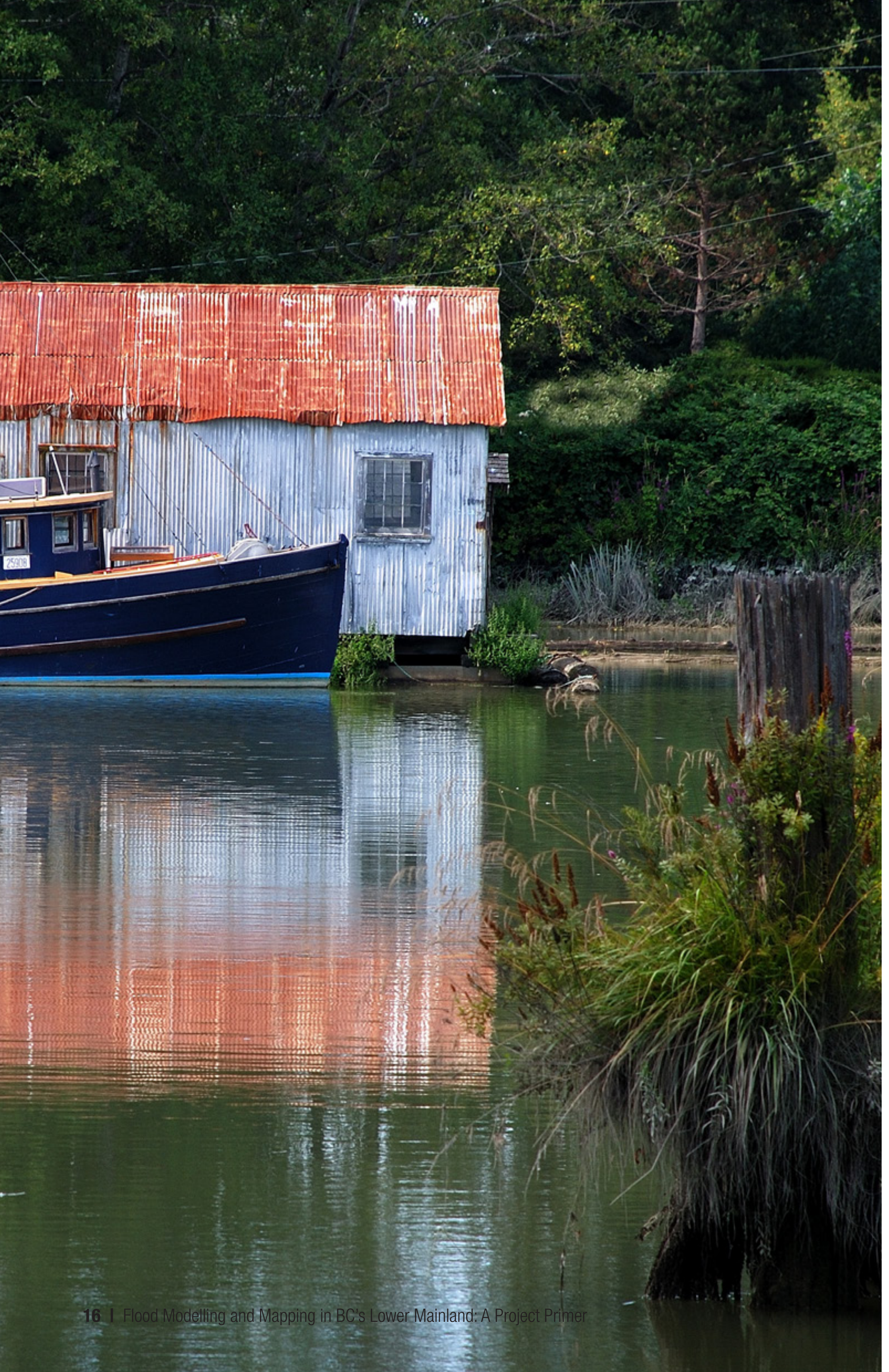
There is value to modelling mitigation options, but by doing so, the Flood Modelling and Mapping Project is not endorsing these particular options.

- **Dike Raising:** *Elevating dikes to meet current Provincial flood standards.*

  In this scenario, all lower Fraser River and sea dikes were raised to meet Provincial design standards for dike crest elevation. Raising dikes (to prevent breaching and overtopping) increased the flood water level from just downstream of the Harrison River confluence to the Port Mann Bridge by about 0.3 m in comparison to the base run, which included some dike overtopping. The difference in flood water level reduces progressively downstream of the Port Mann Bridge due to the lower river gradient and increasing tidal control. Upstream of the Agassiz-Rosedale Bridge, the impact on flood levels is limited, as there are few dikes. The estimated 0.3 m rise of flood level demonstrates that dike design levels must be established with full consideration of potential future diking and other flood mitigation measures throughout the Lower Fraser, and with additional consideration of climate change effects on flows and sea level, sediment transport and other factors.

