LOWER MAINLAND FLOOD MANAGEMENT STRATEGY

Phase 1 Summary Report

May 2016

Fraser Basin Council

INSIDE

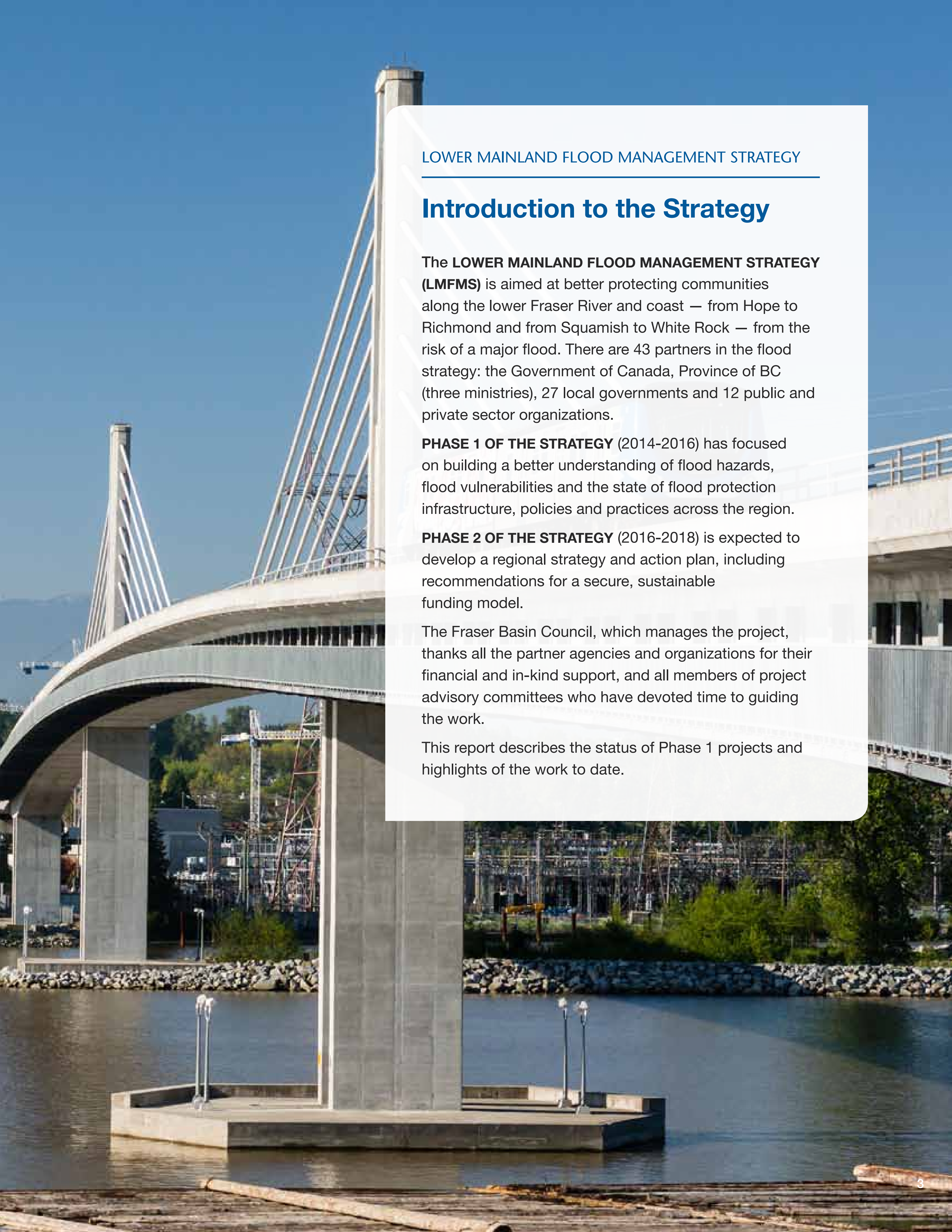
TABLES

Fraser Basin Council

MAPS

See two companion maps to this summary report that show the extent of flood under coastal and Fraser River flood scenarios.

Coastal Map	***Fraser River Map***
Scenario A | Present Day	Scenario C | Present Day
Scenario B | Year 2100	Scenario D | Year 2100



Introduction to the Strategy

The **LOWER MAINLAND FLOOD MANAGEMENT STRATEGY (LMFMS)** is aimed at better protecting communities along the lower Fraser River and coast — from Hope to Richmond and from Squamish to White Rock — from the risk of a major flood. There are 43 partners in the flood strategy: the Government of Canada, Province of BC (three ministries), 27 local governments and 12 public and private sector organizations.

PHASE 1 OF THE STRATEGY (2014-2016) has focused on building a better understanding of flood hazards, flood vulnerabilities and the state of flood protection infrastructure, policies and practices across the region.

PHASE 2 OF THE STRATEGY (2016-2018) is expected to develop a regional strategy and action plan, including recommendations for a secure, sustainable funding model.

The Fraser Basin Council, which manages the project, thanks all the partner agencies and organizations for their financial and in-kind support, and all members of project advisory committees who have devoted time to guiding the work.

This report describes the status of Phase 1 projects and highlights of the work to date.

Phase 1 Highlights at a Glance

PROJECT 1
Analysis of Future Flood Scenarios

Details on page 6

It's time to plan for larger, more frequent floods.

The BC Lower Mainland is vulnerable to major, catastrophic floods from the Fraser River freshet (spring) and from coastal flooding (winter). In 2014 the Province of BC published a study that described the modelled results of 140 different Fraser River flood scenarios for the Lower Mainland over the next 200 years, reflecting different variables for climate, peak river flows and sea level rise.

In 2015 technical consultants for the Lower Mainland Flood Management Strategy (Kerr Wood Leidal) analyzed information from this report and other provincial and municipal flood hazard studies, reports and models relevant to the region. Four flood scenarios and related floodwater levels were selected for comparative purposes and as the basis for the regional flood vulnerability assessment (Project 2). These scenarios are:

Two Coastal Flood Scenarios
(Present Day and Year 2100): See Table 1 on page 8

Two Fraser River Spring Freshet Flood Scenarios
(Present Day and Year 2100): See Table 2 on page 8

The research makes one thing clear: under climate change, major floods in the Lower Mainland are expected to increase in magnitude and frequency. This is so because of projections for sea level rise and for larger peak flows on the Fraser River. Flood mitigation planning for the Lower Mainland must account for the changing face of flood hazards.

PROJECT 2
Regional Assessment of Flood Vulnerabilities

Details on page 10

A major Lower Mainland flood would be Canada's most costly natural disaster.

The Lower Mainland Flood Management Strategy partners retained Northwest Hydraulic Consultants to carry out a flood vulnerability assessment in 2015-2016.

The assessment sets out projections for damages and losses related to buildings in Lower Mainland floodplain areas – and the related direct and indirect economic losses – under different flood scenarios.

Four major Lower Mainland flood scenarios were assessed for comparative purposes — two coastal flood scenarios (Present Day and 2100) and two Fraser River flood scenarios (Present Day and 2100). For more about the flood scenarios, see Project 1 on page 6.

The key takeaway is that any one of the four major Lower Mainland flood scenarios analyzed would be expected to trigger the most costly natural disaster in Canadian history to date, creating severe strain on the regional, provincial and national economies.

Flood risks in the Lower Mainland are very serious and are projected to worsen over the next 85 years, both in terms of flood frequency and severity, based on sea level rise and other projected impacts of climate change.

The two present day flood scenarios are expected to result in losses estimated at $19.3 billion (coastal flood) and $22.9 billion (Fraser River flood). Year 2100 flood scenarios are estimated to be higher, totalling $24.7 billion (coastal flood) and $32.7 billion (Fraser River flood). Each would be three to five times more costly than the Alberta floods of 2013.

The study estimated flood-related direct losses and some indirect economic losses related to residential, commercial and public/institutional buildings, some infrastructure, cargo shipping delays and agriculture. Estimates are based on current population levels and development in Lower Mainland floodplain areas. If growth continues, the Year 2100 losses are likely underestimated. The project shows that the Lower Mainland is exposed to a high degree of flood risk. It demonstrates the urgent need for a comprehensive flood management strategy, and commitments for action.

PROJECT 3A
Lower Mainland Dike Assessment

Details on page 25

Flood infrastructure in the Lower Mainland needs upgrading & policies and practices need updating.

In 2015 the Inspector of Dikes oversaw an assessment of Lower Mainland dikes as part of Phase 1 of the Lower Mainland Flood Management Strategy.

The assessment, carried out by Northwest Hydraulic Consultants, shows that 71% of the assessed dikes are vulnerable to failure by overtopping during either a major Fraser River or coastal flood. Only 4% of assessed dike segments meet current provincial standards for dike crest height, which includes 0.6 m of freeboard above the water surface elevation of the design flood event.

The design flood in the Lower Mainland is the greater of either the 1894 Fraser River flood of record (peak flow of 17,000 cubic metres per second at Hope) or a winter coastal storm surge flood event of approximately 1:200 annual exceedance probability.

In all, 74 dikes were assessed based on current records, and these were divided into 118 segments for the purpose of the project. These dikes — stretching 500 km and managed by 35 diking authorities — represent about 50% of all dikes in BC.

Dikes can fail for different reasons. The assessment covered, not only dike crest height, but also geometry, geotechnical stability during floods and earthquakes, erosion protection, control of vegetation/animal encroachments, appurtenant structures on the dikes and administrative arrangements, including secured rights of way and inspection practices.

A key reason that Lower Mainland dikes are considered vulnerable to failure is because most were reconstructed in the 1970s and 1980s according to the standard of the day, which has since been recognized as too low. The standard has been updated through more accurate flood modelling.

Based on average rankings across multiple criteria, the majority of assessed dikes in the Lower Mainland (69%) were scored as Poor to Fair, 18% as Unacceptable to Poor, and 13% as Fair to Good. Few of the dike segments assessed meet current provincial standards, and no dikes fully meet provincial standards.

