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City of New Westminster
Floodplain Management Strategy Update

Prepared by:

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: (604) 980-6011
www.nhcweb.com

NHC Project Contact:
Monica Mannerström, M.Eng., P.Eng.
Principal

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Corporation of the City of New Westminster
511 Royal Avenue
New Westminster, BC V3L 1H9

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Report prepared by:

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Neil Peters, M.A.Sc., P.Eng.
Senior Flood Management Engineer

Report reviewed by:

4 November 2022

Monica Mannerström, M.Eng., P.Eng.
Principal

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TRADITIONAL ACKNOWLEDGEMENT

We recognize and respect that New Westminster is on the unceded and unsurrendered land of the Halkomelem speaking peoples. We acknowledge that colonialism has made invisible their histories and connections to the land. As a City, we are learning and building relationships with the people whose lands we are on.

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- Brittany Tom, P.Eng. Integrated Storm Water Engineer
- George Otieno, P.Eng. Infrastructure Engineer
- Eugene Wat, P.Eng. Manager of Infrastructure Planning

The following NHC personnel participated in the study:

- Neil Peters, P.Eng. Technical Lead
- Daniel Maldoff, EIT Project Engineer
- Natalia Leon Barrios, P.Eng. Hydraulic Modelling Lead
- Hanna Hamid, Ph.D. Hydraulic Modeller
- Alicia Van Boven, EIT Junior Hydrotechnical Engineer
- Seth Bryant, P.Eng. Risk Analyst
- Shane McConachie GIS
- Monica Mannerström, P.Eng. Project Manager

NHC partnered with Subconsultants on the relevant project components:

- Simon Kras, P.Eng. Senior Engineer, WSP
- Steven Coulter, P.Eng. Geotechnical Engineer, Thurber Engineering Ltd.
- Gary Williams, R.P.Bio President, GL Williams & Associates Ltd.
- John Taylor, P.Eng. CSAP, Core6 Environmental Ltd.

EXECUTIVE SUMMARY

Introduction

The City's Flood Management Strategy (FMS) was developed in 2009-2011 and provided city-wide flood protection maps/drawings and cost estimates intended as a starting point for funding applications, prioritizing flood protection projects, assessing development applications, and identifying land requirements for dikes. An updated Floodplain Management Strategy is needed to address climate change flood risks, new seismic design requirements for dikes and to help regulate ongoing floodplain land development.

The Floodplain Management Strategy Update expands on the scope of the 2011 Feasibility Plan and takes an integrated approach by including non-structural flood risk mitigation measures as well as structural measures such as dike upgrades. The report assesses and incorporates aspects of emergency response planning, land development regulation, stormwater, environmental considerations, dike inspections/operation/maintenance, and public education campaigns.

The City of New Westminster is located on the unceded land of the Halkomelem speaking peoples along the north bank of the Fraser River, and on the eastern end of Lulu Island in the Fraser River delta. The land-use within the 520 hectare (5.2 square kilometre) floodplain consists of commercial, industrial, single and multifamily residential properties. A seven kilometre long dike protects approximately 350 hectares of Queensborough on Lulu Island while the 170 hectares of floodplain lands on the mainland is unprotected.

The Flood Hazard and Climate Change

Fraser River flood levels at New Westminster are impacted by both sea level rise and by potential increases in Fraser River peak flows. Depending on location, the projected Year 2100 dike design levels could be approximately 1.1 to 1.5 m above the current Provincial design profile, which is based on the 1894 flood of record.

While the sea level rise component is relatively well understood (other than timing), potential climate change caused increases to Fraser River floods are very uncertain. Given this uncertainty, and where cost-effective, it is recommended that the dikes be raised to a lower year 2050 design level with allowances in dike design and land acquisition to accommodate a future raise to year 2100 levels.

Risk Analysis

The approach adopted by the Fraser Basin Council's 2021 "Flood Risk Assessment of BC's Lower Mainland" was applied to the City's floodplain areas. This approach is considered by the Fraser Basin Council to be the current best practice approach for the Fraser Basin Area. Based on historical flood probabilities, dike breach assumptions and data used in the Fraser Basin Council study, the expected annual flood damage (to buildings only) was estimated to be approximately four million dollars per year, with Queensborough accounting for about 75% of the damage. For a single flood event scenario, the building damage in Queensborough from a dike breach during recurrence of the 1894 flood was

estimated to be $284 million. Other types of damage, such as to transportation infrastructure, plus indirect damages were not estimated using this methodology.

Structural Mitigation

Conceptual dike designs and cost estimates were developed for Queensborough, Downtown, and the Braid and West Industrial Areas. Because the alignments of the existing Queensborough dike and proposed mainland dikes are located on developed urban lands, there are numerous constraints and limitations to dike design and construction. Where feasible and cost-effective, the designs were to the Year 2050 Design Crest Levels (DCLs) with provisions for future dike raising. In areas with limited space for dikes (i.e. where sheet pile walls are required) designs were prepared to meet the Year 2100 DCL. Seismic ground improvement was assumed except where the dikes were near existing buildings.

All designs have been developed to minimize encroachment into the Fraser River (e.g. dikes to be widened to the land side). Where encroachment into shoreline habitats cannot be avoided, dike upgrades will require specific environmental considerations.

Class D cost estimates to upgrade the existing Queensborough dikes and to construct new dikes for the mainland areas are summarized in the following table. The costs to upgrade the Queensborough dike, without and with seismic ground improvement, are $56 million and $85 million, respectively. Approximately 60% of these costs are for raising a 2 km long section of South Dyke Road. The total City-wide estimated cost for flood protection improvements, including assumed seismic costs, is $154 million.

Item	Queensborough	Downtown (including Poplar Landing Tie-in Dike)	Braid Industrial Area	West Industrial Area	Total
Dike Length (m)	6,490	2,485	2,290	1,360	**12,625**
Construction $M	55.9	20.5	25.9	17.7	**120**
Seismic $M	28.7	2.5	1.2	1.1	**34**
Total $M	84.6	23.0	27.1	18.8	**154**
Cost $M/km (without seismic)	8.6	8.3	11.3	13.0	**9.5**
Cost $M/km (with seismic)	13.0	9.3	11.8	13.9	**12.2**

Building a new dike for the West Industrial area is considered a lower priority than a new dike for the Downtown. Therefore, to prevent backwater flooding along the low-lying railway corridor into the Downtown, a closure dike to high ground (i.e. The Poplar Landing Tie-in Dike) is required. The design and construction of this tie-in dike, costing approximately $2.6 million, should be coordinated with land development at the Poplar Landing site.

A regular dike maintenance and inspection program is critical to dike safety. Section 5 of this report provides recommendations to improve inspections and to complete a new Operation and Maintenance Manual for the Queensborough dike.

Annual Freshet Response Planning

The technical basis for the City's Annual Freshet Response Plan has been updated using the output from the Fraser River model developed for the Fraser Basin Council in 2019. Criteria and guidance are provided for temporary flood protection, dike and foreshore monitoring, and evacuation planning.

Integrated Floodplain Management/Non-Structural Mitigation

The land use planning tools and floodplain development regulations currently employed by the City are based on historical flood information and guidelines. Given that the Queensborough community will continue to depend on the perimeter dike as the primary defense against flood events, the current policies and development permit requirements for Queensborough are appropriate. However, for the mainland, climate change effects are now a critical factor that must be considered in land development regulation.

The key deficiency in the current approach is the lack of detailed floodplain maps and development permit requirements that consider the projected increases in flood levels due to climate change. Support for implementation of new regulations and flood protection improvements could be gained through a flood education campaign.

Economic Analysis and Project Prioritization

The economic analysis completed by WSP Canada shows a business case for flood protection improvements for both Queensborough and Mainland New Westminster. The analysis shows a stronger business case for improvements to Queensborough, indicating that this section should be prioritized for flood protection improvements. The cost-benefit table with allowances for climate change is provided below.

Cost-Benefit Analysis Summary

	QUEENSBOROUGH			MAINLAND		
Level of Protection	**Investment**	**Reduction in Consequence Cost**	**Cost-Benefit**	**Investment**	**Reduction in Consequence Cost**	**Cost-Benefit**
1:100	$44.7 M	$292.5 M	6.54	$33.8 M	$58.1 M	1.72
1:200	$47.0 M	$321.5 M	6.84	$37.8 M	$64.1 M	1.69
1:500	$49.7 M	$342.7 M	6.89	$42.4 M	$67.8 M	1.60
1:1000	$51.7 M	$351.0 M	6.79	$45.7 M	$69.1 M	1.51

Notes: WSP defines "Cost-Benefit Ratio" to be the "Reduction in Total Cost" divided by the "Cost of Upgrades". The Cost-Benefit ratios shown are for the year 2050 climate change scenario.

Queensborough offers a much higher return on investment, with the highest cost-benefit ratio for protection to the 500-year return period event. For the Mainland section, the cost-benefit ratio is highest for protection to the 100-year return period event. However, it may still be practical, for planning purposes, to improve flood protection to the same return period as Queensborough (500-year) to avoid incurring the costs of phased improvements.

Based on the analysis, Queensborough should be prioritized for capital spending on flood protection.

Recommendations

The City's Floodplain Management Strategy is an integrated, multi-faceted approach that includes both structural flood protection improvements and non-structural measures. Effective mitigation of the flood risks requires ongoing efforts by the City along with increased support from senior governments. While climate change effects on future Fraser River floods are uncertain and the effects of sea level rise will occur over time, the current risks from large Fraser River floods are very significant. Implementation of the following recommendations should begin without delay.

1. Prepare floodplain maps for the mainland that incorporate climate change effects. Establish Development Permit Area requirements for the mainland floodplain areas.
2. Develop and implement a public information and flood education campaign to prepare the community for flood emergencies and to build support for flood protection improvements.
3. Monitor evolving climate change science and design criteria, update the Strategy as required and adopt a phased approach (i.e. where cost-effective, build to Year 2050 design levels but with provisions for future dike raising).
4. With support from the City Emergency Management Office, prepare detailed evacuation plans for Queensborough and Downtown Waterfront Areas to ensure public safety and minimize the impacts of disrupted access.
5. To advance the preliminary designs of Queensborough Dike Upgrades and a new dike for the Downtown Waterfront, the City should complete the following work:
    - Conduct a detailed seismic assessment of the dike alignment, including a Seismic Flood Hazard Assessment and confirm seismic design requirements with the Inspector of Dikes.
    - Identify additional Rights of Way (ROW) requirements. Prepare a Dike Lands Plan to facilitate ROW acquisition and to ensure that development approval processes leave adequate room for and facilitate dike construction, operation and maintenance.
    - Assess the potential for Fraser River channel change that could lead to scour and assess the adequacy of the existing riprap bank protection. Improve erosion protection as may be required.
    - Evaluate the cost effectiveness of alternative designs and phasing for upgrading the 2 km section of the Queensborough dike contiguous with South Dyke Road, integrating seismic design. Conduct a public consultation process.
    - Coordinate preliminary design of the Poplar Landing Tie-in dike with the design of the new housing development at 1400 Quayside Drive. Consider proceeding with construction of the Tie-in Dike as a separate project prior to Waterfront Esplanade flood protection improvements.

6. Complete the preparation of an Operation and Maintenance Manual for the Queensborough Dike and make improvements to the dike inspection program.
7. Build on existing partnerships to increase success of senior government funding applications especially through collaboration with the City of Richmond, as it shares responsibility with the City of New Westminster for the Lulu Island perimeter dike.

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ABBREVIATIONS

Acronym / Abbreviation	Definition
AEP	Annual Exceedance Probability
CGVD28	Canadian Geodetic Vertical Datum of 1928
CGVD2013	Canadian Geodetic Vertical Datum of 2013
DCL	Design Crest Level
DFO	Department of Fisheries and Oceans
DPA	Development Permit Area
DEM	Digital Elevation Model
EGBC	Engineers and Geoscientist of British Columbia
FBC	Fraser Basin Council
FCL	Flood Construction Levels
FMS	Floodplain Management Strategy
FRA	Flood Risk Analysis
FREMP	Fraser River Estuary Management Program
IOD	Inspector of Dikes
JPC	Joint Program Committee
LMFRA	Flood Risk Assessment of BC's Lower Mainland
MOF	Ministry of Forests
ROW	Right of Way
OCP	Official Community Plans
QP	Qualified Professional
RGC	Regional Growth Strategies
RFC	River Forecast Centre
WSE	Water Surface Elevation

1 INTRODUCTION

1.1 Background

The City of New Westminster is the oldest incorporated city in the Province of British Columbia and is in the heart of Metro Vancouver on the unceded land of the Halkomelem speaking peoples. Situated on the north bank of the Fraser River and on the eastern end of Lulu Island at the upstream end of the Fraser River delta, New Westminster covers twelve square kilometers of which five square kilometers are designated as floodplain areas (**Figure 1.1**). Within the floodplain, the land-use consists of commercial, industrial, single and multifamily residential properties.