- **Dike Setbacks:** *Building new dikes that are set back from the river to create more "room for the river" with the potential to reduce flood water levels.*

  In this scenario, about 15 km of existing diking was set back by about 400 m, which resulted in a 0.15 m reduction in flood water levels in that section of the river. Dike setbacks may be useful at certain points in the river where the flow is constricted by riverbank dikes. Large setbacks would be required to accomplish significant flood level reductions. Dike setbacks have very limited effect on water levels in low-gradient, tidally-influenced reaches of the Fraser.



- **Sediment Removal:** *Removing sediment from the tops of gravel bars to create more flow capacity within the river channel.*

  In this scenario, about 2 million cubic metres of sediment was removed from gravel bars between the Agassiz-Rosedale Bridge and the Harrison River, resulting in a 0.2 m reduction of local water levels. Even very significant sediment removals such as this one (which is significantly more than what has previously been approved by regulators) have limited potential to lower the flood water level in the region. The riverbed is known to change during a large flood event. Localized sediment removal areas would fill during a large flood and would not provide permanent lowering of the flood water level. There may be small, localized flood level reductions at specific excavation sites until these fill in with future deposition from the river.

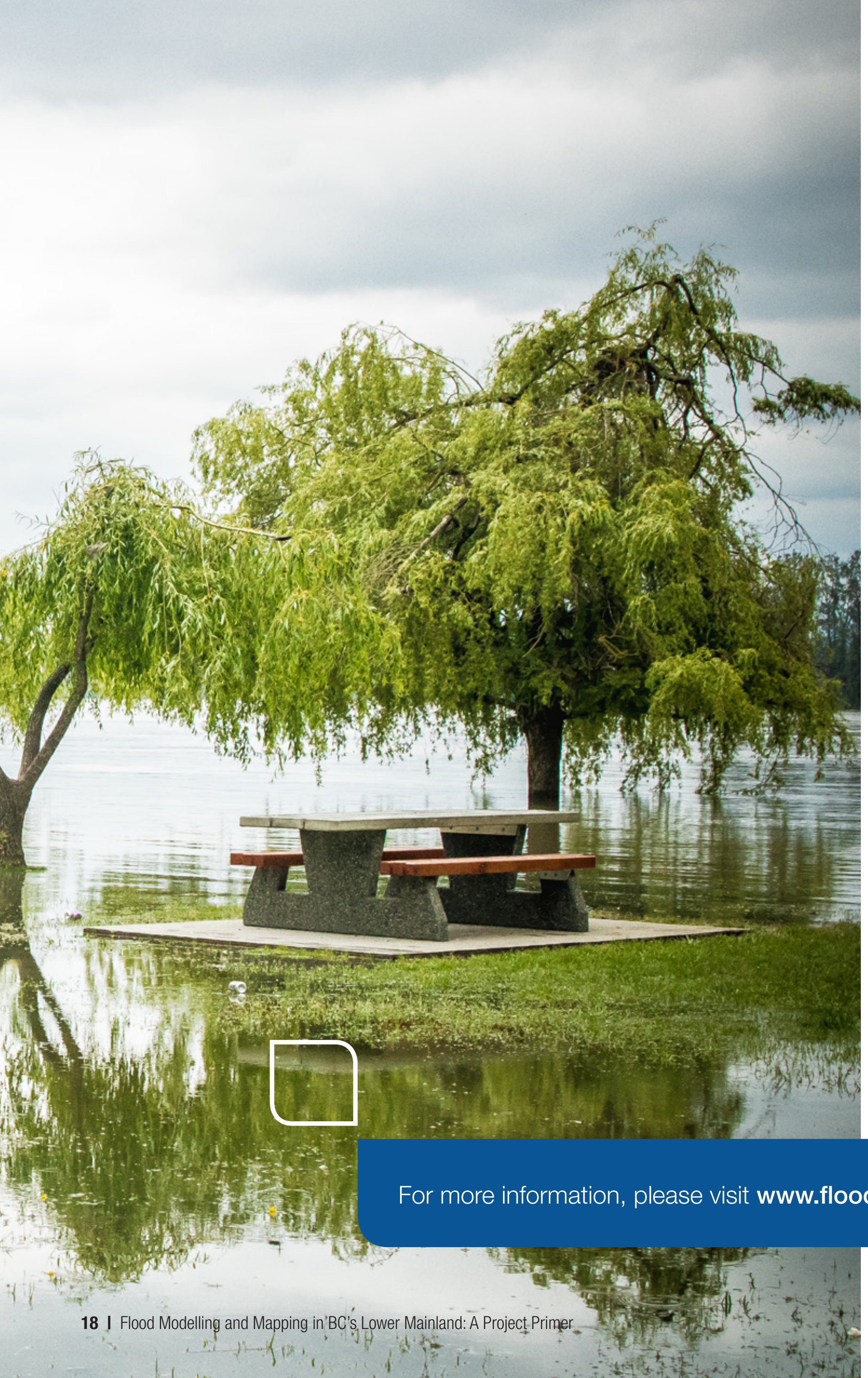
- **Land Raising:** *Raising land to meet or exceed current municipal Flood Construction Levels, which are often a condition of development in floodplain areas.*