Among the report recommendations are to prioritize dike upgrades, and where it is not feasible to upgrade dikes sufficiently, to consider a range of structural and non-structural flood management strategies.

PROJECT 3B
Review of Flood Management Policies and Practices

Details on page 30

The final report for Project 3B will be completed in late June 2016. Here are the highlights to date.

A diversity of flood protection works, land use policies and management practices are in place throughout the Lower Mainland.

Many communities rely on flood protection dikes and associated works such as pumps, floodgates and erosion protection works, but often lack dedicated funding for major upgrades and rehabilitation. Moreover, some communities, including First Nations, are not presently protected by diking systems at all.

In a 2015-2016 review of local flood management policies and practices, most communities identified flood protection works as a top priority. Some also identified riverbed sediment management as an important tool in the suite of management options to alleviate flooding, erosion and seepage problems.

Most communities use land use planning and policies to limit community vulnerability to flooding. The two primary approaches are flood construction levels and horizontal setbacks. These are typically implemented through bylaws, development permit areas and other policies and practices related to zoning, subdivision approvals and building permits. Growth can be guided away from flood-prone areas, and habitable living space can be built above predicted flood levels with floodproofing practices.

Challenges for local governments include: a lack of funding for major repairs and upgrades to flood protection works, lack of a consistent policy framework to guide communities across the Lower Mainland, challenges associated with historic settlements, and challenges associated with changing flood hazards over time, particularly due to sea level rise and other climate change impacts.

Some of the priorities and suggestions raised by local governments include: a dedicated, multi-year funding program to support rehabilitation of flood protection works; more integrated and comprehensive approaches to flood management planning; reconciling the need for regional consistency with flexibility to accommodate unique local circumstances; improving regulatory and permitting processes; improving knowledge to better inform flood hazard management decisions; developing a long-term plan to manage sediment; and evaluating management options in relation to a diversity of economic, social, environmental and technical criteria.

Project 1 | Analysis of Future Flood Scenarios

Project Status: Complete

Building the Lower Mainland Flood Scenarios

In 2014 the Province of BC (Ministry of Forests, Lands and Natural Resource Operations) published the results of a modelling study called *Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios.* That report sets out 140 possible Fraser River scenarios, including projected floodwater levels, for the 170 km stretch from Hope to the river's mouth over the next 50, 100 and 200 years. The scenarios were developed using the Fraser River hydraulic model and different variables for climate, peak flows and sea level.

The Fraser Basin Council subsequently retained engineering consultants Kerr Wood Leidal (KWL) to analyze this study and other flood hazard studies, reports and models available across the region. The aim was to select appropriate flood scenarios as a foundation for a regional vulnerability assessment (Project 2: See page 10).

The Bottom Line: Prepare for Larger and More Frequent Floods

The research makes one thing clear: under climate change, major floods in the Lower Mainland are expected to increase in magnitude and frequency. This is because of projections for sea level rise and for larger peak flows on the Fraser River.

Flood mitigation planning for the Lower Mainland must account for the changing face of flood hazards.

The Future of Fraser River Freshet Flooding

Fraser River spring freshet (snowmelt) presents a risk of catastrophic flood in the Lower Mainland, with greatest risk in communities adjacent to the Fraser River from Chilliwack to Richmond.

Current design standards for Fraser River flood infrastructure, such as dikes, are based on water levels of the Fraser River flood of record (1894). The 1894 flood had a peak flow of 17,000 m^3/sec (measured at Hope), just slightly higher than the estimated 1-in-500 year flood.

A 1-in-500 year flood is of a magnitude expected to occur – *as a long-term average* – once in every 500 years. Flood risk can also be expressed as Annual Exceedance Probability (AEP): the probability that a flood of a particular magnitude will be equalled or exceeded in any given year (1:500 AEP). This represents a 0.2% risk of a flood of that magnitude in any given year.

A Fraser River freshet peak flow of 16,500 m^3/sec (at Hope) today would currently be considered a 1-in-500 year flood event; by Year 2100, a flood of that magnitude may be expected to have a return period of just 50 years due to the effects of climate change on flood risk. A Fraser River peak flow of 19,900 m^3/sec would today be considered a 1-in-5000 year flood, but by Year 2100 it might be considered a 1-in-500 year event.

A Fraser River freshet peak flow of 16,500 m^3/sec (at Hope) today would currently be considered a 1-in-500 year flood event; by Year 2100, a flood of that magnitude may be expected to have a return period of just 50 years due to the effects of climate change on flood risk.

Given that some parts of BC have recently experienced mild winters and dry summers, it may seem surprising to plan for larger peak flows on the Fraser River. Climate change, however, heightens the risk of high temperatures in spring. Higher temperatures lead to more rapid melt of snowpack and, when combined with episodes of heavy rainfall, can result in higher peak flows and increased risk of flood. Rapid melt of a large snowpack, with heavy precipitation, could lead to extreme flooding on the Fraser.

For details, see: *Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios (2014)*, Northwest Hydraulic Consultants and *Selecting and Using Climate Change Scenarios for British Columbia (2011)*, PCIC.

The Future of Coastal Flooding

Coastal flooding typically occurs when storm surges combine with high tides during the winter storm season. This is the dominant flood risk for Lower Mainland communities near the mouth of the Fraser and up the coast.

Under current Province of BC projections, sea level is expected to rise one metre by the Year 2100, and two metres by Year 2200, which increases the risk of coastal flooding.

While most BC coastal flood studies reference a 1-in-200 year flood as the minimum requirement for flood assessments and mitigation planning, KWL recommends that a more conservative requirement be considered for developed areas where coastal flooding could occur more regularly or have higher consequences. Given the extensive development and infrastructure in Lower Mainland communities, and the population base, the consultants recommend basing a regional vulnerability assessment on a 1-in-500 year coastal flood.

Flood Scenarios for Planning

KWL recommended two coastal flood scenarios (Present Day (A) and Year 2100 (B)) and two Fraser River freshet flood scenarios (Present Day (C) and Year 2100 (D)) – on which to base the Lower Mainland regional vulnerability assessment. The river flooding scenarios relate to the main stem of the Fraser, not its tributaries. The four scenarios were selected to provide a comparative analysis. The KWL report recognizes that uncertainty remains regarding the potential changes in Fraser River flood. Until those uncertainties are reduced through future work, these results support a preliminary quantitative flood risk analysis.

Year 2100 was chosen as a reasonable time horizon for planning, relevant to the lifespan for new buildings and infrastructure.

Coastal Flood Scenarios

Coastal flood scenarios can be developed in different ways. For the regional vulnerability assessment, KWL used a uniform measurement of coastal water surface elevation for all locations. The scenarios used data on water levels recorded at Point Atkinson, a station offering over 50 years of data. Under the KWL analysis, coastal flood scenarios show water levels projected at 3.4 metres (Present Day) and 4.4 metres (Year 2100). The Year 2100 coastal scenario reflects one metre of sea level rise. KWL consultants note that the design of flood protection works typically requires site-specific analysis and reliable long-term wind and water level data, which would help account for the effects of waves. This was not undertaken for the purposes of a region-wide vulnerability assessment.

Table 1: Coastal Flood Scenarios for BC Lower Mainland

Scenario	Description	Flood Water Level (GD)[3]
Coastal Scenario (A) Present Day	• 1-in-500 year storm surge flood • Still water ocean state[1] • Includes .6 m allowance for uncertainties and site variation[2] • Current sea level	3.4 m
Coastal Scenario (B) Year 2100	• 1-in-500 year storm surge flood • Still water ocean state[1] • Includes .6 m allowance for uncertainties and site variation[2] • Includes 1 m sea level rise	4.4 m

[1] *Encompasses ocean tides and storm surges between mid-October and mid-January but does not include localized wind and wave effects*

[2] *Allowance is for differences in shorelines and local wave effect, which vary across the region*

[3] *Geodetic datum*

Fraser River Flood Scenarios

In planning for a major freshet flood, the 1894 Fraser River flood of record and a future 1-in-500 year flood will be used, as shown.

Table 2: Fraser River Freshet Flood Scenarios for BC Lower Mainland

Scenario	Description	Flood Water Level (GD)[1]
Fraser Freshet Scenario (C) Present Day	• Based on 1894 flood of record • High tide conditions • Current sea level • 17,000 m^3/sec peak flow at Hope	Varies by location in floodplain: 1.55 m to 39.55 m
Fraser Freshet Scenario (D) Year 2100	• Based on 1-in-500 year flood • High tide conditions • 1 m sea level rise & moderate climate change • 19,900 m^3/sec peak flow at Hope	Varies by location in floodplain: 2.89 m to 40.39 m

[1] *Geodetic datum*

Year 2100 was chosen as a reasonable time horizon for planning, relevant to the lifespan for new buildings and infrastructure

Flood Reports & Maps Online

Reports

Reports from Phase 1 of the Lower Mainland Flood Management Strategy (LMFMS) are now available.

Project 1

Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios

Analysis of Flood Scenarios

Project 2

Regional Assessment of Flood Vulnerability

Project 3

Lower Mainland Dike Assessment

Regional & Subregional Maps

The report *Regional Assessment of Flood Vulnerability* includes 10 subregional maps of the Lower Mainland that illustrate lands subject to flood in municipalities, First Nations communities and unincorporated areas under coastal flood scenarios A and B and Fraser River flood scenarios C and D.

The subregional maps include some essential facilities and other key infrastructure vulnerable to flood — including fire halls, police stations, emergency operations centres, hospitals, airports, port facilities, BC Hydro substations and schools.

Visit floodstrategy.ca

Project 2 | Regional Assessment of Flood Vulnerabilities

Project Status: Complete

Background

In preparing a flood mitigation strategy for the Lower Mainland, it is important first to understand what is at risk in the event of a major flood and the costs associated with these risks.