A seven-kilometre-long dike protects approximately 350 hectares of the Queensborough area at the eastern end of Lulu Island while 170 hectares of floodplain lands on the mainland is unprotected. The current city population is approximately 75,000 and is projected to reach over 100,000 in 2040.

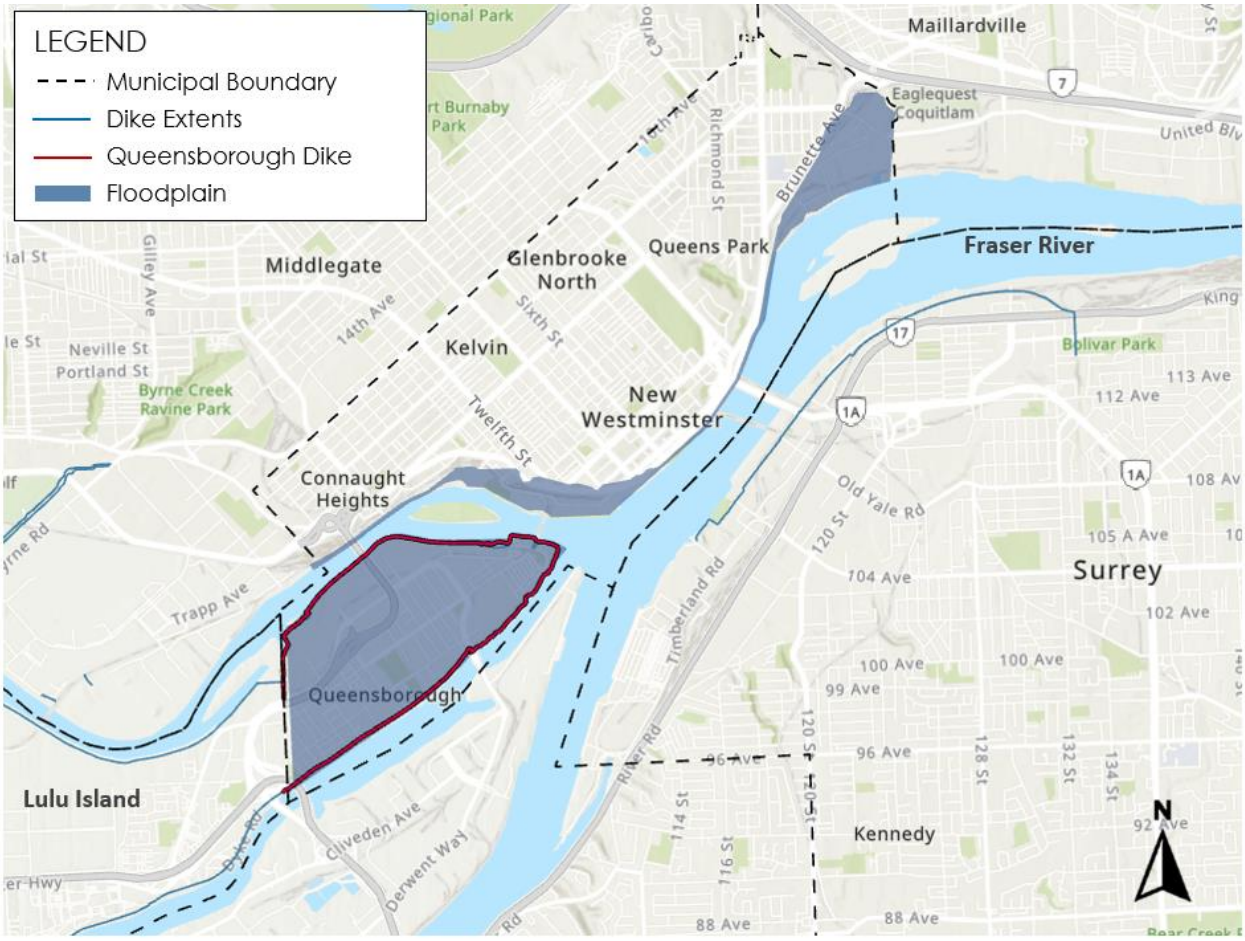


Figure 1.1 **Location Map** [Floodplain Boundary taken from City of New Westminster City Views Map]

The City's Floodplain Management Strategy (FMS) was developed in 2009-2011 and consisted of two phases:

1. The Conceptual Plan (Delcan, 2009) established an appropriate level of flood protection, provided a recommended city-wide approach and prioritized flood protection improvements. This entailed an assessment of risks, constraints, potential routes, and technical options for providing an acceptable level of protection.
2. The Feasibility Plan endorsed by City Council in April 2011 was developed to further establish details of the Floodplain Management Strategy. The Feasibility Plan (Delcan, 2011) provided functional level city-wide flood protection maps/drawings and cost estimates intended for the City to use as a starting point for funding applications; to plan and prioritize future flood protection projects; to assist in assessing flood protection requirements for development permit applications; and to help identify land requirements for flood protection works.

There are three primary reasons why the City needs an updated Floodplain Management Strategy:

1. Over the past decade, significant changes and foreshore land developments have occurred on the mainland and on lands adjacent to the dike in Queensborough;
2. Design flood levels for flood protection have changed significantly to reflect new modelling of climate change effects from both sea level rise and from potential increases in peak Fraser River flows; and
3. Projects to construct new dikes and/or upgrade existing dikes must now address seismic vulnerability and seismic design requirements.

1.2 Scope of Work and Report Outline

This Floodplain Management Strategy Update expands on the scope of the 2011 Feasibility Plan and takes an integrated approach by including non-structural flood risk mitigation measures as well as structural measures (i.e. dike upgrades). For example, the report assesses and incorporates aspects of emergency response planning, land development regulation, stormwater and environmental considerations, dike inspections/operation/maintenance, and public education campaigns.

The project objectives are outlined below and are addressed in the indicated report sections and appendices:

- Review the Fraser River flood hazards and develop flood maps that show inundation depths and extents for various flood magnitudes, dike breach and climate change scenarios (Section 2 and Appendix A)
- Recommend appropriate dike design criteria to address both climate change effects and seismic vulnerability (Section 2 and Appendix B)
- Review flooding consequences and risk in alignment with work being completed by the Fraser Basin Council (FBC) on the regional Lower Mainland Flood Management Strategy (Section 3 and Appendix C)
- Update the dike conceptual designs and cost estimates (Section 4 and Appendix D)

- Review and update the City's dike inspection forms and dike operation and maintenance manuals (Section 5 and Appendix E)
- Update the technical basis for the City's Flood Response Plan (Section 6 and Appendix F)
- Review the City's current floodplain land use planning and development controls and other potentially beneficial non-structural measures (Section 7 and Appendix G)
- Review inland stormwater management considerations (Section 8 and Appendix H)
- Review environmental considerations (Section 8 and Appendices I and J)
- Update cost benefit analysis and prioritization of areas for dike improvements (Section 9 and Appendix K).
- Recommendations are provided in Section 10.

1.3 Aboriginal Rights and Title

The City acknowledges there are multiple First Nations holding Aboriginal Rights to shoreline areas where existing municipal dikes are located and future flood mitigation measure may be planned. The City affirms First Nations' interests to these areas must guide shoreline works along the Fraser River and recognizes that inclusive decision making should be inherent to project outcomes. Therefore, the City commits to meaningful First Nations engagement and consultation prior to the implementation of any flood mitigation works.

2 THE FLOOD HAZARD, CLIMATE CHANGE SCENARIOS AND DIKE DESIGN CRITERIA

The initial parts of this section (subsections 2.1 to 2.5) describe the Fraser River flood hazard, hydraulic modelling, flood scenarios, water level profiles and the development of flood inundation and hazard maps. The latter parts of this section (subsections 2.6 to 2.8) describe hydraulic, geotechnical and other dike design criteria.

Subsection 2.6 presents recommended dike design crest levels for both the Queensborough and Mainland areas. Since the Queensborough dike is contiguous with the City of Richmond dike and protects all of Lulu Island, the New Westminster climate adaptation approach and design criteria are compared to those adopted by Richmond. Subsection 2.7 discusses how the recommended approach for climate change adaptation attempts to address the uncertainties in climate change effects. Subsection 2.8 describes geotechnical, including seismic design and other dike design criteria.

2.1 Fraser River Flood Hazard

The Fraser River watershed drains more than one quarter of the land area of British Columbia extending 1,375 km from the Rocky Mountains north and east of Prince George to the Lower Fraser Valley and Georgia Strait. Approximately 45% of the annual runoff at Mission is contributed by the Upper Fraser

and Nechako sub-basins, about 25% is contributed by the Thompson River sub-basin and the remainder 30% by the lower Fraser and Harrison River sub-basins.

Major floods are caused by rapid snow melt over a large proportion of the watershed, augmented by rainfall. Rainfall has the potential to cause very high flows if snowmelt has already filled the river channel to capacity. The greater the size of the snowpack the greater potential there is for flooding, however, the actual occurrence of a major flood in the Lower Fraser Valley depends on the complex sequence of weather, rates of snowmelt, and the timing of peak flows in each sub-basin.

In addition to Fraser River freshet flooding, high winter ocean levels due to storm surge combined with an "atmospheric river" event can result in moderately high river levels, but given historic climate conditions, this type of event has much less potential for flood impacts on the City than a major freshet flood.

2.2 Hydraulic Modelling

Since the City is in the Fraser River estuary, flood levels are affected by both ocean levels and peak Fraser River flows. Potential flood levels along the foreshore (i.e. flood profiles) corresponding to estimated river flood flows and ocean levels can be determined by hydraulic modelling.

NHC (2006, 2008) developed a 1D hydraulic model and dike design profile for the Fraser River from Hope to the Ocean. Output from the 1D model, simulating a recurrence of the 1894 flood of record plus a freeboard allowance of 0.6 m, was adopted by the Province as the official dike design crest profile. In 2019, NHC developed a 2D hydraulic model for FBC. This model allows simulating dike breaches and subsequent inundation of the floodplain. Permission to use the model for the current work was obtained from FBC. The FBC 2D model was developed to CGVD2013 vertical datum and elevations in this report reference this vertical datum.

2.3 Flood Scenarios

The 2D model developed by NHC (2019) was used to simulate a total of nine freshet flood base scenarios and three breach scenarios (**Table 2.1**). Base scenarios assume that the dikes hold during the flood event, allowing for overtopping of the dikes but not breaching. Base scenarios result in maximum flood depths in the main channel, whereas breach scenarios provide a realistic representation of flood extents and depths inside the Queensborough dike following a breach. **Figure 2.1** shows the two breach locations selected for modelling.

Table 2.1 Flood scenarios

Scenario	AEP	Present-day	2050	2100
Base	2%	●	●	●
	1%	●	●	●
	0.2%	●	●	●
Queensborough Dike North Arm Breach	0.2%	●*	●	
Queensborough Dike Annacis Channel Breach	0.2%	●*		

* The 1894 freshet flood was used for the present-day breach simulations, which has an estimated AEP of just under 0.2%.



Figure 2.1 Queensborough dike breach scenario locations

Approximately downstream of the Alex Fraser Bridge (and Boundary Road in Queensborough), Fraser River design flood levels are governed by winter ocean levels, upstream by freshet floods. However, the shift-point migrates upstream as sea levels rise. A review of previous freshet and winter model simulations shows that climate change winter conditions could be close to climate change freshet conditions, but freshet conditions will likely continue to be more critical in the New Westminster reach.

2.4 Water Level Profiles

Water level profiles were prepared along the Queensborough Dike and the Mainland Areas. The profiles include the base flood scenarios in **Table 2.1**. The 2008 design water levels, with and without freeboard, were also included for comparison. Since the 2008 model is in vertical datum CGVD28, the water levels were transformed to CGVD2013 for consistency with the 2D model results. The 2008 design levels are generally slightly higher than the 2019 modelled water levels (present conditions). This is because the

earlier model assumed that flows would be confined by dikes along the river and the more recent modelling allowed some overtopping.