  In this scenario, 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. While raising land in the floodplain can avoid or minimize flooding of raised parcels, there can be negative impacts for surrounding lands unless these too are raised or otherwise managed for flood, particularly if the raised area is outside present diking. For the case simulated (largely inside a dike), there were negligible impacts on flood levels in the river (less than 0.01 m). Results will vary depending on location and the extent and height of land raising.

- **Upstream Storage:** *Storing flood waters upstream during the freshet to reduce downstream flows.*

  In this scenario, existing dams and reservoirs on the Nechako and Bridge Rivers were used to temporarily store flood waters, which has previously been done during one or more serious high-water events. Upstream storage provided benefits in lowering flood water levels. It was estimated that the 0.5% AEP (200-year) flood could be reduced to a 1% AEP (100-year) flood. 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 a very high flood magnitude (e.g., 0.2% AEP [500-year] flood) due to the very large storage requirement.

While each of the five mitigation options explored warrants further exploration later in the LMFMS, the path forward will likely involve a combination of approaches, which will benefit from further modelling. Implementing any combination of approaches will require a comprehensive, regionally coordinated response with multiple interventions along the whole lower reach of the Fraser.



Key Recommendations and Next Steps

Work will continue through 2019 and 2020 to complete Phase 2 of the Lower Mainland Flood Management Strategy. Regarding the hydraulic model, key activities will include:

- **Work with partner organizations to identify regional priorities and flood mitigation options for the LMFMS:** The Fraser Basin Council will continue to meet with representatives from partner organizations to further explore the results of modelling and options going forward. The model results will be used to support a regional Flood Risk Assessment, which will help identify priorities for flood risk reduction at a regional scale.
- **Communicate results of the flood modelling and mapping:** The Fraser Basin Council will work to create communications materials to increase awareness of the project findings on flood hazards, exposure to flooding and potential mitigation options. These information products will be shared and discussed with a variety of organizations that have flood management roles and responsibilities.
- **Maintain, enhance, and continue to use the *Lower Fraser River 2D Flood Model*:** Further work is required to establish the necessary arrangements and procedures for ongoing access and use of the model among multiple parties. Planning is also needed to facilitate periodic updates of the flood model to ensure ongoing accuracy and utility. Additional model runs can help decision makers explore how flood risk reduction options – such as different types of flood infrastructure or land use policies – perform when implemented at a regional scale, separately or in combination. This and other model applications will be explored and implemented over the coming year(s).

For more information, please visit **www.floodstrategy.ca**

Notes on Flood Scenario Maps

1. For important limitations and disclaimers, see Hydraulic Modelling and Mapping in B.C.'s Lower Mainland – Final Report prepared for Fraser Basin Council by Northwest Hydraulic Consultants Ltd. (2019)
2. These maps are for information only and intended for flood scenario comparison and flood mitigation planning. They may also be informative for emergency planning. They are not to be used for designating floodplains, establishing Flood Construction Levels or designing dikes or other structures.
3. Flood depths do not include freeboard allowance.
4. Except for the "Dike Breach" scenarios, it is assumed that dikes remain intact when dike crests are overtopped. Since most dikes would likely fail under such circumstances, actual flood extents and depths may significantly exceed those shown.
5. For "Dike Breach" scenarios, actual dike breach locations and characteristics may vary.
6. Climate change projections of river flows and sea level rise include a high degree of uncertainty.

Credits and Acknowledgements

This work would not have been possible without the financial assistance of Public Safety Canada through the National Disaster Mitigation Program and the partners of the Lower Mainland Flood Management Strategy that provided matching funding and in-kind contributions. The Fraser Basin Council would also like to thank and acknowledge all the project partners and stakeholders who contributed to this project. The project was supported by a Technical Advisory Committee, which included those working within federal, provincial, local and First Nations entities as well as infrastructure owners. Northwest Hydraulic Consultants Ltd. were the engineering consultants. They were supported by EcoPlan International, which assisted with communications materials.

Fraser Basin Council

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