The Fraser Basin Council retained Northwest Hydraulic Consultants (NHC), assisted by several subcontractors, to carry out a region-wide vulnerability assessment based on the four major flood scenarios set out in Project 1. The NHC analysis sets out quantitative projections on damage to and destruction of buildings and equipment in flood-prone areas, including the associated direct and indirect economic losses.

The project further estimates flood damages related to essential facilities such as fire halls, police stations, ambulance stations, hospitals and schools and certain infrastructure such as BC Hydro substations, railways, roads, airports and municipal facilities. Qualitative disruption scenarios were prepared to supplement the quantitative assessment and to flag associated issues.

This quantitative and qualitative vulnerability assessment is the first of its kind at the regional scale and is intended as a tool for regional and local decision-making.

Hazus-MH 2.1 software (Canadian Flood Module) was used to complete the analysis on economic losses related to residential, commercial, industrial and public/institutional buildings. The US Federal Emergency Management Agency (FEMA) developed the Hazus software, which uses GIS information and a standardized methodology for estimating physical, economic and social impacts of disasters such as earthquakes, floods and hurricanes.

The Canadian Flood Module was developed through a collaboration of FEMA and Natural Resources Canada (NRCan) and was released for use in November 2015. The Canadian flood module includes national data from the 2011 Population Census as well as a national building inventory. The LMFMS project is the first regional-scale use of the Canadian Hazus flood module.

Losses from interruptions to rail traffic were estimated based on freight transshipped through Port Metro Vancouver. Indirect losses are more difficult to estimate because of the wide range of variables.

Agricultural losses were separately calculated based on federal and provincial data. Consultants prepared an inventory of flood-prone assets based on various government and private sector data.

See the full NHC report *Lower Mainland Flood Management Strategy Project 2: Regional Assessment of Flood Vulnerability* (vulnerability assessment report) for details. The report is available at **floodstrategy.ca**.

What are the Impacts of a Major Lower Mainland Flood?

Flood Waters Would Cause Damage, Loss and Widespread Disruption

All communities in the Lower Mainland are vulnerable to the direct or indirect impacts of a major coastal or Fraser River flood. A major Lower Mainland coastal flood would be expected to inundate 54,700 hectares in present day (61,100 ha by 2100) and a Fraser River flood to inundate 99,300 hectares in present day (110,300 ha by 2100).

In addition to land under local government jurisdiction within the Lower Mainland, there are 30 First Nations with a total of 90 reserves and treaty lands in the project area. One-third of the reserves are not subject to inundation; the remaining two-thirds (61 reserves, affecting 26 First Nations) are vulnerable to flooding. For details, see the vulnerability assessment report (Appendix B, Annex C).

Flood presents major economic risks, as well as risks to public health, social well-being and the environment.

Transportation and trade-related impacts would be far-reaching. The Lower Mainland may become grid-locked for personal, commercial and industrial transportation by road, rail and air. Supply lines will consequently be disrupted. “Just-in-time” delivery is common throughout the region, which is very efficient for most purposes, but not designed for rare events such as disasters. As a result, the available food supply and other supplies could be impacted in as little as four days.

Disruption to the flow of goods into and out of Port of Vancouver and the Greater Vancouver area due to a flood would have severe consequences on the regional, provincial and national economy, with significant indirect losses and declines in taxes and other government revenues.

Communications facilities are vulnerable to system overload or damage, including 911 call centres, cell towers, cables, the internet and telephone land lines, which represent risks to people, property and business continuity.

Environmental contamination would be significant in a flood, as a result of chemicals, fertilizers, petroleum products and raw sewage from agricultural, transportation, septic, municipal wastewater, industrial and hazardous waste storage sites and from existing contaminated sites.

A major flood is expected to result in:

- **damage to and destruction of residential, commercial, industrial, public/institutional and agricultural buildings, equipment and other property**
- **damage to or destruction of essential infrastructure**
- **disruption of private and public services**
- **displacement of people**
- **environmental contamination**

As in any natural disaster, there is also the sobering potential for serious injury and loss of life.

Amount Of Debris Generated

650,000 US TONS

(595,000 METRIC TONNES)

OF DEBRIS

A Look at Properties Damaged or Destroyed

A major Lower Mainland flood would be expected to damage or destroy many buildings in floodplain areas.

Table 3 on page 13 sets out projections on the number of residential, commercial, industrial and public/institutional buildings that would be damaged or destroyed in Lower Mainland communities under flood scenarios A, B, C and D, together with total building-related costs and debris generated. Note that agricultural building costs are summarized in a separate table.

If a flood were to occur today in the Lower Mainland under scenarios A or C, it would be expected to generate 650,000 US tons (595,000 metric tonnes) of debris. That would more than double by Year 2100 under flood scenarios B or D.

Property damage and losses for all Lower Mainland communities are included in the analysis that follows.

Assumptions in the Flood Assessment

Four basic flood scenarios were central to the assessment: two coastal flood scenarios A and B (Present Day and 2100) and two Fraser River flood scenarios C and D (Present Day and 2100). Certain assumptions are built into the scenarios and the analysis.

Assumption about Dikes & Floodproofing

To simplify the analysis, it was assumed that all Lower Mainland dikes would breach in all flood scenarios, and that flood waters would inundate all low-lying areas for the duration of the flood. This is a simplified, worst-case scenario to identify vulnerability and to assess losses at a regional level.

While it is possible that all dikes could fail, the scenarios do not predict where or how any dikes would fail. It is also possible that some Lower Mainland dikes would fail, while other dikes would not. For example, if during a Fraser River flood some upstream dikes in the Fraser Valley fail, this could have impacts downstream. The upstream floodplain might store a significant amount of water such that downstream dikes may not fail, or it may be that downstream flooding is less extensive or severe than if all dikes failed at once.

The Lower Mainland Dike Assessment (see page 25) evaluated the current status of dikes in relation to several criteria. This project found that the vast majority of dikes have deficiencies ranging from the elevation of the dike, to vulnerability to seismic events and other factors. Therefore it is not unreasonable to assume widespread dike failures for the purposes of the vulnerability assessment and the four flood scenarios.

It is assumed that no buildings or infrastructure have been elevated above predicted floodwaters to reduce or prevent flood damages. This is known as floodproofing and typically involves raising the ground level by adding fill or by placing habitable living space or vulnerable electrical/mechanical equipment above garages, carports, crawl spaces, parkades or other building features that would be less susceptible to flood damages.

Assumption about the Extent of Flood

Coastal Flood: Flood levels were projected horizontally across the land, with an additional 0.6 m allowance for wave action and uncertainties. Future increases in storminess due to climate change were not considered (i.e., more severe coastal storm surge events). The specific localized effects of waves on different coastal communities were not considered. **Fraser River Flood:** Flood levels were projected horizontally across the floodplain, perpendicular to the river except in some areas for which there are floodplain maps, in which case the maps were used to project water levels. Flooding from Fraser River tributaries was not included in the assessment.

Assumption about Flood Duration & Recovery

Coastal Flood: Two Weeks. A coastal storm surge flood (scenarios A and B) was assumed to last two weeks, which includes flooding and the subsequent drainage of flood waters.

Fraser River Flood: Four Weeks. The duration of a Fraser River flood (scenarios C and D) was assumed to be four weeks, encompassing both flooding and the drainage of flood waters.

Flood duration is relevant to calculations on transportation disruption, specifically disrupted cargo shipments, and on agricultural losses. Initially, agricultural losses were calculated on short-duration floods (two-day coastal flood, two-week Fraser River flood) and those losses are tallied in Table 7. However, the total agricultural losses were later grossed up 2.25X to reflect the impacts of a two-week coastal flood and four-week Fraser River flood. See page 17 for detail.

Flood duration is not applied to building-related losses, which are calculated in Hazus software. Default recovery times for buildings calculated in the Hazus software is between 1 and 33 months. Note that full recovery times will vary.

Assumption about Future Growth & Development

Due to significant uncertainty about population growth and community development over the long-term, it was assumed that there would be no additional growth in population, number of buildings or infrastructure in Lower Mainland floodplain areas between present day and 2100. However, if growth in these areas continues, damage estimates will be significantly underestimated.

Table 3: Residential, Commercial, Industrial & Public/Institutional Buildings – Damaged & Destroyed



Flood Scenario	# Buildings Damaged	# Buildings Destroyed	Total Building-Related Losses ($)	Debris Generated*
A | Coastal (Present Day)	7,200	1,100	$14.2 B	650,000 tons
B | Coastal (Year 2100)	8,200	3,700	$19.1 B	1.65 M tons
C | River (Present Day)	3,600	690	$9.0 B	656,000 tons
D | River (Year 2100)	9,200	1,700	$18.4 B	1.34 M tons

***Note:** Debris is stated in US tons*

What will Flood Cost?: The Economic Losses

Residential, Commercial, Industrial and Public/Institutional Buildings

The building-related losses, including some indirect costs, were estimated for residential, commercial, industrial and public/institutional buildings, using the Hazus software and additional analysis.

These estimates encompass:

- Building repair and replacement costs
- Building contents
- Building inventory
- Relocation expenses
- Capital-related income losses
- Wage losses
- Rental income losses.

Infrastructure

Estimates were made for damage to infrastructure such as electrical substations, airports, marine facilities, rail lines, critical highways and arterial roads, rapid transit lines, wastewater treatment plants, police and emergency services, hospitals, municipal halls and works yards. Most of these estimates could not be made using the Hazus software; a simplified valuation approach was followed.

Excluded Losses

The estimates **do not include** other losses that have potential to be significant, such as:

- economic losses associated with disruption of infrastructure or businesses (other than interruption of cargo shipments)
- losses relating to future growth in population density or development in floodplain areas: see "Assumptions" on page 12.
- environmental decontamination
- debris clean-up

Essential Facilities Impacted

Table 4 sets out projections on some of the essential facilities expected to suffer damage under flood scenarios A, B, C and D. In addition to those listed in Table 4, critical public facilities vulnerable to flood include four municipal halls, seven works yards, three prisons with over 1,000 inmates and two energy utilities (False Creek and Richmond).