Queensborough dike crest elevations shown were initially extracted from the digital elevation model (DEM) developed for the 2D model. However, the information was found to include some inaccuracies and a field survey of the dike crest was carried out by NHC on 20 May 2021. The surveyed crest information was incorporated into the hydraulic model and all the model scenarios re-simulated.

The updated profiles are included in Appendix A. The dike stationing was modified to match the Delcan stationing (Delcan, 2011).

2.5 Flood Mapping

Flood Depths

Flood depth maps for the flood scenarios in **Table 2.1** were generated using the model output and are provided in Appendix A. **Table 2.2** describes the depth categories displayed on the flood depth maps.

Table 2.2 Description of flood depth categories (adapted from (MLIT, 2005))

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

Hazard Severity

Flood hazard maps for the flood scenarios in **Table 2.1** were generated based on peak depth and velocity, according to the following formula:

Hazard Rating (HR) = depth x velocity

Hazard rating categories are described in **Table 2.3**. Flood hazard maps are provided in Appendix A. (A debris factor was not included.)

Table 2.3 Description of hazard rating categories

Hazard Rating	Degree of Flood Hazard	Description
≤ 0.75	Low	Caution: Flood zone with shallow flowing water or deep standing water
0.75 to 1.25	Moderate	Danger: Flood zone with deep or fast flowing water
1.25 to 2.0	Significant	Danger: Flood zone with deep fast flowing water
> 2.0	Extreme	Extreme danger: Flood zone with deep fast flowing water

Flood Animations and Velocities

Flood animations and velocity diagrams were output directly from the HEC-RAS 2D model for the following scenarios:

- Base run under present-day 1% AEP (100-year) flood conditions
- Base run under year 2100 0.2% AEP (500-year) flood conditions
- Queensborough Dike North Arm breach under 1894 freshet flood conditions
- Queensborough Dike North Arm breach under year 2050 0.2% AEP (500-year) flood conditions
- Queensborough Annacis Channel breach under 1894 freshet flood conditions

Animations have been provided separately as a digital deliverable in MP4 format. The animations show a plan view of depth values (in metres) across the study area, and throughout the simulations window of two weeks. The timestep used in the animations is 1 hour. A timestamp is included in the upper right corner of the animation. Peak depths are seen on June 1st for the present-day and 1894 simulations, and between June 4th and 5th for the climate change simulations.

Flood velocity diagrams are also included in Appendix A. Flood velocity values are in m/s and correspond to the peak of the flood event.

In summary, a total of nine base scenarios and three breach scenarios were simulated using the 2D hydraulic model developed by NHC (2019) for FBC. Water level profiles, depth maps, hazard maps and velocity diagrams were produced and are provided in Appendix A.

Culverts, highway underpasses and local features were not specifically included in the model. For model limitations please see the report “Hydraulic Modelling and Mapping in BC’s Lower Mainland: A Lower Mainland Flood Management Strategy Project” (NHC, 2019). The results presented in the above sections served as the basis for subsequent phases of the project.

2.6 Design Flood Profiles and Dike Design Crest Levels

The flood level profiles considered for dike design (see **Table 2.4**) include the current provincial dike design flood profile based on the 1894 flood of record, and the Year 2050 and Year 2100 0.2% Annual Exceedance Probability (AEP) flood profiles developed for the Fraser Basin Council (NHC, 2019). Dike design levels, including freeboard, are provided in Table 2.5 and Table 2.6 for several locations along the Queensborough Dike and the Mainland. The 2011 Feasibility Plan design levels and typical dike raise amounts (Queensborough) and dike height (mainland) are also shown.

The Ministry of Forests is currently finalizing the development of a separate 2D model of the Fraser River and updating the dike design profile to incorporate climate change effects. It is presently unclear when the profile will become available and whether the Inspector of Dikes (IOD) will establish the new profile as a minimum standard for major dike upgrades.

Table 2.4 Flood Profiles Considered as a Basis for Dike Design

Item	Flood Profile		
	Current Provincial Design Profile (1894 flood of record)	**FBC 0.2% Year 2050**	**FBC 0.2% Year 2100**
Report Reference	NHC 2008	NHC 2019	NHC 2019
Sea Level Rise (m)	0	0.5	1.0
Peak Flow at Hope (m^3/s)	17,000	19,140	22,935
Annual Exceedance Probability (AEP)	Slightly less than 0.2%	0.2%	0.2%
Model	MIKE11 1D	HEC-RAS 2D	HEC-RAS 2D
Channel Confinement	Confined – all dikes and linear embankments raised to contain flow	Unconfined – existing dikes allowed to overtop into floodplain but not breach	Unconfined – existing dikes allowed to overtop into floodplain but not breach

Table 2.5 Queensborough Flood Levels and Dike Crest Elevations

Item	Location				
	North Arm STA 0+360	North End of Stanley St STA 2+240	U/S End of Lulu Island STA 3+560	South End of Stanley St STA 4+500	Boundary Rd. South STA 7+080
Typical Existing Dike Crest Elevation (from 2021 survey)	3.8	3.9	4.2	4.2	4.0
Current Provincial Design Crest Level (DCL)	3.9	4.1	4.4	4.3	4.1
Feasibility Plan DCL (Delcan 2011)	4.2	4.4	4.7	4.5	4.4
FBC 0.2% Year 2050 DCL (including 0.6 m freeboard and 0.1 m subsidence allowance)	4.5	4.8	5.0	4.8	4.5
Typical Dike Raise for Year 2050	0.7	0.9	0.8	0.6	0.5
FBC 0.2% Year 2100 DCL (including 0.6 m freeboard and 0.2 m subsidence allowance)	5.2	5.4	5.9	5.6	5.2
Typical Dike Raise for Year 2100	1.4	1.5	1.7	1.4	1.2
City of Richmond DCL					5.1

Notes: All elevations to CGVD2013. Stationing as per Delcan 2011. Existing dike elevations and dike raise heights vary. Current provincial DCL is from MFLNRO Dike Inventory Map revised October, 2009 converted to CGVD2013. Elevations have been rounded off to nearest 0.1 m and are intended for conceptual, but not detailed design.

Table 2.6 Mainland Flood Levels and Dike Crest Elevations

Item	Location						
	21st St. STA 0+600	Rialto Court (Poplar Landing) STA 2+160	Reliance Court STA 2+880	Inn at Westm. Quay STA 3+440	Sixth St. STA 4+040	Brunette River Mouth STA 6+400	United Blvd at Braid St. STA 8+280
Typical Existing Foreshore Elevation (from Delcan 2011 and Lidar)	3.6	3.6	3.6	3.5	3.5	3.6	4.0
Current Provincial Design Crest Level (DCL)	3.9	4.2	4.4	4.5	4.6	4.9	5.0
Feasibility Plan DCL (Delcan 2011)	4.2	4.5	4.6	4.8	4.9	5.2	5.3
FBC 0.2% Year 2050 DCL (including 0.6 m freeboard)	4.6	4.7	4.8	4.8	4.8	5.2	5.3
Typical Dike Height for Year 2050 Design	1.0	1.1	1.2	1.3	1.3	1.6	1.3
FBC 0.2% Year 2100 DCL (including 0.6 m freeboard)	5.3	5.4	5.5	5.6	5.6	6.1	6.1
Typical Dike Height for Year 2100 Design	1.7	1.8	1.9	2.1	2.1	2.5	2.1
City of Burnaby DCL at STA 0+000	N/A						
City of Coquitlam Year 2100 DCL							6.0

Notes: All elevations to CGVD2013. Stationing as per Delcan 2011. Foreshore elevations vary and therefore dike heights may not be representative. Current provincial DCL is from MFLNRO Dike Inventory Map revised October, 2009 converted to CGVD2013. Elevations have been rounded off to nearest 0.1 m and are intended for conceptual, but not detailed design.

2.6.1 Climate Adaptation Approach and Dike Crest Elevations Proposed by City of Richmond

The City of Richmond Dikes are contiguous with the Queensborough Dikes at Boundary Road and these dikes form one perimeter dike for Lulu Island. Conceptual designs for upgrading Richmond's dikes along the south side of Lulu Island (Richmond Dike Master Plan – Phase 3) and along the north side of Lulu Island (Richmond Dike Master Plan – Phase 4) were published in February 2019 and May 2021, respectively.

The minimum dike crest elevations for the Richmond south dike are provided in Figure 2.2, taken from Richmond's Phase 3 report. The proposed Richmond dike level at Boundary Road of 5.0 m CGVD28 (5.1 m CGVD2013) is similar to the level of 5.2 m CGVD2013 in Table 2.5 (FBC 0.2% Year 2100 level for Boundary Road South STA 7+080). The difference of 0.1 m in levels at Boundary Road is due to the difference between the FBC 0.2% Year 2100 flood profile and the MFLNRO 2014 profile used by Richmond and to the rounding-off of the datum conversion.

Table 3-4: Flood Levels and Dike Crest Elevations

Item	Downstream of Nelson Road (flat profile)	Upstream of Nelson Road (sloped profile)		
		Nelson Road	Boundary Road (Border with City of New Westminster)	Eastern Tip of Lulu Island
Governing Flood Hazard	tide + storm surge (with historic winter Fraser River flow)	Fraser River freshet		
Level of Performance	500-year return period (0.2% annual exceedance probability)			
Climate Change Allowance	1 m sea level rise	1 m sea level rise and 20% freshet flow increase		
Design Flood Level (m, CGD28)[a]	3.8		4.2	4.6
Wind/Wave Effects Allowance	None			
Freeboard (m)	0.6			
Land Subsidence Allowance (m)	0.2			
Minimum Dike Crest Elevation (m, CGVD28)[b]	4.7[c]		5.0	5.4

Notes:

a) From (BC MFLNRO, 2014).

b) The City's adopted downstream design crest elevation (4.7 m) exceeds the minimum required elevation (4.6 m). This is a result of updated coastal water level analysis methods (joint probability analysis) that result in a discrepancy when compared to previous methods (additive method).

c) Dikes may need to be overbuilt to achieve target crest elevation following post-construction settlement. This should be addressed by an additional site-specific crest elevation allowance to be determined during detailed design.

The master plan also allows for further upgrading by providing proof of concept for dike raising to between 5.5 m downstream of Nelson Road and 6.0 m at the boundary with the City of New Westminster.

Figure 2.2 City of Richmond Proposed Flood Levels and Dike Crest Elevations for the South Side of Lulu Island (City of Richmond, 2019)

The City of Richmond dikes at Boundary Road have not yet been raised and existing crest elevations are similar to the City of New Westminster's dikes. Because both communities rely on each other's sections of the perimeter dike, it will be important to coordinate construction phasing to ensure that a consistent level of protection is provided. The two cities' design approach may differ because dike design levels for Queensborough upstream of Boundary Road are much more sensitive to the magnitude of Fraser River peak flows than to sea level rise and storm surge, which are the major factors in determining dike design levels downstream of Boundary Road.

2.7 Proposed Climate Change Adaptation Approach for Dike Design

There are significant uncertainties associated with the 0.2% AEP flood profiles for the Year 2050, Year 2100 and beyond. The science of sea level rise is well documented, and the projected amounts will undoubtably occur, but the rate of rise (i.e. timing) remains uncertain. The effects of climate change on Fraser River peak flows are even more difficult to model and predict, but recent studies indicate that peak flow increases in the range of 15 to 40% may be possible. One study has also suggested that the Fraser River Basin may transition from one where peak flow results from spring snowmelt to one where peak flow is often caused by fall/ winter extreme rainfall events, caused by the phenomenon of "atmospheric rivers" (Curry et al., 2019). This could lead to coinciding ocean storm surge and peak flow events, both associated with low pressure systems, further exacerbating flood levels in the lower river.

Given this large uncertainty and the significant costs involved in construction of flood protection works to the Year 2100 DCLs in the above tables, a phased approach to construction may be appropriate, particularly for the earthen dike sections (i.e. initially upgrade to the Year 2050 profile). However, the designs, land acquisition and development planning need to provide the flexibility for raising of the flood protection works to future higher levels, if required. For sections of dike comprised of structural flood walls (e.g. sheet piling and/or concrete walls) where the geometry of adjacent development has limited flexibility to accommodate future dike raising, site specific designs would be required. Although costly, demountable flood protection systems may be an effective solution in some of these areas.

As dikes are only as good as their weakest section, it is important to ensure that the entire dike can be raised and upgraded to a consistent standard at the same time. This is particularly significant for Queensborough where a breach at almost any point in the perimeter dike can impact much of the community.