Table 4: Essential Facilities Damaged

Flood Scenario	Fire Stations	Police Stations	Hospitals	Ambulance Stations	Schools
A | Coastal (Present Day)	12	6	3	3	80
B| Coastal (Year 2100)	15	8	3	3	95
C | River (Present Day)	21	8	4	3	116
D | River (Year 2100)	23	11	4	5	120

People Displaced

A major flood under any of the four flood scenarios is expected to force many people to move from their homes to take up temporary shelter within or outside the region. These people will be in need of food, supplies and emergency services.

The numbers in Table 5 are based on 2011 Population Census data and the projected extent of flooding associated with each of the flood scenarios. If population growth in floodplain areas continues, the numbers could be expected to be higher by 2100 under scenarios B and D.

Table 5: People Displaced & Seeking Shelter

Flood Scenario	# People
A | Coastal (Present Day)	238,000
B | Coastal (Year 2100)	261,000
C | River (Present Day)	266,000
D | River (Year 2100)	311,000

Infrastructure Impacted

The vulnerability assessment identifies some key Lower Mainland infrastructure that is susceptible to flood and sets out related loss estimates based on rough replacement (valuation) costs developed by the U.S. Federal Emergency Management Agency (FEMA). This infrastructure analysis could not be done within the Hazus software.

Table 6 sets out examples of infrastructure subject to flood damage and the associated loss estimates. It covers:

- electrical substations
- airports
- marine facilities
- rail lines
- critical highway routes and arterial roads
- rapid transit lines
- wastewater treatment plants
- emergency facilities
- hospitals
- municipal halls and work yards
- schools.

These are order-of-magnitude estimates for regional planning purposes, and much more work would be required to refine the results. Note that there may be minor double counting of select facilities (emergency facilities, hospitals and schools) because of differences in the source data and methodologies used; this duplication represents about 2% of the total damages estimated under the Hazus software. For a list of assumptions on infrastructure losses, see the following page.

Table 6: Economic Loss Projections Related to Infrastructure

	Quantity Affected				Valuation Cost ($)	Corresponding Loss Estimate (Millions $)			
Infrastructure Type	A	B	C	D		Scenario A	Scenario B	Scenario C	Scenario D
Substation[1]	19	37	23	30	$11,000,000	$209	$407	$253	$330
Airports – YVR[2]	1	1	1	1	$29,260,00	$29	$29	$29	$29
Airports – Local[3]	4	4	5	5	$2,750,000	$11	$11	$14	$14
Major marine facilities[4]	10	20	15	15	$3,685,000	$37	$74	$55	$55
Minor marine facilities[5]	10	20	15	15	$737,000	$7	$15	$11	$11
Rall lines[6]	18	18	22	26	$4,125,000	$74	$74	$91	$107
Critical highway routes[7]	25	27	24	28	$27,500,000	$688	$743	$660	$770
Rapid trasit lines[8]	5	5	5	5	$4,125,000	$21	$21	$21	$21
Wastewater plants[9]	3	5	8	9	$22,000,000	$66	$110	$176	$198
Police/emergency services[10]	23	24	31	37	$2,600,000	$60	$62	$81	$96
Hospitals[11]	3	3	4	4	$4,000,000	$12	$12	$16	$16
Municipal halls / works yards, etc.[12]	8	9	7	14	$2,500,000	$20	$23	$18	$35
Schools[13]	80	95	116	120	$2,400,000	$192	$228	$278	$288
Sub-Total $	-	-	-	-	-	$1426	$1809	$1703	$1970
Dikes (pumpstations not included)[14]	34	34	36	36	$1,000,000	$34	$34	$36	$36
Bridges[15]	-	-	3	3	$1,000,000,000	-	-	$3,000	$3,000
Total ($ Million)	-	-	-	-	-	**$1,460**	**$1,843**	**$4,739**	**$5,006**
Rounded Total ($ Billion)	-	-	-	-	-	**$1.4 B**	**$1.8 B**	**$4.7 B**	**$5.0 B**

Table 6 Assumptions

1 *Assume all substations are of medium size and repair costs amount to 50% of FEMA valuation cost*
2 *50% of FEMA valuation cost for key components (1 of each)*
3 *Repair and clean-up*
4 *50% of FEMA valuation cost for key components (1 of each)*
5 *10% of FEMA valuation cost for key components (1 of each)*
6 *Assume 5km must be rebuilt at each inundated section at 50% of FEMA valuation cost*
7 *Assume 5km must be rebuilt at each inundated section at 50% of FEMA valuation cost*
8 *Assume 5km must be rebuilt at each inundated section at 50% of FEMA valuation cost*
9 *Assume all plants are of medium size and repair costs amount to 10% of FEMA valuation cost*
10 *Repair and clean-up \$2,600/m^2* 1,000 m^2 (ref. Marshall & Swift)*
11 *Repair and clean-up \$4,100/m^2* 1,000 m^2 (ref. Marshall & Swift)*
12 *Repair and clean-up \$2,500/m^2* 1,000 m^2 (ref. Marshall & Swift)*
13 *Repair and clean-up \$2,400/m^2* 1,000 m^2 (ref. Marshall & Swift)*
14 *Replacemenet/upgrade of 200m long breached sections, assumed cost of \$5,000/m*
15 *Mission Rail, Patullo, CN Rail*

For consideration of some of the service disruptions expected with flooded infrastructure, see "Vulnerability of Key Infrastructure and Potential for Service Disruptions" on page 20.

In a coastal flood, infrastructure losses are estimated at \$1.4 billion (Present Day) and \$1.8 billion (Year 2100). In a Fraser River flood, infrastructure losses are estimated at \$4.7 billion (Present Day) and \$5 billion (Year 2100) as set out in Table 6.

Table 7: Agricultural Losses under Flood Scenarios

Flood Scenario	Flood Vulnerable Area (Hectares)	Lost Farm Gate Sales (Millions)	Damage to Equipment	Damage to Buildings	Replanting Loss (Millions)	Total: Short-Duration Flood*	Total: Long-Duration Flood*
A | Coastal (Present Day)	14,626	$16.5 M	$12.7 M	$37.9 M	N/A	**$67.1 M**	**$100 M**
B | Coastal (Year 2100)	15,214	$17.4 M	$14.6 M	$40.9 M	N/A	**$72.9 M**	**$200 M**
C | River (Present Day)	43,459	$410.1 M	$50.7 M	$223 M	$9.5 M	**$693.2 M**	**$1.6 B**
D | River (Year 2100)	43,813	$423 M	$50.7 M	$227.3 M	$9.5 M	**$700.6 M**	**$1.6 B**

****Note:** The estimates by category in this table are based on floods of short duration (two-day coastal flood and two-week Fraser River flood). As noted, agricultural losses would increase under a longer duration flood (two-week coastal flood and four-week Fraser River flood).*

Agriculture-Related Losses

Agricultural loss calculations include damage to agricultural buildings (but not farm houses, which were included in the Hazus residential building analysis), damage to equipment and lost farm gate sales, based on federal and provincial data.

Projected losses are higher under Fraser River scenarios because river flooding would occur over a longer period and during the spring/summer when crops are in the ground.

Floods of more than two-weeks duration are expected to have considerably higher associated costs. Consultants estimated losses would increase by a factor of 2.25. The totals for short- and long-duration floods are set out below. The longer flood duration loss estimates were used in the summary of total economic losses in Table 8 on page 18.

Agricultural Losses under Coastal Flooding (Present Day & Year 2100)

$67-73 million in estimated losses (short-duration flood)

- 14,000-15,000 hectares of farmland flooded
- $17 million in lost farm gate sales
- $13-15 million in equipment damage
- $38-41 million in building damage

$100-200 million in estimated losses (long-duration flood)

Agricultural Losses under Fraser River Flooding (Present Day and 2100)

$693-700 million in estimated losses (short-duration flood)

- 43-44,000 hectares of farmland flooded
- $410-423 million in lost farm gate sales
- $10 million in replanting costs
- $51 million in equipment damage
- $223-227 million in building damage (excluding farm homes)

$1.6 billion in estimated losses (long-duration flood)

Table 8: Total Economic Loss Projections under Flood Scenarios

Flood Scenario	Residential[1]	Commercial[1]	Industrial[1]	Public/ Institutional Buildings[1]	Interrupted Cargo Shipments[2]	Infra-structure[3]	Agriculture[4]	Total
A | Coastal (Present Day)	$5.6 B	$6.3 B	$1.6 B	$720 M	$3.6 B	$1.4 B	$100 M	$19.3 Billion
B | Coastal (Year 2100)	$7.1 B	$8.6 B	$2.6 B	$910 M	$3.6 B	$1.8 B	$200 M	$24.7 Billion
C | River (Present Day)	$2.6 B	$3.8 B	$1.6 B	$880 M	$7.7 B	$4.6 B	$1.6 B	$22.9 Billion
D | River (Year 2100)	$6.6 B	$7.6 B	$2.9 B	$1.2 M	$7.7 B	$5.0 B	$1.6 B	$32.7 Billion

Table 8 summarizes economic loss projections for all types of loss included in this vulnerability assessment, across the entire region, based on longer duration flood: a two-week coastal flood (Scenarios A and B) or four-week Fraser River Flood (Scenarios C and D).

Notes

[1] *Building-related loss projections encompass the cost of repair or replacement of residential, commercial, industrial and public/institutional buildings damaged or destroyed by flood, and include losses relating to inventory, relocation and wages.*

[2] *These are revenues from delays and cancellations in cargo shipping.*

[3] *Included in infrastructure are electrical substations.*

[4] *These losses include agricultural buildings and equipment damaged or destroyed, lost farm gate sales and replanting costs.*

Notes & Limitations on Hazus Analysis

The Hazus software used in Project 2 to calculate building-related losses has limitations, and output generally needs to be supplemented with additional assessment.

Some limitations are:

- The module offers helpful regional-scale estimates, although there are limitations because of data gaps that could not be addressed within the project budget. Not all data sources had up-to-date data.
- Building repair and replacement costs reflect those costs in the United States; such costs are expected to be higher in the Lower Mainland. Hazus calculations were multiplied by 1.6 to account for the difference.
- Currency conversion ($US to $CDN) was set at 10%. This is acknowledged to be low, as the conversion rate was 32% as of March 2016.
- The Canadian version of Hazus lacks a module for calculating indirect losses.
- For full details on limitations, see the *Lower Mainland Flood Vulnerability Assessment* report.

Summary of Losses under Coastal and Fraser River Flood Scenarios

Coastal Flood Scenarios

A | Coastal (Present Day)

$19.3

BILLION DOLLARS

A major coastal flood today of two weeks duration is projected to cause $14.2 billion in losses related to residential, commercial, industrial and public/institutional buildings in the Lower Mainland, $3.6 billion in interrupted cargo shipments,$1.4 billion in infrastructure losses and $100 million in agricultural losses. This amounts to **$19.3 billion**.

B | Coastal (Year 2100)

$24.7

BILLION DOLLARS

By 2100 coastal flood damages are projected at $19.1 billion for building-related losses, $3.6 billion for interrupted cargo shipments, $1.8 billion for infrastructure losses and $200 million for agricultural losses. This amounts to **$24.7 billion**.

Fraser River Flood Scenarios

C | River (Present Day)

$22.9

BILLION DOLLARS

A major Fraser River flood lasting four weeks would today cause $9 billion in losses relating to residential, commercial, industrial and public/institutional buildings in the Lower Mainland, $7.7 billion in interrupted cargo shipments, $4.6 billion in infrastructure losses and $1.6 billion in agricultural losses. This amounts to **$22.9 billion**.

D | River (Year 2100)

$32.7

BILLION DOLLARS

By the year 2100, a major flood is expected to be more significant, resulting in greater building-related losses, primarily as a result of deeper flood waters. The estimate is $18.4 billion in building-related losses, $7.7 billion in cargo shipment interruptions, $5 billion in infrastructure losses and $1.6 billion in agricultural losses.This amounts to **$32.7 billion**.

The consequences of infrastructure damage and disruption, including cascading effects, is difficult to project and would likely drive costs higher than the above projections. See the full report for limitations on the analysis.

Vulnerability of Key Infrastructure and Potential for Service Disruptions

Here is a look at some of the key infrastructure in Lower Mainland flood-prone areas and the potential for service disruptions under the flood scenarios A, B, C & D.

For details of infrastructure and the potential for disruption by subregion and by community under all four flood scenarios, see Appendix B to the vulnerability assessment report: Identification of Infrastructure & Asset Vulnerability.

Electrical Substations

- BC Hydro substations in nine of the 10 sub-regions will be exposed to some flood risk.
- 19-37 substations will be exposed in coastal flood scenarios A and B and 23-30 in Fraser River flood scenarios C and D.
- The Richmond-Delta sub-region has the most vulnerable substations followed by Vancouver-Burnaby-New Westminster; together these areas account for 67-83% of vulnerable substations.
- Electrical equipment is elevated (transformer cabinets up to 1.5 m above grade).
- There is some degree of redundancy in the system to allow some substations to go off-line if needed.
- Flood damaged equipment would require repair or replacement, which could only occur after flood waters recede, for safety reasons.
- A station damaged or disrupted by flood waters could affect other areas that may be outside of the floodplain.
- Loss of electricity would seriously impact the daily lives of residents, in particular the elderly and other vulnerable populations.
- Affected businesses and industries, which could include those outside of floodplain areas, may not be able to operate, incurring loss of revenue.
- Hospitals have generators, but if fuel supply is affected, electricity could be interrupted

Electrical Generation & Transmission Grid

- Less than 10% of Hydro's electrical generation is within the Lower Mainland, and none of those facilities are in floodplain areas.
- All but one of the 10 sub-regions have transmission lines in areas vulnerable to flooding under one or more of the scenarios.
- All transmission lines are elevated.
- There is vulnerability if the foundations of transmission towers are undermined through erosion, or if powerlines or other infrastructure are damaged or downed by felled trees and other hazards.
- Damaged or downed low-voltage power lines could result in local loss of power and potential risk of electrocution, particularly if cables are in populated areas.
- If high-voltage lines are downed, this could disrupt power to multiple substations and have wide-ranging impacts.

Airports

- Vancouver International Airport (YVR) is Canada's second busiest airport. It is vulnerable to flood under all flood scenarios, as are smaller airports in the region: Boundary Bay Airport, Pitt Meadows Airport and Delta Heritage Air Park.
- Flood would impact all YVR runways, taxiways to terminals, grounds of the main and south terminals, all access roads to the terminals and the SkyTrain Canada line.
- YVR would be non-functional for the duration of a flood, resulting in cancellations and/or re-routing of passengers and cargo flights.
- Major retrofits are needed, some are underway, to address future flood levels.
- Abbotsford International Airport (YXX) is not in floodplain and may be able to accommodate diverted demand to a limited extent; however, Highways 1 and 11 are subject to flood so access routes are an issue. The Abbotsford airport may be a key facility for emergency supplies.
- Other airports in the region (Boundary Bay Airport and small regional airports) are unlikely to accommodate more traffic due to size and the fact they too are vulnerable to flood under one or more scenarios.
- Other possible areas for diversion: Victoria, Kelowna and airports in Washington State.

Ports & Ferries

- Port of Vancouver (previously Port Metro Vancouver) is Canada's busiest port and North America's largest port by total tonnage – operating 28 marine cargo terminals, three cruise ship terminals, three Class 1 railroads (CN, CP and BNSF) and a regional short line railroad.
- There are various Port of Vancouver facilities subject to flooding in seven of the 10 sub-regions, under all flood scenarios.
- Port equipment may be vulnerable, such as electrical motors for cranes (a lesson learned from Hurricane Sandy in the US). Elevated cargo containers and bulk products at the port may be less sensitive to flood.
- Access routes to port facilities – both road and rail – are critical, and these would be disrupted and potentially damaged due to flood.
- There is possible risk to fuel transport or fuel storage facilities, which is also a potential source of environmental contamination.
- Port disruptions would have serious economic consequences for business that replies on imports and exports. The 2014 trucker strike disruption, for example, was estimated to cost $126 million a day.
- Some shipments could be diverted to functional facilities, but at increased cost.
- Access to the BC Ferries Tsawwassen terminal would be severed during a coastal flood and the Horseshoe Bay ferry terminal may be subject to flooding. The TransLink Seabus terminals in Vancouver and North Vancouver are at risk of flood under scenarios A and B, and the Barnston Island ferry crossing is vulnerable under all flood scenarios

Railways

- All three Class 1 railways in the Lower Mainland (CN, CP and BNSF) are vulnerable to some flooding under all scenarios, which could prevent rail freight entering or leaving the region, with cascading events for supply chains.
- Rail passenger service is also vulnerable under all scenarios, including the West Coast Express commuter trains.
- For example, under a Fraser River flood today (scenario C), Highway 7 and the CP Rail mainline in Mission could both be flooded, affecting all rail/road transportation on the North Side of the Fraser River.

Critical Regional Routes

- Highways 1, 7 and 11, north and south of the Fraser, are subject to flooding in multiple sections.
- Highway 99, linking the Vancouver area to Squamish and south to the US border, is also vulnerable, under some scenarios.
- Other critical routes subject to flood include Knight Street, Marine Way, Boundary Road, Highway 91A, Brunette Ave, Stewardson Way/Front Street, King George Boulevard, Highway 7B and South Fraser Perimeter Road, along with municipal arterial roads.
- Disruption to road networks could disrupt emergency services to vulnerable people, isolate portions of the workforce and disrupt intra-regional trade.

Rapid Transit

- Public transit across the region will be impacted by flood through disruptions to SkyTrain, West Coast Express and roads used by transit buses, though some buses may be rerouted.
- The SkyTrain Expo, Millennium and Canada lines will be subject to flooding in parts of Vancouver (including Waterfront Station) and the Canada line is vulnerable to flood in Richmond and Sea Island where it is at grade. In addition, many of the electrical controls for elevated sections of SkyTrain are at grade.
- Loss of service in one part of the SkyTrain system will impact overall passenger capacity due to switching and other issues.
- A disruption in transit service will prevent many people from travelling for work, school, health care and recreation.

Water Supply and Waste Treatment

- Drinking water supply for much of the region is not expected to be impacted by flood. Metro Vancouver's water supply is primarily from mountain reservoirs and storage facilities that are outside of floodplain. Water distribution is in floodplain areas but at pressure and less sensitive to disruption. There is potential for scouring of water lines where they cross the Fraser River.
- Public and private wells located within floodplain areas may be vulnerable to contamination if flood waters include contaminants and enter well heads.
- Wastewater treatment facilities are of concern since 10 across the region are vulnerable to flood: five operated by Metro Vancouver and five operated by local governments in the Fraser Valley.
- The Squamish wastewater treatment plant is not subject to coastal flooding, but is vulnerable to local river flood. The Britannia Beach wastewater treatment facility is also vulnerable to coastal flood.
- Floodwater and debris may damage wastewater treatment facilities.
- Pipes may back up and flood the facilities; systems may remain waterlogged and incapacitated long after flood waters have receded.
- Plants also need power, so a loss of power could also result in sewage backups.
- Failure of one or more plants could mean raw sewage flows into the Fraser River or directly to the Strait of George, with associated environmental contamination.

Emergency Services

- Most emergency operations centres for local governments are located within municipal halls, police stations or fire halls. Most are not subject to flood, but four do have some vulnerability under one or more flood scenarios.
- A significant number of emergency service facilities (fire, police and ambulance) are vulnerable to flood in Region 5 (Richmond/Delta) and 10 (Chilliwack/Abbotsford).
- These facilities are important for emergency response and recovery and for protecting public health and safety.