The Floodplain Management Strategy Update must consider the large uncertainty in the magnitude of future Fraser River design flows and the sensitivity of the flood levels to these flows. The above approach proposes that the Year 2050 0.2% AEP design crest levels be used as the basis for conceptual designs and cost estimates, but with provisions for future higher levels, if and when required.

Raising of the dike sections comprised of floodwalls presents significant challenges. These floodwall dikes may form an integral part of valuable public amenities and/or river front structures, and it may be very difficult to change the shoreline geometry in future. In these areas, flood walls could be initially constructed to higher levels (i.e. the Year 2100 DCLs) or the sub-structure designed to allow future raising by demountable systems. This Floodplain Management Strategy Update project can only provide

general concepts and rough costs; detailed site-specific evaluation of design options and costs will be needed on a reach by reach, and in some areas, on a property by property basis.

A 0.2% AEP flood standard has been proposed as it is consistent with the Province's long standing use of the 1894 flood of record as the design standard for Fraser River Dikes. The results from the risk assessment indicate that upgrading the dikes to the 0.2% AEP is appropriate as a minimum standard.

Over the next few decades, scientific and modelling advances may result in a better understanding of the potential effects of climate change on Fraser River peak flows and flood profiles. The need for further dike raising should be re-assessed in the next 10 to 15 years, or when there is significantly greater confidence in updated flood profiles.

With respect to rising sea levels, flood management planning should also consider very long-term increases. The MFLNRORD "Flood Hazard Area Land Use Management Guidelines Amendment (2018) recommends using an estimate of 2 m sea level rise by the Year 2200 (relative to the Year 2000). For New Westminster, a further 1 m of sea level rise would result in flood profile increases (i.e. above the Year 2100 flood profiles) of about 0.7 m at the downstream boundaries of New Westminster diminishing to about 0.4 m near the Coquitlam boundary, where sea level rise has less effect (MFLNRO, 2014).

These sea level rise effects on the flood profile are highly uncertain both in timing and amount, however they may still be useful to guide long term planning of major new community development. The provincial Guidelines recommend "Land use adaptation strategies as set out in Official Community Plans and Regional Growth Strategies should allow for sea level rise to the year 2200 and beyond."

2.8 Geotechnical and Other Design Criteria

Other key dike design criteria are summarized Table 2.7. These criteria are similar to those applied by the 2011 Feasibility Plan (Delcan, 2011) except that an allowance for long term regional subsidence of the Fraser Delta has been applied for the Queensborough Dike. The freeboard allowance, crest width, side slopes, and rights of way allowances are consistent with the Dike Design and Construction Guide (MWLAP, 2003).

Much of the mainland shoreline and approximately 50% of the Queensborough dike is protected from river erosion, scour and waves by rock riprap revetments. To minimize impacts on fish habitat, existing dikes would be raised and widened to the land side. For the purposes of conceptual design and cost estimates, the extent of erosion and bank protection work has been limited to extension of existing slope protection to the top of the dike.

Considering the channel changes taking place in the Lower Fraser River over time such as a general lowering of the riverbed in some areas and localized scour near bridge structures and pipe crossings, it is recommended that the status of rock riprap protecting the City's dikes and shorelines be investigated. This would involve review of available as-constructed drawings, past bathymetric surveys, and some additional surveying, possibly using side sonar, to identify undermined or vulnerable riprap. An inspection at low tide to assess the condition of the visible riprap should also be carried out to identify areas of slumping rock and/or active erosion. Further recommendations with respect to annual dike inspections are included in Section 5.

Table 2.7 Dike Design Criteria (Earthen Embankments)

Item	Criteria	Comments
Freeboard	Minimum of 0.6 m	Standard provincial freeboard (no additional wave allowance).
Long Term Regional Subsidence of Fraser Delta (allowance)	0.1 m by Year 2050 and 0.2 m by Year 2100	Applies to Queensborough only. References: Mazzotti et al., 2009 and Ertolahti, 2014.
Overbuilding for Short Term Settlement	Varies depending on soil conditions and height of dike raise	See geotechnical report in Appendix B
Crest Width	Minimum of 4 m	
Side Slopes	3H:1V vegetated slopes 2H:1V with riprap revetment on water side	During detailed design, land side slopes may be increased where special seepage control measures have been incorporated into the design.
Rights of Way Allowances	7.5 m from each dike toe.	As recommended by Inspector of Dikes. Actual ROW may vary due to site specific constraints.
Dike Foreshore Setbacks	As per existing alignment	
Seismic Design	Varies	See discussion below and Appendix B

With reference to the design levels in Table 2.5 and Table 2.6, the dike design approach is proposed as follows:

- Earthen Dikes
  - Use the Year 2050 0.2% AEP design levels and criteria in Table 2.7 to develop conceptual designs, cost estimates and ROW acquisition requirements (i.e. a typical raise of 0.6 to 0.9 m in Queensborough).
  - Design the dike so it can be raised to the Year 2100 design 0.2% AEP levels in a cost-effective manner (e.g. design is “flexible”).
  - Check that sufficient ROW is acquired to meet Year 2100 design without major constraints.
- Floodwalls
  - For concrete floodwalls, use the Year 2050 0.2% AEP design levels to develop conceptual designs, cost estimates and ROW acquisition requirements. Design the structures with provisions for future permanent raising, or for future raising with demountable flood protection systems to the Year 2100 design levels.
  - For sheetpile floodwalls, where shoreline constraints would prohibit future changes in geometry, and where phasing is not cost-effective, the sheetpile floodwall/shoreline should be designed/costed to the Year 2100 levels.

2.8.1 Seismic Design

For the past several years, the BC Ministry of Forests' Inspector of Dikes has required that major upgrades to high consequence dikes comply with the "Seismic Design Guidelines for Dikes, 2nd Edition" (Golder, 2014). The City of New Westminster Queensborough Dike (Dike No. 140) has been classified by the Province as a high consequence dike, and therefore it is assumed that seismic design requirements would need to be met. Given the provincial dike consequence classification methodology and criteria, it is likely that new dikes constructed on the mainland would be considered high consequence and would also require seismic assessment and design.

The 2014 Ministry Guidelines utilize a performance-based design framework which specifies maximum allowable displacements of the dike crest under different levels of ground shaking. The intent of these requirements is focused on preserving the structural integrity of the dike body. Given the occurrence of a significant earthquake event, seismic design is intended to reduce the extent of damage to the dikes, the costs of repair and to minimize the risk of flooding during the period after the earthquake and before repairs can be completed.

In October 2021, Engineers and Geoscientists of British Columbia (EGBC) published new Professional Practice Guidelines "Seismic Assessment and Seismic Design of Dikes in British Columbia" (EGBC, 2021) with the support of Emergency Management BC, the Ministry of Forests, and the Fraser Basin Council. The 2021 EGBC Guidelines are intended as a supplement to the earlier Ministry Guidelines and introduce a probabilistic-based design approach. However, the probabilistic-based design approach involves the completion of a "Seismic Flood Hazard Assessment" and may only be used after completion of a performance-based assessment and with the approval from the Inspector of Dikes.

Based on review of surficial geology mapping, available geotechnical reports and regional experience, Thurber Engineering anticipates that the dikes included in the scope of this study are typically underlain by sand with a high susceptibility to liquefaction (Appendix B). Golder Associates (2021) recently prepared "dike seismic vulnerability maps" as part of a regional study for the Fraser Basin Council. These maps classify the Queensborough dikes as category 3 (vulnerable to severe damage) and category 4 (vulnerable to extreme damage) for earthquake events with a magnitude equal to a 1:475 event or larger. From these results, it is inferred that the City's dikes would generally not meet the performance-based displacement criteria as specified in the 2014 Ministry Guidelines, without ground improvement.

Although regional information indicates that much of the Queensborough dike and the mainland shorelines are susceptible to earthquake damage, site specific assessments are needed. For example, the geotechnical assessment for the new Boundary Road pump station on Annacis Channel (GeoPacific Consultants Ltd., 2018) determined that the site was underlain by a thick non-liquefiable layer of soft to firm silty clay extending to approximately 16 m below existing grades. No specific seismic design considerations were recommended. However, at the Anthem Properties site on the North Arm (at Furness Street just downstream of the railway bridge), while some layers of silty clay are present, the geotechnical investigation and seismic assessment predicted extensive liquefaction in sandy soils within the top 20 m for the 1:2475 event (Advisian, 2019). Therefore, to comply with the Ministry Guidelines, the seismic design of the new dike section at this site incorporated ground improvement with stone columns.

A detailed seismic assessment and input from the Inspector of Dikes is needed to estimate the scope of work and costs related to seismic design for dike upgrades and new dike construction. For the purposes of the conceptual design and cost estimates as presented in Section 4 the following approach and assumptions were made:

- For earthen dike upgrades, ground improvement (using stone columns as described in Appendix B) was assumed to be required for the full length of dike, except where:
  - the dike is in close proximity to existing buildings and ground improvement may not be feasible;
  - construction of a superdike (i.e. an over width dike) may be an acceptable alternative to ground improvement; and
  - relatively high ground is present landward of the dike and the probabilistic-based design approach determines that the seismic flood hazard is low (e.g. this assumption was applied to much of the dike adjacent to Port Royal at the eastern end of Lulu Island).
- For floodwall dike sections (both concrete and sheetpile floodwalls) seismic design was generally assumed to be infeasible due to the close proximity to existing buildings and/or application of the probabilistic-based design approach (e.g. this assumption was applied to the sheetpile floodwall adjacent to and supporting the Waterfront Esplanade).

3 RISK ANALYSIS

This section summarizes the Flood Risk Analysis (FRA) undertaken to quantify the current or 'baseline' flood risk for the City of New Westminster (the City) through flood risk modelling. The baseline flood risk estimate achieved by this work provides the City information with which to rank their flood risk management investments (against other priorities), along with information required to support future senior government funding applications.

Flood risk modelling is a process to quantify the consequences of flooding and their probabilities. A hallmark of such risk modelling is the integration of a wide-range of event consequences and their probabilities (e.g., 1:10-year, 1:30-year, 1:50-year). This supports decision makers in planning for a more realistic range of flood threats, rather than basing decisions around a single design event which happens very rarely or could potentially be exceeded.

The City is an urbanized municipality, partially within the delta and floodplain of the Fraser River. The fluvial flood prone region of the City is commonly divided into the four zones shown in **Figure 3.1** with the three zones on the North-Bank ('WestIndustrial', 'Downtown', 'BraidIndustrial') separated by the Fraser North Arm from Queensborough.

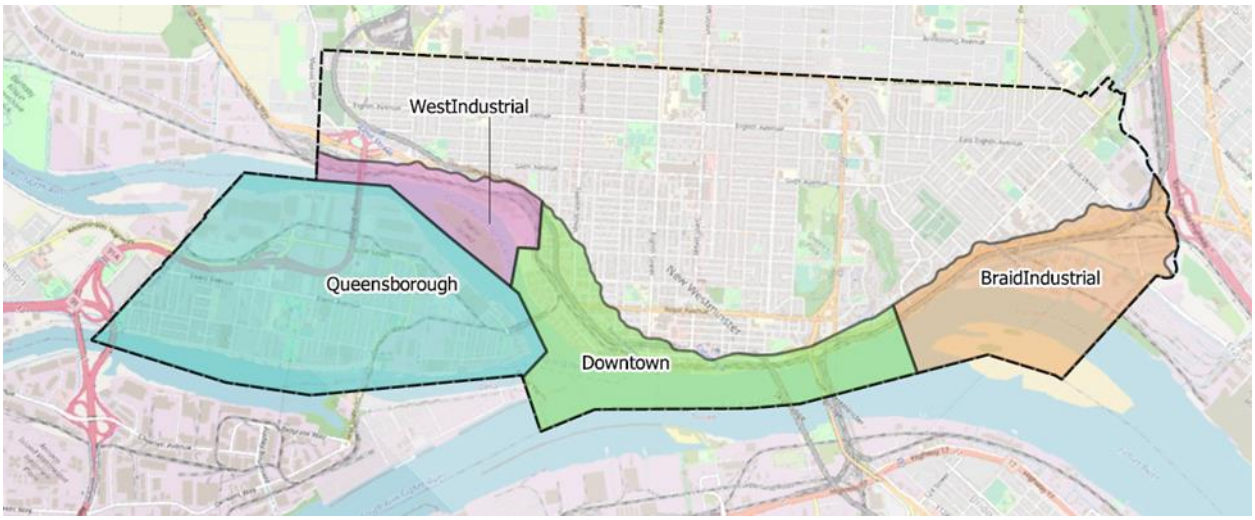


Figure 3.1 Study area risk assessment zones.