Health Care Providers

- Hospitals in Regions 5 (Delta/Richmond) and 10 (Chilliwack) and a psychiatric hospital in Region 7 (Coquitlam) are subject to flood in two or more scenarios. Existing operations and patients would need to be transferred to other facilities.
- Facilities can be impacted by flood via structural damage, loss of power beyond auxiliary power, loss of road access, loss of essential personnel, loss of supplies, including food and medicine, and contamination of facilities from flood waters.
- Some sensitivity can be reduced by ensuring critical equipment on site is above the predicted flood levels.
- The proposed relocation site for St. Paul's Hospital would be subject to flooding under coastal scenario B. The site can be flood-proofed to elevate facilities, but access roads would be flooded.

Schools

- A large number of schools are subject to flooding under all flood scenarios: 80 (Coastal scenario A), 95 (Coastal scenario B), 116 (Fraser River scenario C) and 120 (Fraser River scenario D).
- A majority are public elementary schools; the remaining are public secondary or private schools.
- A majority of all schools vulnerable to flood are in Region 5 (Richmond/Delta) and Region 10 (primarily Chilliwack, but also Abbotsford). Under scenarios C and D, 88% of all flooded schools are in these regions.

Other Infrastructure Services

- Other infrastructure subject to flood (under one or more scenarios) include four municipal halls (Delta, Richmond, Chilliwack and Squamish), seven municipal works yards, three prisons with over 1,000 inmates and two energy facilities in False Creek and Richmond.
- Other infrastructure merits further research, including community centres, public assembly buildings, assisted living facilities, seniors' homes, daycare centres and supermarkets.

Project 3 | Assessment of Flood Infrastructure, Policies & Practices

Project 3A Status: Lower Mainland Dike Assessment (Complete)
Project 3B Status: Review of Flood Management Policies & Procedures (75% complete)

Project 3A: Lower Mainland Dike Assessment

Project 3A is focused on the effectiveness of flood protection in the Lower Mainland under current and future flood scenarios based on assessment of:

- Flood protection infrastructure (a Lower Mainland dike assessment) and
- Flood management policies and practices.

Background

The BC Lower Mainland has over 500 kilometres of dikes to protect communities against Fraser River and coastal floods. These dikes have been built over decades, to variable standards.

In 2015 the Ministry of Forests, Lands and Natural Resource Operations retained Northwest Hydraulic Consultants Ltd., with assistance from Thurber Engineering Ltd. (Vancouver), to carry out an overview assessment of Lower Mainland dikes. The project was carried out under Phase 1 of the Lower Mainland Flood Management Strategy, with oversight from the Provincial Inspector of Dikes and with support of an Advisory Committee. An assessment was made of 500 km of Lower Mainland dikes, which is about half the length of all dikes in BC. The assessment was aimed at:

- evaluating the level of protection the dikes provide
- identifying major deficiencies, and
- providing a database for flood management authorities to use, update and expand over time.

This was a desktop study that relied on data and other information from the Ministry, from diking authorities and from documents, such as dike crest surveys, inspection reports and engineering assessments. No new field investigations were carried out.

Here is a summary highlights. For details, see the full report from Northwest Hydraulics Consultants: *Lower Mainland Dike Assessment* (dike assessment report).

500 KILOMETRES

of dikes in BC Lower Mainland, protect communities against Fraser River & coastal floods

Table 9: Dike Assessment Criteria

Criteria	Factors
1. Dike Crest Elevation	• Adequacy vis-a-vis flood design level • Adequate freeboard
2. Geometry	• Crest width • Landside slope • Waterside slope
3. Geotechnical Stability – General	• Dike stable for flood conditions • Dike safe to be raised • Minimal potential for seepage and landside heave • Minimal settlement
4. Geotechnical Stability – Seismic	• Meeting provincial guidelines
5. Erosion Protection	• Location of dike/setback • Protection from erosion
6. Vegetation/Animal Control	• Woody vegetation or brush on slopes • Animal burrows or damage
7. Encroachments	• Buildings/ fences encroaching on right of way • Roads/railways affecting dike
8. Appurtenant Structures	• Operational status of any structures (pump stations, flood boxes, culverts) • Buried utilities
9. Administration	• Secured access and rights of way • Operations manuals • Regular inspections • Emergency supplies • Flood response plan

Each of the criteria was scored on a four-point scale: “good (=4)”, “fair (=3)”, “poor (=2)”, and “unacceptable (=1)”.

Dike Assessment Criteria

Each dike in the assessment was evaluated on nine criteria, summarized in Table 9.

How Will our Dikes Hold?

Few Lower Mainland dikes meet current provincial standards, and none fully meet or exceed the standards. With scoring averaged across nine criteria on the four-point scale, the majority of dikes (69%) scored as poor to fair (2-3 points), 18% as unacceptable to poor (1-2 points), and 13% as fair to good (3-4 points).

Table 10: Overall Assessment of Lower Mainland Dikes

Average score of assessed dikes*

Rating	Fair-Good	Poor-Fair	Unacceptable-Poor
Point Rating	3-4 points	2-3 points	1-2 points
% of Assessed Dikes	**13%**	**69%**	**18%**

**Note: Each dike segment was assessed on nine criteria, each scored on a 4-point scale and given equal weight in assessing a final score for that dike.*

Here are some of the reasons the dikes are deficient:

- Research and flood modelling over the past 10 years has resulted in more accurate design flood levels (that is, higher projected water levels than the dikes were originally designed to withstand)
- Structural and geotechnical design criteria (such as wider dike crests and seismic criteria) have become more stringent over time
- Increasing encroachments of buildings, roads, appurtenant structures and buried utilities on and within dikes can interfere with maintenance and, in some cases, potentially create areas of weakness.

Dike Crest Height

The design flood in the Lower Mainland is the greater of either the 1894 Fraser River flood of record (peak flow of 17,000 cubic metres per second at Hope) or a winter coastal storm surge flood event of approximately 1:200 annual exceedance probability.

Fraser River dikes were built to standards developed for the Fraser River flood Control Program in the 1960s and 1970s. Hydraulic modelling between 2006 and 2014 shows that present flood levels would be up to one metre higher in some areas, assuming flood flows are confined by dikes. The Province has accordingly updated standards for the design flood on the Fraser River, which includes a higher dike crest height.

With respect to the crest height of Lower Mainland dikes, only 4% of the 118 dike segments assessed are currently built to a standard sufficient to withstand the design flood (including 0.6 m freeboard). Another 25% of the dikes have 0.3 m of freeboard allowance, and these dikes may or may not withstand the design flood. There are 17% of the dikes with a crest that would match the projected water level of the design flood, and 54% with crests below the projected water level; in both cases, these dikes would be expected to be overtopped.

In general, the Fraser River dikes can withstand only a 1:100 year flood (as measured at Mission) with a few dikes capable of withstanding a 1:200 year flood, but no dikes fully meet the current provincial standard. Some dikes will experience localized overtopping at the 1:20 year flood level.

Lower Mainland sea dikes must have site-specific design criteria based on location and wave exposure. Current design criteria for coastal sea dikes, set in the early 1970s, are now considered too low by most coastal engineering practitioners. The Province has not yet set new standards or required dikes to be raised to address sea level rise. However, sea dike guidelines were published in 2011.

Table 11: Crest Height of Lower Mainland Dikes

Dike Segments Meeting Provincial Standard	Dike Segments Below Provincial Standard		
			
Not expected to be overtopped by major flood	**May or may not be overtopped by major flood**	**Expected to be overtopped by major flood**	
Design flood level + .6 m of freeboard	Design flood level + .3 m of freeboard	Design flood level + no freeboard	Below design flood level
4%	**25%**	**17%**	**54%**

Geotechnical Stability for Flood Conditions

Geotechnical stability for flood conditions could not be assessed on 22% of the dike segments because of insufficient information. The remaining 78% were scored as follows: 10% as “good,” 36% as “fair,” 27% as “poor” and 5% as “unacceptable.”

Table 12: Geotechnical Stability of Lower Mainland Dikes for Flood Conditions

Average score (4-point scale)

Segments Assessed				Segments Not Assessed*
Good	**Fair**	**Poor**	**Unacceptable**	**N/A**
3-4 points	2-3 points	1-2 points	1	N/A
10%	**36%**	**27%**	**5%**	**22%**

**Note: Insufficient Information*

Geotechnical Stability for Earthquake

Seismic ratings were assigned for 71% of the dike segments: 18% almost met seismic guidelines, though none did so over their entire length, and 53% were seismically unstable. No assessment was made on 29% of dike segments because of insufficient information.

Dikes constructed next to sloping ground over Fraser River sediment are of particular concern with respect to seismic stability. The project consultants expect the dikes to be deformed or displaced during a 1-in-2,475 year return period earthquake. Liquefaction of foundation soils is generally the greatest risk for seismically induced displacements. However, the strain softening of fine grain foundation soils can also displace dikes that are overly steep.

The Other Criteria

Dikes can fail for reasons other than insufficient height or geotechnical stability. As noted on page 26, nine different criteria were included in the dike assessment. The scores for each of these criteria related to each of the dike segments are available in the dike assessment report.

Dike Assessment Report

The *Lower Mainland Dike Assessment* report (July 2015) been made is available to all LMFMS partners. Once posted by the Province, the report will also be linked at **floodstrategy.ca**.

The report includes a list of dikes included in the assessment, an overview of provincial standards and guidelines, details on assessment criteria, the geotechnical report and a matrix setting out the scores for all assessed dikes in all communities.

With respect to the crest height of Lower Mainland dikes, only 4% of the 118 dike segments assessed are currently built to a standard sufficient to withstand the design flood

Project 3B | Review of Flood Management Policies and Practices

The Fraser Basin Council, with support from the Adaptation to Climate Change Team (ACT) at Simon Fraser University, is leading Project 3B. The project will be completed by the end of June 2016.

The aim of Project 3B is to summarize and evaluate the effectiveness of current flood protection policies and practices across the Lower Mainland. The project includes analysis of gaps, limitations, challenges and barriers with respect to existing flood management policies and practices, and recommendations on short-, medium- and long-term priorities. The project also explores in a preliminary way the potential transferability of policies and practices across different jurisdictions within the Lower Mainland.

This project evaluates the effectiveness of flood policies and practices in several ways:

- A literature review to help in summarizing the infrastructure, policies and practices used by different local governments
- Interviews with representative local governments to identify a range of current approaches with respect to flood protection infrastructure, policies and practices so as to identify which of those approaches are working well and to flag which need improvement
- A quantitative analysis, piloted in one community, to estimate the value of building permits approved in floodplain areas and to identify what flood construction levels were used.

A History of Settlement and Flood Management in BC

BC is a mountainous region, and early European settlement often occurred in river valleys (i.e., floodplain areas), setting a trend of development that would continue for the centuries that followed. Today, development in the Lower Mainland is generally exposed to some degree of flood hazard, whether it is from coastal flooding, river flooding or flooding from other watercourses.

In August 1966, the Lower Mainland Regional Planning Board's Official Regional Plan (covering the area from Hope to the Georgia Strait) was approved. The plan included a policy that floodplains were to be kept free of urban uses, save where urban development was already present. Further urban development was to include floodproofing measures. Future development on floodplains was to be limited to uses that would not be highly susceptible to flood damage. The Lower Mainland Regional Planning Board was dissolved in 1969 and its planning functions divided among four regional districts.

Some floodplain areas are classified as part of the Agricultural Land Reserve (ALR). Despite development pressures throughout the Lower Mainland over the years, the ALR has prevented widespread development in floodplain areas.

The large Fraser River flood of 1972 and resulting damage in the BC Interior (particularly near Kamloops) was a catalyst for new legislation, policies, and procedures at the provincial level. These initiatives were aimed at controlling development in the floodplain and reducing potential damages. From 1975 to 2003, the province managed development in designated floodplain areas under the Floodplain Development Control Program. The Floodplain Development Control Program fulfilled a key term of the Fraser River Flood Control Program Agreement (1968-1995) between BC and Canada, which committed the Province of BC "to a program of land use zoning and flood proofing to diminish potential losses in the area covered by [the] Agreement."

2003/2004 Legislative Changes and Provincial Guidelines

A major shift in policy occurred in 2003, corresponding with the end of the Floodplain Development Control Program. This policy shift involved a significant change in how the Province of BC participated in land use regulation in flood-prone areas. Since 2003, each local government has had the authority to exercise discretion in developing its own policies for zoning, development permits, subdivision approvals, bylaws and building permits related to flood management. With this shift in 2003, the provincial government published a set of guidelines for municipalities to follow in developing flood bylaws, subdivision approval and associated land use decisions.

The Disaster Financial Assistance (DFA) Agreement states that structures built in an area designated as a floodplain under the *Local Government Act* must be "properly flood protected" to be eligible for assistance. Historically, "properly flood protected" has meant that all habitable areas of homes and buildings are above the design flood profile (i.e., 1894 Fraser River flood of record or 200-year event elsewhere in BC).

The design flood profile used for these purposes (compensation and DFA regulations) did not include an allowance for sea level rise, subsidence or wave effects. Hence, the provincial guidelines are being updated with an amendment to address sea level rise (SLR).

The draft amendment of the guidelines assumes 0.5 m of global sea level rise by 2050, 1.0 m by 2100 and 2.0 m by 2200 relative to the year 2000.

Flood Management in 2016

Responsibility for flood risk management is shared by all levels of government and by the private sector. The federal government's contributions have included providing data and earth science information, sharing infrastructure costs for flood protection improvements, sharing flood response/recovery costs (Disaster Financial Assistance) and addressing issues related to reserves under the *Indian Act*.

The Province of BC creates standards and guidelines and is responsible for processing and reviewing applications under the *Dike Maintenance Act*, contributes to funding programs for flood protection improvements, is the authority on Crown lands, approves subdivisions in rural areas and provides land use and other guidelines.

Local authorities implement land use planning and regulatory tools, and many also own, operate and maintain dikes. The bulk of flood management (e.g., land use planning and zoning and building of flood protection structures) now rests largely with local governments. The challenges posed by sea level rise further increase the importance of intergovernmental collaboration to address current and future coastal hazards.[1]

[1] Arlington report, scan of provincial policies and how they will be adaptable for Climate Change Adaptation

Current Flood Protection Works

Many communities rely on flood protection dikes and associated works such as pumps, floodgates and erosion protection works. As noted in Project 3A (Lower Mainland Dike Assessment), the standards and guidelines associated with dikes in BC have increased in recent years. Many coastal communities, such as Vancouver, West Vancouver and North Vancouver, have had relatively little coastal flooding historically, and dikes were not constructed in these areas. With sea level rise, however, existing developments will be exposed to an increasing coastal flood risk. As well, many First Nations communities, including those in river floodplain areas, are not currently protected by diking systems.

The management of riverbed sediment is considered by some communities as an important tool in the suite of management options. Suggested benefits of riverbed sediment management – or channel maintenance – include maintaining the capacity of the river channel to convey floodwaters, thus avoiding the need to continually raise dikes; "training" the river to remain within, or return to its main channel to relieve erosion pressures from the riverbanks and diking systems; and lowering river levels to alleviate seepage problems. Seepage refers to a situation in which water seeps through or under diking systems, raising water levels on land without a dike being overtopped or otherwise failing.

Current Land Use Planning and Policies

Most communities use land use planning and policies to help limit community vulnerability to flooding. The two primary approaches are flood construction levels and horizontal setbacks. These are typically implemented through bylaws, zoning, development permit areas and other policies and practices.

Growth can be guided away from flood-prone areas, and habitable living space can be built above predicted flood levels with floodproofing practices, such as through the addition of fill to raise the ground elevation or use of structural techniques such as building habitable space above crawlspaces, garages and parkades or other design features. Communities may also use risk tolerance criteria, community-wide flood management strategies, subdivision regulations, geotechnical reports, covenants and neighbourhood/area plans as other means of managing development in floodplains..

Current Challenges

These are some of the challenges identified by local governments during interviews and meetings:

Funding Challenges

- How to fund major repairs and upgrades to flood protection works
- How to fund the technical analysis needed to inform optimal infrastructure design and land use decisions
- How to access funding when there is limited ability to cost-share, especially in small communities and rural areas

Policy Challenges

- How to floodproof in historic settlement areas
- How to establish and implement sea level rise planning areas
- How to establish a consistent policy framework to guide diverse communities across the Lower Mainland
- How to plan and manage for changing flood hazards over time, particularly due to sea level rise and other climate change impacts

Land Use Challenges

- How to secure land or rights-of-way to enable dike improvements, changes to dike alignment, or land use change

Priorities and Suggestions

Here are some of the priorities and suggestions raised by local governments and others during interviews and meetings:

Infrastructure and Projects

- Establish and implement a dedicated, multi-year funding program to support the rehabilitation of flood protection works and associated works, such as pumps and flood gates
- Improve regulatory and permitting processes
- Implement more environmentally sound flood management practices
- Profile case examples to raise awareness and learn from best practices
- Initiate new pilot or demonstration projects to learn in the field

Knowledge

- Improve the knowledge base to better inform flood hazard management decisions (e.g., flood hazard mapping, flood vulnerability and risk information)
- Integrate traditional knowledge and local knowledge with scientific and engineering knowledge

Planning

- Strengthen local and regional scale engagement among First Nations, local governments, senior governments, infrastructure providers, environmental and other non-governmental organizations, other stakeholders and the public to profile flood issues, raise awareness and solicit input on management options
- Evaluate management options in relation to diverse economic, social, environmental and technical criteria
- Update flood construction levels and associated bylaws, development permit areas and other policies in relation to changing flood hazards and best available knowledge
- Reconcile the need for regional consistency with flexibility to accommodate unique local circumstances
- Implement more integrated and comprehensive approaches to flood management planning at both local and regional scales
- Develop a long-term plan to manage sediment-related flood and erosion hazards
- Strengthen emergency planning and preparedness functions in the near-term to increase readiness while flood mitigation infrastructure, policies and practices are being strengthened over the short, medium and long-term
- Strengthen internal processes in all organizations such as inter-departmental coordination and cross-fertilization (e.g., engineering, planning, building, environment and emergency management)
- Strengthen regional collaboration and coordination

Innovations and Opportunities

In addition to improvements to existing flood management infrastructure, policies and practices, there is an opportunity to learn from local innovations within the Lower Mainland and beyond.

A variety of management options, governance approaches and emerging innovations are being applied within the region, across North America and around the globe. Some local and global examples that warrant further consideration for the Lower Mainland include:

- Funding mechanisms such as municipal utilities, gas tax funding, reserve funds and green bonds
- Collaboration such as through:
  - Local and sub-regional inter-jurisdictional committees and MOUs
  - Community-to-Community Forums between local governments and First Nations
  - Peer-to-peer learning
- Alternative structural and non-structural approaches to flood management:
  - Setback dikes and fish-friendly pumps
  - Greenshores and other softer approaches to erosion protection
  - Wetlands preservation and restoration to store floodwaters
  - Foreshore lease and other coastal sediment management approaches such as beach nourishment and barrier islands to reduce coastal flood hazards
  - Room-for-the-river options
- Lessons learned from Alberta and elsewhere.

The primary recommendation of the Project 3B analysis to date is to evaluate the full spectrum of historic, current and potential future flood management options using multiple criteria and in relation to a variety of local circumstances across the Lower Mainland. This will be undertaken in Phase 2 of the Lower Mainland Flood Management Strategy. Some of the criteria proposed for this evaluation include:

- Benefit-cost analysis and other economic analysis
- Effectiveness and technical feasibility
- Social and cultural considerations
- Environmental considerations.