3.1 Approach

This FRA adopted the approach and data of the Fraser Basin Council's recent Flood Risk Assessment of BC's Lower Mainland (LMFRA) (IBI Group, 2020) along with many of the recommended refinements (for local applications). To construct their suite of risk models, the LMFRA collected extensive asset data from local and regional sources like BC Assessment, Natural Resources Canada, Integrated Cadastral Information Society, and the Province of BC. Following this, data analysis techniques, including machine learning and crowd-source image processing, were used to prepare asset inventories for risk modelling. By leveraging the data and models of the LMFRA, the FRA described here was able to estimate the baseline flood risk using locally calibrated models[1].

This refinement of the LMFRA risk model suite and application to the FRA of the City undertook the following steps:

1. Acquiring model data from the Fraser Basin Council and clipping it to the study area.
2. Collecting, combining, and compiling water surface elevation (WSE) information from updated hydraulic modelling representing the flood hazards facing the study area and their associated probabilities.
3. Spot-checking and refining the LMFRA models to improve accuracy at the local scale.
4. Generating dike failure information using the fragility functions of the LMFRA.
5. Performing a sensitivity analysis on key parameters to study uncertainty.
6. Executing the refined flood risk modelling suite and generating risk maps and figures divided into the zones shown in **Figure 3.1**.

[1] Many quantitative flood risk models rely on data and models calibrated to U.S. or European buildings.

3.2 Results

Results from the refined LMFRA risk model suite executed using the updated WSE information are summarized in **Table 3.1** and the 'Baseline - EAD' map in Appendix B. Rather than the impacts that could be expected during a particular flood, these annualized consequences reflect the threat facing the City, on average, per-year under the current conditions. Such average values are generally more useful for decision makers as they incorporate the probability or 'risk' of flooding, rather than focusing on a single design flood event that may very rarely occur or could potentially be exceeded.

Table 3.1 Baseline flood risk estimate for tangible direct damages.

Type	Consequence ($CAD/year)				
	Zone (Figure 3.1)				TOTAL
	Queensb.	WestInd.	Downtown	BraidInd.	
Multi-family Dwellings	3,000	-	1,000	-	4,000
Non-Residential Properties	831,000	138,000	4,000	23,000	996,000
Single-family Dwellings	3,147,000	-	-	-	3,147,000
TOTAL ($CAD/year)					**4,147,000**

Figure 3.2 displays these same results[2] , but shows the impacts estimated for the full range of events considered (1:10 to 1:1000 annual exceedance probability, AEP). This figure reflects that high-probability 'nuisance' floods cause less damage than low-probability 'extreme' floods; however, the higher frequency of nuisance floods increases their importance to the overall flood risk.

[2] The area under each curve is equivalent to the annualized '$CAD/year' consequence totals shown in Table 3.1

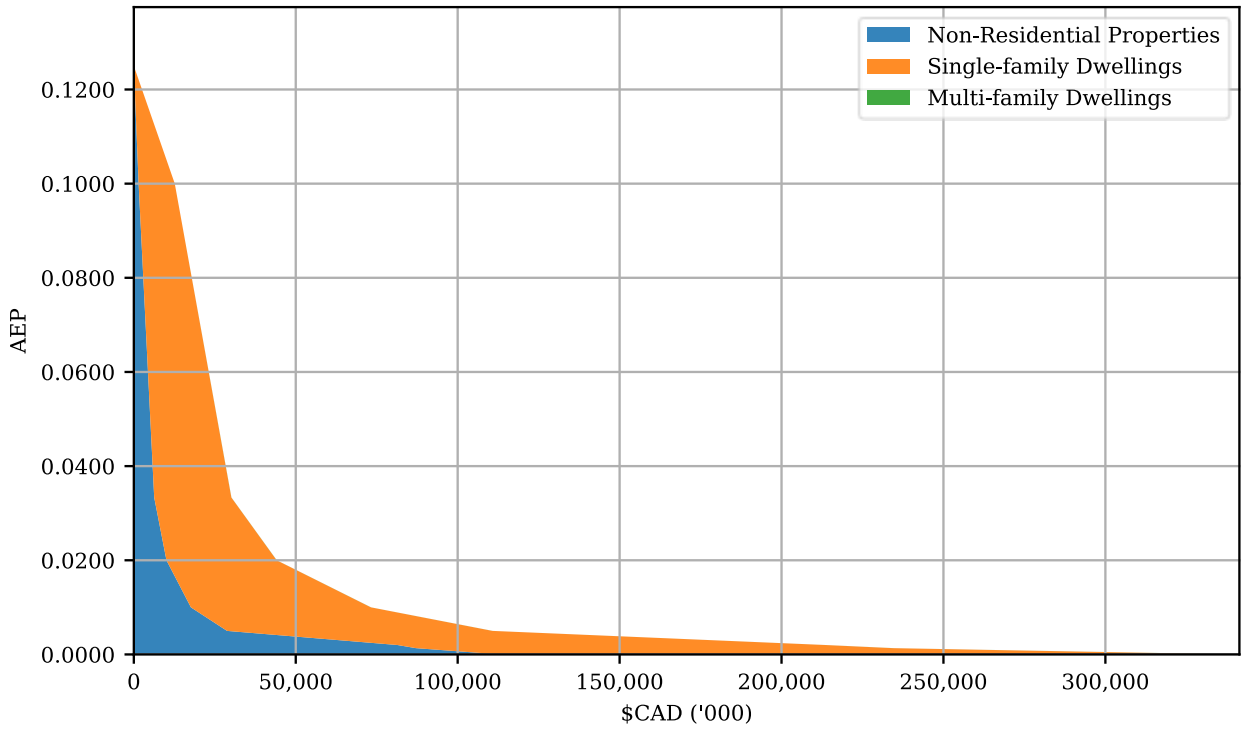


Figure 3.2 Baseline flood risk curve for tangible direct damages from all zones.

These results show the predominant flood risks facing the three North-Bank zones arise from exposure of non-residential properties. While these zones also contain extensive multi-family dwellings, the information available suggests these assets are sufficiently elevated to avoid even extreme floods under current conditions[3].

For the Queensborough zone, flood risks mostly arise from the exposure of single-family dwellings during a difficult to predict dike breach or breaches. To incorporate such breach mechanics in this FRA, the methods and assumptions of the LMFRA were adopted; however, this simplified approach is associated with a high degree of uncertainty. The geotechnical report in Appendix B includes a brief overview and discussion of the dike fragility curves utilized in the LMFRA.

The risks in all zones are expected to increase with climate change, as shown on the 'Baseline - 2050CC 500yr Poplar Breach' map in Appendix C.

3.3 Conclusion

The results presented above provide an estimate of the tangible flood risk facing the City, absent intervention or significant dynamics (e.g., climate change, new development). Like all model results,

[3] Basement parkades are prevalent for these structures, but not included in the risk modelling as these are generally required to be flood proofed.

these values are uncertain and should be used with caution (see Appendix C for a discussion of limitations and sensitivity analysis). This 'quantitative' exercise does not capture all flood risks facing the City, focusing only on more tangible and direct consequences of potential flooding. Because of limited data and resources, this FRA simplifies many significant mechanisms influencing flood risk in the study area (e.g., dike breach probabilities) and therefore the results should be taken together with other qualitative work when evaluating the level of risk and potential interventions.

Recognizing these limitations, this FRA demonstrates the significant flood risk facing the City and supports decisions to strengthen resilience and improve flood protection. In particular, the consequence ($CAD/year) values shown in **Table 3.1** provide the basis for future cost-benefit-analysis of mitigation measures. For a more detailed discussion of the background, methods, and results of this FRA, see Appendix C. A section on potential future refinements is also included.

4 CONCEPTUAL DIKE DESIGNS AND COST ESTIMATES

4.1 Introduction

Updating the 2011 Feasibility Plan conceptual dike designs and costs estimates is a key objective of this project. Using the dike design crest levels and other criteria as outlined in Section 2, WSP Canada Inc. prepared the "Conceptual Dike Designs and Cost Estimates" report and drawings in Appendix D.

Because the alignments of the existing Queensborough dike and proposed mainland dikes are located on and/or adjacent to developed urban lands, there are numerous constraints and limitations to dike design and construction. Considering each dike segment, the WSP report in Appendix D provides a description of flood protection options, design constraints, and the rationale for the selected design.

Section 4.2 below provides an overview of the dike upgrade designs for Queensborough and the Downtown, the two highest priority areas as identified in the 2011 Feasibility Plan, and discusses key issues to address. The conceptual designs for the West Industrial and Braid Industrial areas are presented in Appendix D. Section 4.3 summarizes the costs for all areas, and Section 4.4 outlines the required next steps for implementation.

4.2 Overview of Dike Upgrade Designs, Constraints and Alternatives

4.2.1 Queensborough

The existing 7 km long Queensborough dike is an earthen dike located along the top of the riverbank, with about half of the dike's riverside slope being armoured with rock riprap, and with a 2 km long section of the dike along Annacis Channel being contiguous with South Dyke Road. There are only two sections of concrete floodwall, an 80 m long, sheetpile supported section in the industrial area on the North Arm near the Richmond border, and a 360 m long section in front of a multifamily residential development just downstream of the railway bridge on the North Arm. Further descriptions of the existing dike are provided in Section 5.2.

As noted in Section 2 the typical dike raise heights are 0.5 m to 0.9 m to the Year 2050 design crest levels and 1.2 m to 1.7 m to the Year 2100 design crest levels. For earthen dikes with standard 3H:1V sideslopes, a raise of 0.7 m would increase the width of the dike by 4.2 m and a raise of 1.5 m would increase the total width by 9 m, not including some further width that may be required for upgraded bank protection. Given the location of existing buildings and intensity of land use adjacent to the dike, acquiring sufficient rights of way to accommodate the wider and higher dikes will be challenging, and in some areas, new floodwalls (and raising of the two existing floodwalls) are required to minimize impacts on the adjacent developments.

An overview plan of the proposed dike upgrades with stationing is shown in **Figure 4.1**. For more detail, the location of the dike alignments superimposed on orthophoto imagery and typical sections are shown on the drawings included in Appendix D. The proposed upgrades are summarized for each dike segment in **Table 4.1**. For reference, **Table 4.1** also includes the dike improvements proposed in the 2011 Feasibility Plan.