For more about Phase 2, see Next Steps: Action Agenda for Flood Mitigation in the Lower Mainland on page 36.

Other Updates: Engagement and Communications

There are three advisory committees that helped guide Phase 1 projects, thanks to the contributions of staff representatives from partner agencies and organizations. Each of the committees has met four to six times since May 2014 to provide guidance and receive updates.

As part of its communications outreach, the Fraser Basin Council has also provided regular briefings to the Joint Program Committee on Integrated Flood Hazard Management, which brings together flood management professionals from partner agencies and other organizations with interests in flood management. Since 2014, the FBC has delivered community presentations about the Strategy, on request.

Here is a summary:

- Mission Rotary Club
- Mission Regional Chamber of Commerce
- Seabird Island First Nation
- Community-to-Community Forum of Fraser Valley local governments and First Nations
- Lower Mainland Chambers of Commerce
- Sto:lo Business Match
- Lower Mainland Local Government Association – Flood Committee
- BC Real Estate Association Floodplain Mapping Working Group
- Metro Vancouver Regional Engineers Advisory Committee – Climate Protection Subcommittee
- Agriculture sector meetings
- Ministry of Agriculture staff (Abbotsford)
- FVRD and Fraser Valley municipalities (floodplain management workshop)
- Metro Vancouver Regional Planners Advisory Committee
- People of the River Conference
- Lower Mainland Local Government Association AGM
- Metro Vancouver Lunch & Learn
- MEOPAR Marine Hazards Workshop
- Meetings on Flood Management and the Environment
- Local Government Management Association Conference
- Delta Dikes and Drainage Advisory Committee
- Insurance Bureau of Canada
- Livable Cities Forum
- Association of Professional Engineers and Geoscientists Conference
- Regional Emergency Planners Committee
- North Shore Climate Adaptation Working Group
- Salish Sea Ecosystem Conference
- Adaptation Canada Conference

Next Steps: Action Agenda for Flood Mitigation in the Lower Mainland

Here is a plan for developing an **Action Agenda**, proposed by the Fraser Basin Council as Phase 2 (2016-2018) of the Lower Mainland Flood Management Strategy.

Goal

To strengthen flood management infrastructure, policies and practices in the Lower Mainland to increase community resiliency and reduce community vulnerability to regionally significant river and coastal flood hazards.

Deliverable

An Action Agenda that outlines an agreement among partner organizations about flood mitigation priorities for the Lower Mainland, actions that need to be undertaken, associated costs and a cost-sharing model.

Project Components

1. Establish and facilitate a ***Leadership Committee*** to provide senior-level strategic advice and oversight on the Action Agenda.
2. Evaluate and recommend national, provincial, regional and local ***Priorities for Flood Mitigation*** across the Lower Mainland.
3. Evaluate and recommend optimal ***Flood Management Options*** to address the priorities including a diversity of local circumstances across the Lower Mainland.
4. ***Engage Decision-makers, Stakeholders and the Public*** to raise awareness and to inform the Action Agenda
5. Evaluate and recommend one or more ***Funding and Governance Models*** for implementation.
6. ***Confirm Commitments*** for implementation of the Strategy.

Description

1) Establish and facilitate a *Leadership Committee* to provide senior-level strategic advice and oversight on the Action Agenda.

Phase 1 of the Lower Mainland Flood Management Strategy was overseen by the Joint Program Committee (JPC) for Flood Hazard Management, which was established in 1998. The JPC currently includes over 100 members and alternates representing more than 50 organizations across all orders of government, the private sector and civil society. In 2014, three multi-interest Advisory Committees were established to provide advice and guidance on the three priority areas of Phase 1 of the Strategy, including: Flood Scenarios, Flood Vulnerability, and Flood Management.

To develop the Action Agenda, it is recommended that partners in the Strategy establish a Leadership Committee composed of senior officials from key agencies and organizations that have flood management responsibilities and will be involved in implementing the Action Agenda. The roles of the proposed Leadership Committee would include:

- Providing strategic review and feedback on key aspects of the Action Agenda
- Vetting draft recommendations with senior staff and elected officials prior to adoption for the Action Agenda
- Confirming funding commitments to implement the Action Agenda and,
- Other roles and responsibilities as appropriate.

2) Evaluate and recommend national, provincial, regional and local *Priorities for Flood Mitigation* across the Lower Mainland.

The Lower Mainland includes urban and rural communities, First Nations and non-First Nations communities; agricultural lands; and many different types of critical infrastructure that serve communities, the region as a whole, and provincial, national, and international interests. It may not be possible to address flood mitigation for all of these aspects of the region in the short-term. It is therefore vital to identify priorities for capital investment and refinements to policies and practices – both in terms of geographic location and timeline (i.e., short, medium and long-term).

The Regional Flood Vulnerability Assessment and the Lower Mainland Dike Assessment (from Phase 1) provide information to assist in identifying priorities during Phase 2. Additional analysis may include:

- Overlaying maps of dike status with vulnerability to highlight the relative status of diking systems in relation to different degrees of vulnerability
- Evaluating direct damages and indirect losses associated with critical infrastructure (this was beyond the scope of work in Phase 1)
- Consulting with all orders of government, utilities and infrastructure, and the private sector to identify additional priorities and,
- Undertaking additional local and regional analyses as needed.

3) Evaluate and recommend optimal *Flood Management Options* to address the priorities, including a diversity of local circumstances across the Lower Mainland.

Numerous flood management options are available for consideration within the Action Agenda. Traditional, common approaches in the Lower Mainland include flood protection dikes and seawalls, flood gates and pumps, rock riprap, channel maintenance and a range of policies to establish flood construction levels and setbacks for specific land uses and specific flood hazards. These will be examined along with other options such as beach nourishment, barrier islands, greenshores, rolling easements, managed retreat and other emerging policies and practices.

It is important to recognize that there are diverse local circumstances throughout the Lower Mainland, which may require different approaches to flood management. Considerations include:

- Urban and rural community needs
- Coastal and river flood hazard management
- Historic settlements, recent developments, and future growth
- Soil conditions that may impact opportunities for floodproofing or dike improvements
- Available land and rights-of-way to enable dike improvements and/or re-alignment;
- Different jurisdictions, tenures and governance arrangements
- Beach geometry and exposure to wave effects and,
- Many other local and/or site-specific circumstances.

Management options will be evaluated in relation to different local circumstances using several criteria, including, but not limited to the following:

- Effectiveness – How effective is the option at mitigating flood damages?
- Technical Feasibility – Is it feasible to implement the management option or are there technical constraints, such as engineering design, soil conditions, seismic or other geotechnical constraints?
- Cost Estimate – What are the capital costs as well as operations and maintenance costs?
- Benefit:Cost Analysis – What is the ratio of benefits to costs?
- First Nations - What are the interests, suggestions and concerns of First Nations?
- Environment – What are the positive and negative environmental impacts?
- Public and Stakeholder Acceptance – What are the preferences, suggestions or concerns of the public or stakeholder groups?

4) *Engage Decision-makers, Stakeholders and the Public* to raise awareness and to inform the Action Agenda

Engagement and consultation processes will be undertaken in parallel with the technical analyses outlined above. A combination of meetings, workshops, open houses and other opportunities are envisioned to engage with different decision-makers and stakeholders, including:

- Local government staff and elected officials, including municipalities, regional districts, Lower Mainland Local Government Association and Union of BC Municipalities
- First Nations staff and elected officials
- Provincial and federal government agency staff and elected officials
- Utilities and infrastructure providers
- Other stakeholders (e.g., businesses, industry, agriculture, insurance, real estate and non-government organizations) and
- The public.

5) Evaluate and recommend one or more *Funding and Governance Models* to implement the Action Agenda.

Limited availability of funding is a fundamental challenge to flood management in the Lower Mainland. Significant financial resources will be required to implement a wide range of management options to address priorities throughout the region. It is vital to review and evaluate a range of potential funding and governance models, which could effectively implement the Action Agenda.

Analysis will be undertaken on historic and current models, such as the Fraser River Flood Control Program and the more recent BC Flood Protection Program. Different models will also be reviewed from other jurisdictions such as Alberta, Manitoba, Ontario and the US. In addition to different cost-sharing models, it will also be helpful to assess a range of specific funding mechanisms. This component of the project is critical to answer the following questions:

- Who will pay for flood mitigation in the Lower Mainland?
- What funding sources and mechanisms are most appropriate?
- How will investment decisions be made?

6) *Confirm Commitments* for implementation of the Action Agenda.

To ensure implementation of the Action Agenda, the process will seek commitments for the funding and commitments from partners to implement the recommended management options within their respective areas of jurisdiction.

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PARTNERS IN THE STRATEGY

FEDERAL & PROVINCIAL GOVERNMENTS

GOVERNMENT OF CANADA

PROVINCE OF BRITISH COLUMBIA

- BC Ministry of Transportation and Infrastructure (Emergency Management BC)
- BC Ministry of Forests, Lands and Natural Resource Operations
- BC Ministry of Environment

LOCAL GOVERNMENTS

City of Abbotsford
Village of Belcarra
City of Burnaby
Bowen Island Municipality
City of Chilliwack
City of Coquitlam
Corporation of Delta
Fraser Valley Regional District
District of Hope
District of Kent
Township of Langley
Village of Lions Bay
City of Maple Ridge
District of Mission
City of New Westminster
City of North Vancouver
District of North Vancouver
City of Pitt Meadows
City of Port Coquitlam
City of Port Moody
City of Richmond
District of Squamish
City of Surrey
City of Vancouver
Metro Vancouver
District of West Vancouver
City of White Rock

OTHER ENTITIES

BC Agriculture Council
BC Wharf Operators Association
Canadian National Railway
Canadian Pacific Railway
Greater Vancouver Gateway Council
Insurance Bureau of Canada
Kinder Morgan
Pacific Institute for Climate Solutions
Port of Vancouver
Simon Fraser University (ACT)
TransLink
Vancouver International Airport

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