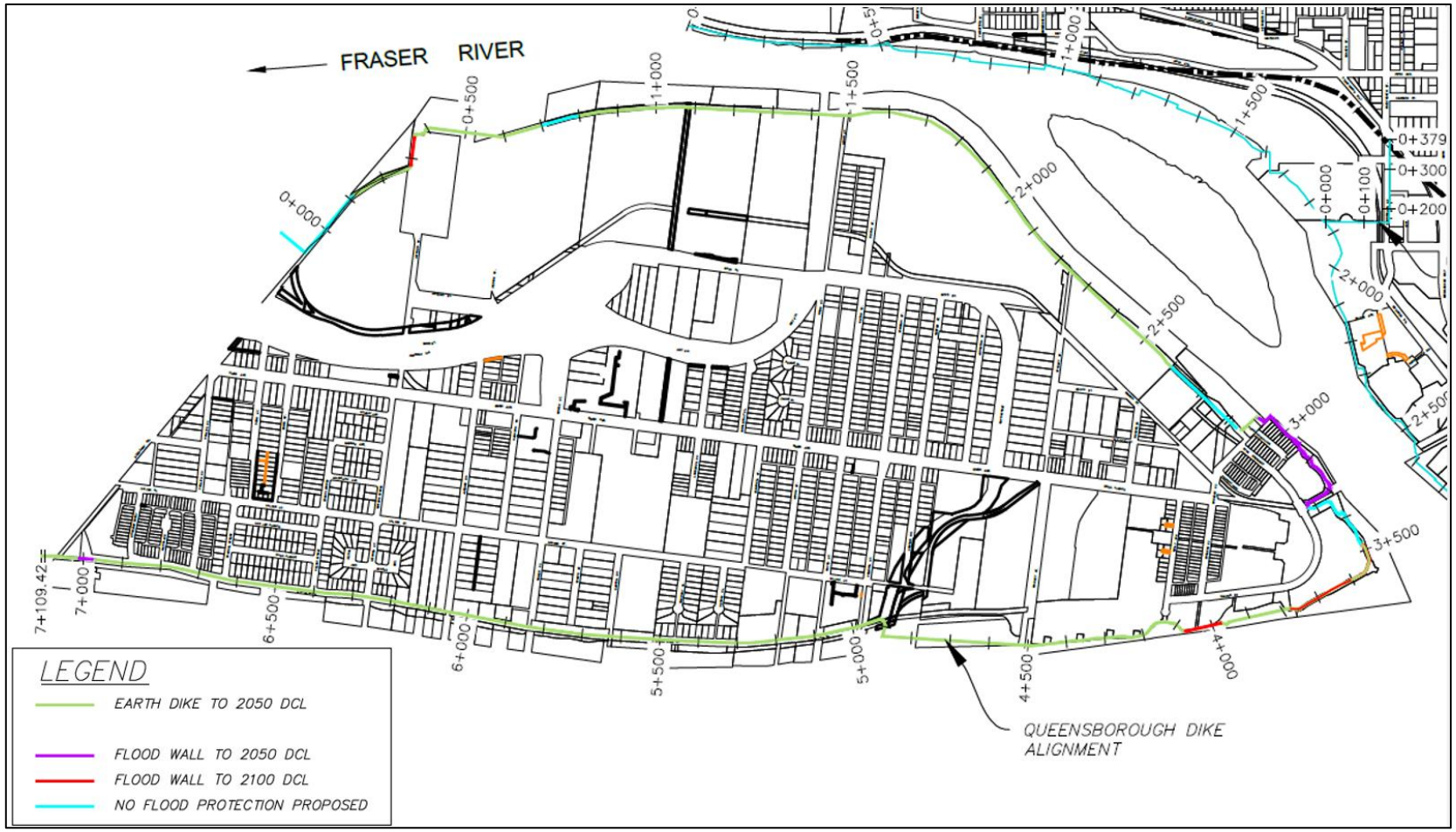


Figure 4.1 Queensborough Dike Upgrade Overview

From the tie in point with the Richmond dike (Sta 0+120) extending 2.5 km to the new Anthem Properties development (Sta 2+600) there is generally sufficient space to widen and raise this section of existing earth dike, provided that additional rights of way can be acquired. **Photo 4.1** shows the dike along the North Arm at approximately Sta 1+100. Key issues to address as part of future preliminary design include:

- Confirmation of the dike alignment, design and ROW adjacent to the industrial buildings and operations between Stations 0+280 to 0+660, and where the Vancouver Port Authority has partial jurisdiction over the lands.
- Design of retaining walls and other details to raise the dike at both the Wood Street and Stanley Street pump stations.
- Assessment of existing bank protection on the waterside slope of the dike (and possible upgrading), plus extension of the riprap to the full design crest level.
- Seismic assessment and design - ground improvement is assumed to be feasible for this dike segment.



Photo 4.1 Dike along North Arm looking northeast towards the Queensborough Bridge.

In 2020, Anthem Properties constructed a section of new dike from Station 2+600 to 2+ 840 as part of a multi-family residential development. Although no improvements are required to meet the Year 2050 DCL, an additional 0.4 m raise would be required to meet the Year 2100 DCL. Seismic ground improvement was completed as part of construction of this 240 m long dike section (Advisian, 2019).

The 1.7 km long dike around the upstream end of Lulu Island (Sta 2+840 to 4+500) was constructed in conjunction with the various development phases of the Port Royal residential area. Most of the residential development planning and the design and construction of these flood protection works occurred prior to 2010, before climate change flood level allowances and seismic design requirements were introduced. Therefore, the setbacks to buildings and ROWs are generally insufficient to accommodate widening and raising to the Year 2050 and Year 2100 DCLs.

As outlined in **Table 4.1** and Appendix D, the following design concepts have been applied depending on the proximity of buildings, site grades landward of the dike and riverbank geometry:

- Raise existing concrete floodwall (Sta 2+920 to 3+280)
- Construct sheetpile walls near the top of riverbank (Sta 3+600 to 3+780 and Sta 3+980 to 4+090)
- Realign the dike to the riverside (Sta 3+780 to 3+980)
- Incorporate a landside retaining wall (Sta 4+180 to 4+480)

Key issues to address as part of future preliminary design for the Port Royal dike segment include:

- Acquisition of adequate ROW
- Landscaping and grading to both minimize impacts on private properties and to retain the dike as a high use public amenity corridor
- Environmental design and approvals (e.g. for the segment realigned to the riverside)
- Seismic assessment and approvals to upgrade the dike without ground improvement

A 330 m long section of the dike just upstream of Derwent Way (Annacis Channel Bridge) passes through an industrial site. As described in Appendix D, construction of a superdike (i.e. overwidth dike) may be possible at this site (Sta 4+500 to 4+830). This could address the seismic design requirement without ground improvement.

The upgrading of the 2 km long section of dike that is contiguous with South Dyke Road presents several design challenges (**Photo 4.2**). For costing purposes, it is proposed that the dike (i.e. South Dyke Road) be raised (0.3 to 0.8 m) to the Year 2050 DCL. The WSP report briefly describes other options but did not complete a detailed evaluation of alternative design concepts.



Photo 4.2 South Dyke Road Looking Southwest near Royal Park (approx. Sta 5+360)

Key issues to address as part of future preliminary design for the South Dyke Road segment include:

- Relocation of existing water and sewer utilities
- Access to properties on both sides of the dike (i.e. driveways, ramps, parking etc.)
- High costs of replacing asphalt paving and sidewalks
- Seismic assessment and design
- Cost effectiveness of phasing construction
- Flexibility to facilitate further dike raises to address long-term sea level rise.

Table 4.1 Summary of Proposed Queensborough Dike Upgrades

Station	2011 Feasibility Plan	Improvements for Year 2050 Design	Upgrades Required for Year 2100 (in addition to Year 2050 Improvements)
-0+090 to 0+000	· none required	• None required: City of Richmond Section • Richmond to construct new earth dike along existing alignment (alignment as recognized by Province of BC)	• City of Richmond Dike Master Plan Phase 4 proposes to construct a dike along the existing ROW through Hamilton Transit Centre and a section of Boundary Road to 5.1 m (CGVD 2013)
0+00 to 0+120	· none required	•City of Richmond Dike and responsibility • Richmond to construct new earth dike along existing alignment (alignment as recognized by Province of BC)	•City of Richmond Dike and responsibility
0+120 to 0+280	· Improve existing earth dyke · Follow existing alignment · Raise dyke ±0.2 m to ±0.4 m · Acquire additional rights of way	• Improve existing earth dike • Follow existing alignment • Raise dike ± 0.5 to ± 0.9 m • Acquire additional rights of way • Confirm safety of 750 mm dia. drainage pipe outfall with check valve near Sta 0+280 • Seismic ground improvement	• Raise dike by additional 0.7 m
0+280 to 0+660	· Construct new earth dyke · New alignment set-back from river · Acquire rights of way	• Shift alignment to accommodate recent development. • Construct sheet pile wall 0+280 to 0+360 • Construct new earth dike 0+360 to 0+660 • Alignment, ROW and design details will need to be worked out with the landowners prior to preliminary design. Vancouver Port Authority has jurisdiction in vicinity of 0+520 to 0+640. • Seismic ground improvement	• Raise dike by additional 0.7 m
0+660 to 1+480	· Existing earth dyke · Follow existing alignment · Acquire additional rights of way	• Existing earth dike • Follow existing alignment • Extend existing riprap bank protection to DCL where required • Acquire additional rights of way • Flood wall and special design considerations	• Raise dike by additional 0.8 m • Flood wall and special design considerations required at Wood St pump station.

		required at Wood St pump station. • Seismic ground improvement	
1+480 to 2+300	· Improve existing earth dyke · Follow existing alignment · Raise dyke ±0.4 m · Acquire additional rights of way	• Improve existing earth dike • Follow existing alignment • Raise dike ± 0.5 to ± 0.9 m • Extend existing riprap bank protection to DCL • Acquire additional rights of way • Flood wall and special design considerations required at Stanley St pump station. • Seismic ground improvement	• Raise dike by additional 0.8 m • Flood wall and special design considerations required at Stanley St pump station.
2+300 to 2+600	· Existing earth dyke · Follow existing alignment · Acquire additional rights of way	• Improve existing earth dike • Follow existing alignment • Raise dike ± 0.2 to ± 0.3 m • Extend existing riprap bank protection to DCL • Acquire additional rights of way • Seismic ground improvement	• Raise dike by additional 0.8 m
2+600 to 2+920	· Construct new earth dyke · New alignment through site with redevelopment · Acquire additional rights of way	• Anthem site dike approx. Sta 2+600 to 2+ 840 (DCL is 4.9 m CGVD2013 - no improvements required) • Construct new earth dike from 2+840 to 2+920 • Acquire additional rights of way • Seismic ground improvement except for Anthem site.	• Anthem Properties dike is designed to accommodate raising the dike to 5.2 m CGVD2013 – an additional 0.4 m raise would be required to achieve Year 2100 DCL. • Raise earth dike by additional 0.8 m
2+920 to 3+280	· Construct concrete flood wall · Follow alignment of existing path and concrete wall · Raise dyke ±0.3 m · Acquire additional rights of way	• Construct concrete flood wall following existing alignment - design wall to allow future raise • Raise floodwall ± 0.8 m • Extend existing riprap bank protection to DCL • Acquire additional rights of way • High use public area - landscaping required plus beach access • Seismic Design: assume ground improvement not feasible due to proximity of buildings. A seismic flood hazard assessment may indicate low risk as ground elevation is high on the landside of the dike.	• Raise floodwall by additional 0.8 m
3+280	· Construct rail crossing	• Construct rail crossing (demountable structure). Design to allow future raise.	• Increase height of demountable rail crossing structure from approx. 1.2 m to 2 m high.

3+280 to 3+480	· Improve existing earth dyke · Follow alignment of existing trail · Raise Dyke ±0.5 m · Acquire additional rights of way	• no improvements proposed, high ground on landside of dike access path.	• Acquire additional rights of way • Raise dike to Year 2100 DCL
3+480 to 3+600	· Improve existing earth dyke · Follow alignment of existing trail · Raise Dyke ±0.5 m · Acquire additional rights of way	• Improve existing earth dike • Follow alignment of existing dike • Raise dike ± 0.6 m to ± 0.9 m • Extend existing riprap bank protection to DCL • Acquire additional rights of way • High use public area - landscaping required • Ground improvement not feasible	• Raise dike to Year 2100 DCL
3+600 to 3+780	· Improve existing earth dyke · Follow alignment of existing trail · Raise Dyke ±0.5 m · Acquire additional rights of way	• Sheetpile floodwall to Year 2100 DCL • Acquire additional rights of way • High use public area - landscaping required • Ground improvement not feasible	• none required
3+780 to 3+980	· Improve existing earth dyke · Follow alignment of existing trail · Raise Dyke ±0.5 m · Acquire additional rights of way	• Improve existing earth dike • Realign dike to foreshore • Raise dike ± 0.6 m to ± 0.9 m • Extend existing riprap bank protection to DCL • Acquire additional rights of way • High use public area - landscaping required • Ground improvement not feasible	• Raise dike to Year 2100 DCL
3+980 to 4+090	· Improve existing earth dyke · Follow alignment of existing trail · Raise Dyke ±0.5 m · Acquire additional rights of way	• Sheetpile floodwall to Year 2100 DCL • Acquire additional rights of way • High use public area - landscaping required • Ground improvement not feasible	• none required
4+090 to 4+500	· Improve existing earth dyke · Follow alignment of existing trail · Raise Dyke ±0.5 m · Acquire additional rights of way	• Improve existing earth dike (needs landside retaining wall Sta 4+180 to 4+480) • Raise dike ± 0.6 m to ± 0.9 m • Extend existing riprap bank protection to DCL • Acquire additional rights of way • High use public area - landscaping required • Ground improvement not feasible	• Raise dike by additional 0.8 m

4+500 to 4+830	· Construct new earth dyke · New alignment adjacent to river · Abandon inland dyke alignment · Acquire additional rights of way	• Consider new earth "superdike" dike parallel to riverbank (e.g. raise industrial storage areas by ± 0.3 m to ± 0.6 m) • Setback waterside crest of dike (right of way) from riverbank at least 30 m • Acquire additional rights of way setback from riverbank • Extend new dike to transition with bridge approach fill at Derwent Way (Sta 4+860) • Seismic Design: assume ground improvement not required given superdike geometry.	• Raise dike by additional 0.8 m
4+930 to 6+960	· Improve existing earth dyke (South Dyke Road) · Increase crest height with road improvement projects. · Raise dyke ±0.2 m to ±0.5 m · Acquire additional rights of way	• Raise existing earth dike (South Dyke Road) • Relocate utilities, reconstruct sidewalks, access ramps, driveway access etc. • Raise dike ± 0.3 to ± 0.8 m (varies) • Acquire additional rights of way • Seismic ground improvement	• Raise dike to Year 2100 DCL
6+960 to 7+030	· Improve existing earth dyke (South Dyke Road) · Increase crest height with road improvement projects. · Raise dyke ±0.2 m to ±0.5 m · Acquire additional rights of way	• Concrete floodwall under bridge approach structure (to maintain vehicle height clearance) • Seismic ground improvement	• Raise floodwall to Year 2100 DCL
7+030 to 7+114	· Improve existing earth dyke (South Dyke Road) · Increase crest height with road improvement projects. · Raise dyke ±0.2 m to ±0.5 m · Acquire additional rights of way	• Raise existing earth dike (South Dyke Road) • Relocate utilities, reconstruct sidewalk/path, • Raise dike ± 0.3 to ± 0.8 m (varies) • Acquire additional rights of way • Seismic ground improvement as required (with consideration of Boundary Rd Pump Station floodbox and discharge conduits through dike)	• Raise dike to Year 2100 DCL

4.2.2 Downtown

The City's Downtown area foreshore extends 3.1 km from Poplar Landing to the Patullo Bridge (Sta 1+880 to Sta 5+000) as shown in **Figure 4.2**. Except for a sub-standard earth dike at Poplar Landing, the floodplain areas are currently unprotected by dikes. The following provides a brief overview of the flood protection works proposed and key design issues for this area. A summary of the proposed improvements is provided in **Table 4.2.** Detailed drawings and discussion of design constraints are provided in Appendix D.

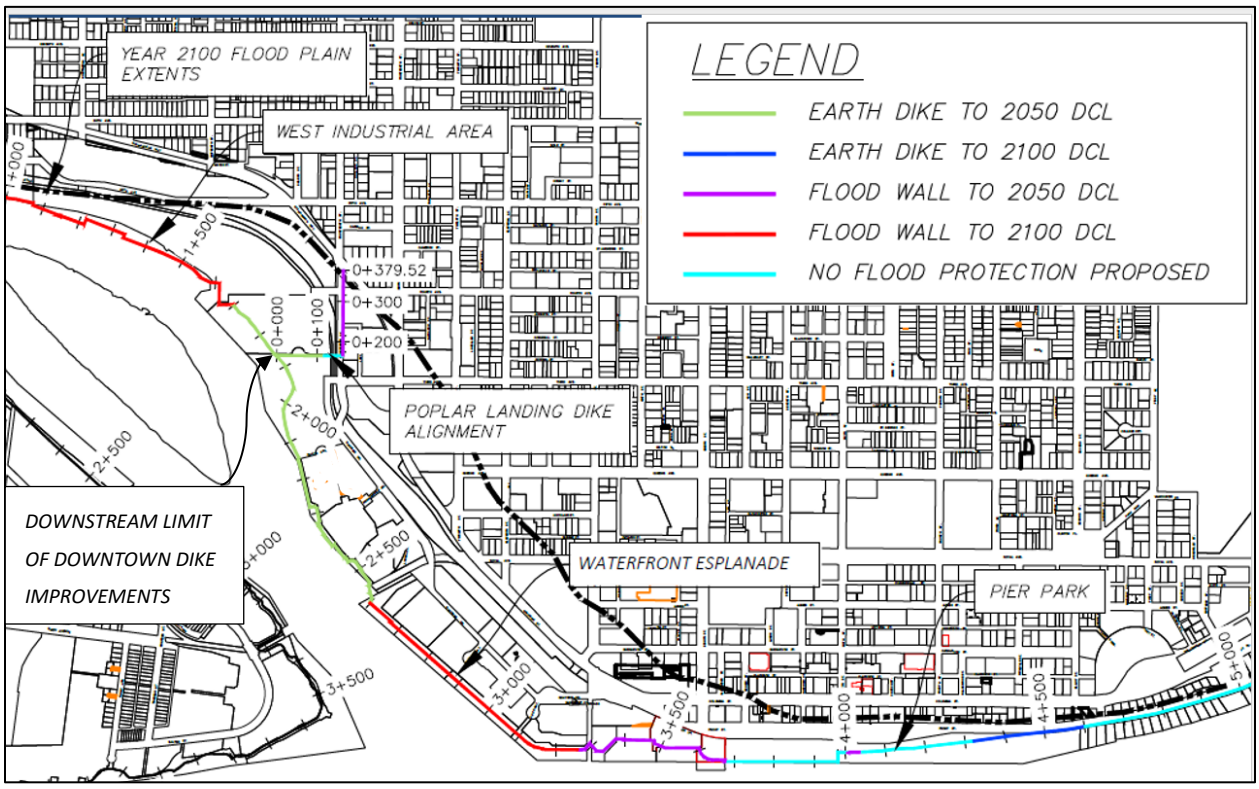


Figure 4.2 Downtown Dike Improvement Overview

Poplar Landing

The Poplar Landing site is at the downstream end of the Downtown dike improvement area. It is proposed that the existing riverside earth dike be widened, raised and protected with riprap. Given that the dike was constructed as an urgent project just prior to the 2007 freshet and that the dike Is heavily vegetated, the dike will have to be reconstructed. Ground improvement to seismic standards would likely be required.

The WSP report in Appendix D notes that, "A new 380 m long interim flood protection structure is proposed west of Poplar Landing Park (see Sheet M113 and as shown in **Figure 4.3** below). The purpose of this structure is to protect the City's downtown from flooding until the dike to the west is constructed. As identified in the original Conceptual Plan (Delcan, 2009), the shoreline west of Poplar Landing Park is relatively low priority given the high cost of the proposed improvements and limited land

area protected. Flood protection west of Poplar Landing Park will likely be constructed after the zones to the east have been protected. In the meantime, the City's downtown would be vulnerable to flooding from the west. For this reason, a tie-in dike is recommended as part of the Conceptual Plan."

The Poplar Landing site may be developed in future for residential use. Metro Vancouver also maintains a Combined Sewer Overflow Storage facility on the site. To achieve cost effective flood protection at this site, the planners for the new development should consider integrating the design of both the riverside dike and the tie-in dike into the site grading and seismic ground improvement plans.

The tie in point to high ground is near Stewardson Way and sky train alignment. **Photo 4.3** is a view looking northwest along 14th Street from the 3rd Avenue Overpass. The proposed concrete floodwall section of the tie-in dike would be located on the southwest (left) side of 14th Street.

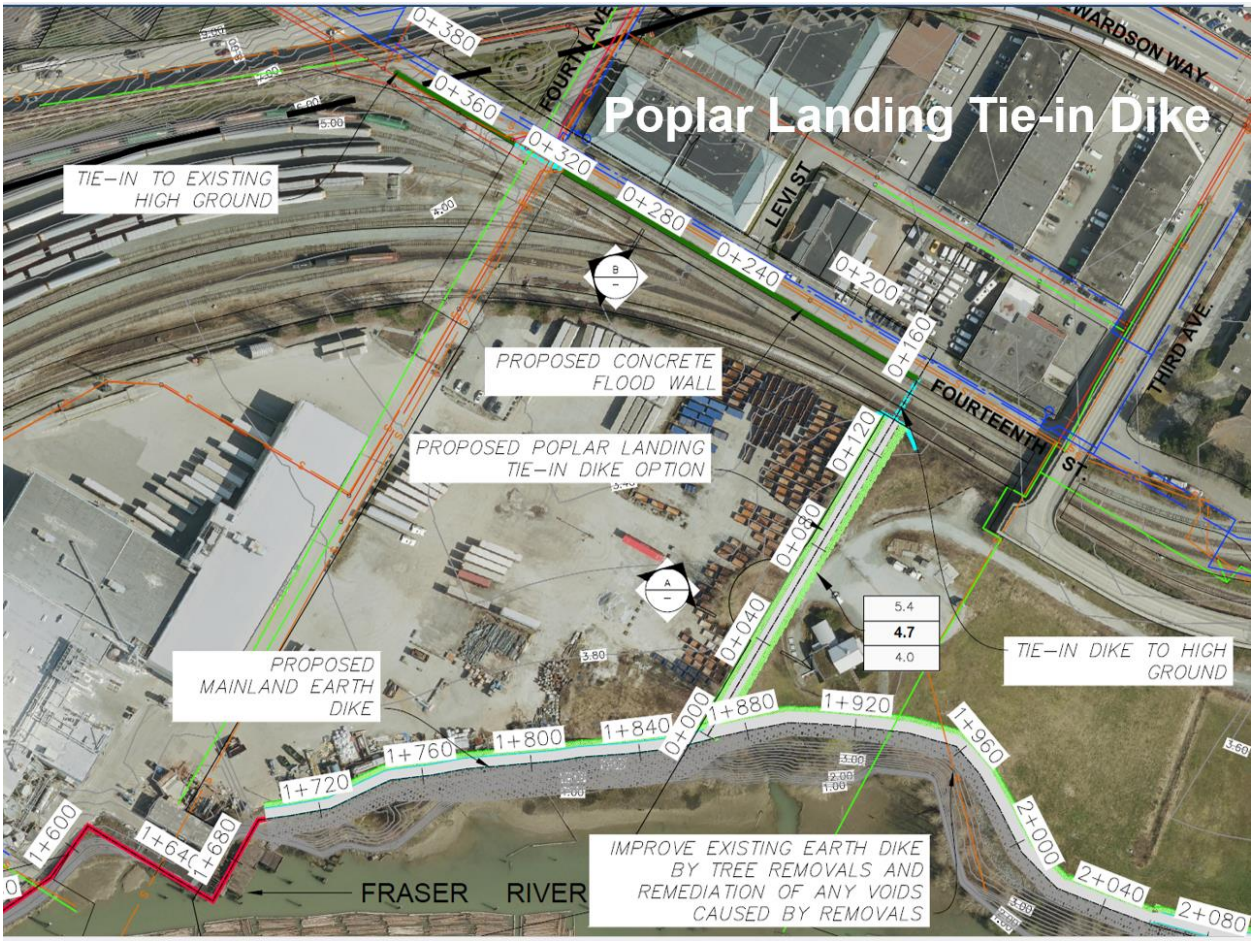


Figure 4.3 Poplar Landing Tie-In Dike (for typical dike sections see Sheet M113 in Appendix D)



Photo 4.3 Looking northwest along 14th Street from the 3rd Avenue Overpass. The proposed concrete floodwall section of the Tie-in Dike would be located on the southwest (left) side of 14th Street.

The Poplar Landing Tie-in Dike is a key component of the diking system needed to protect the Downtown. Planning, design and construction of this component could proceed in the near future and independently of the Waterfront Esplanade section. In summary:

- Backwater flooding from the Fraser River along the low-lying railway corridor into the Downtown can occur for floods larger than approximately a 1:100 AEP event (without climate change). Construction of this Tie-in Dike would eliminate the need to extend temporary emergency flood protection through the industrial lands to the west and would formalize the design, location and arrangements for the temporary closure section across the railway lands.
- Planning, design and construction of the dike should be integrated with development of the 1400 Quayside Drive (Poplar Landing Housing Development). This is necessary to ensure long term flood protection for the Downtown against higher climate change flood levels. An integrated design would likely reduce seismic design costs for the dike.

Waterfront Esplanade

From Rialto Court to the railway bridge (Sta 2+160 to 2+600), it is feasible to construct a 1 to 1.5 m high earth dike by raising the path between the top of riverbank and the existing buildings to meet the Year 2050 DCL. The key design issues to address for this 440 m long dike segment include:

- Landscape architectural design for raising the high use public walkway in close proximity to existing buildings and providing flexibility to raise a further 0.7 m to the Year 2100 DCL
- Acquisition of additional rights of way
- Improvement and extension of existing riprap bank protection
- Completion of a seismic flood hazard assessment (ground improvement assumed not feasible due to proximity of existing buildings).

The 680 m long section from the railway bridge to the access road near the Inn at Westminster Quay (Sta 2+600 to 3+280) includes a boardwalk supported by a 70 year-old timber pile structure (**Photo 4.4**) and an attractive and highly used public walkway and park between the boardwalk and the existing multifamily residential buildings (**Photo 4.5**).



Photo 4.4 Waterfront Esplanade boardwalk looking downstream



Photo 4.5 Waterfront Esplanade Park near Sta 3+000 looking upstream with the boardwalk to the right of the photo. The Year 2100 DCL is almost two metres above the existing grade of the walkway.

The conceptual design plan and typical section for this segment is shown in **Figure 4.4**. Construction to the full Year 2100 DCL is proposed without phasing given the need for a new sheet pile wall and to avoid repeated disruptions to re-establish the public walkway and landscaping. Although it is not part of the dike, the boardwalk could be replaced at a higher elevation (Appendix D includes a separate cost estimate for this component). Key design and implementation issues to address include:

- Landscape architectural design for raising the public walkway by approximately 1.9 m in close proximity to existing buildings (possible disruption to river views for some first-floor residential units)
- Extensive public information and consultation
- Acquisition of additional rights of way
- Riprap scour protection
- Completion of a seismic flood hazard assessment (ground improvement assumed not feasible due to proximity of existing buildings).

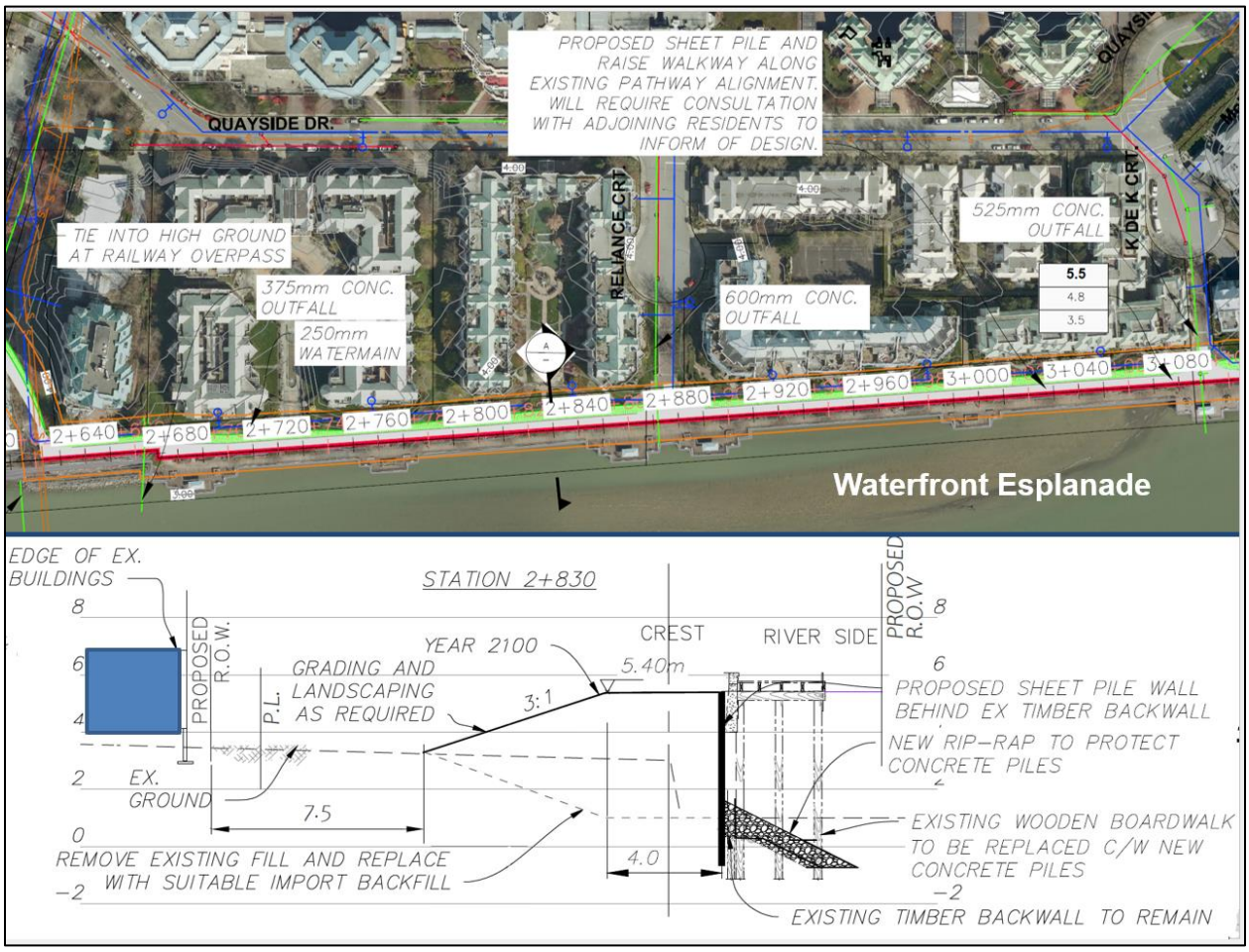


Figure 4.4 Typical Section of Proposed Dike Along Waterfront Esplanade

Westminster Quay

The Westminster Quay segment extends from the Inn at New Westminster Quay to the east side of the Discovery Centre (Sta 3+280 to 3+680). The proposed conceptual design for this 400 m long section is comprised of floodwalls to the Year 2050 DCL integrated with existing buildings, with demountable structures spanning the pedestrian access routes between the buildings. Further raising of the dike to the Year 2100 DCL would require a full assessment of the existing timber pile supported boardwalk and retaining wall and would need to be designed in conjunction with any re-development plans for this area (see discussion in WSP Report and Drawing Sheet M105 in Appendix D).

Pier West

The new Pier West residential tower site (Sta 3+680 to 4+010) is currently under construction with the entire site being raised behind a caisson wall. Landscape drawings for Pier West indicate that finished

grades exceed the Year 2050 DCL levels but may not fully meet the Year 2100 DCL freeboard requirements. No improvements are required for this segment.

Pier Park and Future Extension (Sta 4+010 to 4+600)
The site grading within the 340 m long section of the existing Pier Park upstream from the Pier West site meets the Year 2050 DCL except that a short 30 m long section of concrete floodwall is required near the east end of the Park. A detailed review of the existing park earth fill and grades will be needed to determine how best to meet the Year 2100 DCL through this site.

The City is proposing to extend Pier Park approximately 300 m upstream. A new earth dike to the Year 2100 DCL should be integrated with the Park development. To prevent floodwaters from outflanking the upstream end of the dike along Front Street and the rail corridor, a closure section to tie the dike into high ground is required.

The floodplain area from Pier Park to the mouth of the Brunette River at the Braid Street Industrial Area is very limited. Land use consists of the railway corridor and Sapperton Landing Park. No dike improvements are proposed.

Table 4.2 Summary of Proposed Downtown Dike Improvements

Station and Area Name	2011 Feasibility Plan	Improvements for Year 2050 Design	Upgrades Required for Year 2100 (in addition to Year 2050 Improvements)
1+880 to 2+160 Poplar Landing	· Maintain existing dyke	• Improve/reconstruct existing riverside earth dike • Construct new riprap bank protection • Raise dike ± 0.2 m • Acquire additional rights of way • Seismic ground improvement	• Acquire additional rights of way • Raise dike by additional 0.7 m
Poplar Landing	· tie-in dike not included	• Poplar Landing Tie-in Dike to high ground near Stewardson Way (see Fig. 4.3). Needed if dike to west not constructed. Consists of 135 m of earth dike, closure sections at railway and 4th Ave plus 245 m of floodwall along 14th St. • Seismic ground improvement for earth dike section assumed for cost estimate.	• If dike to west along industrial lands not constructed, raise dike by additional 0.7 m
2+160 to 2+600 Waterfront Esplanade Rialto Court to Railway Bridge	· Construct new earth dyke · Follow trail alignment · Raise ground ± 0.7m · Acquire additional rights of way	• Construct new earth dike • Follow trail alignment • Improve and extend riprap bank protection • Raise ground ± 1.3 m • Acquire additional rights of way • High use public area - landscaping required • Seismic Design: assume ground improvement not feasible due to proximity of buildings. A seismic flood hazard assessment may indicate low risk as ground elevation is high on the landside of the dike.	• Raise earth dike by additional 0.7 m
2+600 to 3+280 Waterfront Esplanade Boardwalk	· Construct new earth dyke · Follow trail alignment · Repair esplanade settlement concerns · Raise ground ±0.3 m · Acquire additional rights of way	• Full replacement of existing timber wall with sheetpile wall and new boardwalk. • Finished grade to Year 2100 DCL following existing walkway alignment. • Raise ground ± 1.9 m • Acquire additional rights of way • High use public area - extensive consultation and landscaping required	• None required – dike already at Year 2100 DCL of 5.5 m

		• Seismic Design: assume ground improvement not feasible due to proximity of buildings.	
3+280 to 3+680 Westminster Quay	· Construct demountable dyke around New Westminster Quay and Discovery Centre · Acquire additional rights of way	• Construct concrete floodwall adjacent to existing buildings with demountable structures at access locations. • Acquire additional rights of way • High use public area • Seismic Design: assume ground improvement not feasible due to proximity of buildings.	• construct new dike to Year 2100 DCL in conjunction with future site redevelopment
3+680 to 4+010 Pier West	· Construct sheet pile dyke, or similar, along the river's edge to integrate with future development · Acquire additional rights of way	• no proposed improvements • dike incorporated into Pier West development • Seismic Design: incorporated into new development	• to be determined. Landscape drawings for Pier West indicate that finished grades may not meet Year 2100 DCL freeboard requirements.
4+010 to 4+340 Pier Park	· Construct earth dyke to integrate with development of Waterfront Pier Park · Dedicate dyke rights of way	• New 30 m long floodwall section needed to bring low areas at west end of park up to Year 2050 DCL • remainder of dike comprised of existing Pier Park fill meets YR 2050 DCL • City owns land - no rights of way required	• to be determined. Incorporate into park grading as needed.
4+340 to 4+600 Pier Park Extension	· Construct earth dyke to integrate with development of Waterfront Pier Park · Dedicate dyke rights of way	• fire damaged section to be rebuilt to full Year 2100 DCL and park grading to incorporate earth dike • closure section tie-in to high ground across railway at upstream end • City owns land - no rights of way required • Seismic Design: assume ground improvement not required due to dike setback and over width fill.	• None required – dike already at Year 2100 DCL of 5.6 m

4.3 Cost Estimates

WSP Engineering developed a preliminary cost estimate for the proposed conceptual design for dike upgrading and new dike construction (Appendix D). The costs are limited to construction costs and include a 50% contingency but do not include an allowance for land acquisition. Since the costs of seismic ground improvement are high and requirements uncertain, seismic design costs have been estimated separately.

Summary tables of the preliminary cost estimates for Queensborough, Downtown and citywide (including the two industrial areas) are provided in Table 4.3, Table 4.4, and Table 4.5. Including assumed seismic design, is estimated that the Queensborough dike upgrading work would cost $85 million. The new flood protection for the Downtown including assumed seismic design would cost $23 million. Adding the two industrial areas, the total cost is estimated to be $154 million.

Table 4.3 Queensborough Dike Upgrade Cost Summary

Item	Earth Dike to Year 2050 DCL (includes retaining wall section)	Concrete Floodwall to Year 2050 DCL	Sheetpile Floodwall to Year 2100 DCL	Raise South Dyke Road to Year 2050 DCL	Total
Dike Length (m)	3580	430	370	2110	**6490**
Construction $M	15.4	1.7	3.4	35.4	**55.9**
Seismic $M	15.1	0.4	0.5	12.7	**28.7**
Total $M	30.5	2.1	3.9	48.1	**84.6**
Cost $M/km (without seismic)	4.3	4.0	9.2	16.8	**8.6**
Cost $M/km (with seismic)	8.5	5.0	10.5	22.8	**13.0**

Table 4.4 Downtown Dike Improvements Cost Summary

Item	Earth Dike to Year 2050 DCL	Concrete Floodwall to Year 2050 DCL (includes demountables)	Sheetpile Floodwall to Year 2100 DCL	Earth Dike to Year 2100 DCL	Poplar Landing Tie-in Dike	Total
Dike Length (m)	580	585	680	260	380	**2485**
Construction $M	2.4	4.0	10.5	1.9	1.8	**20.5**
Seismic $M	1.7	0.0	0.0	0.0	0.8	**2.5**
Total $M	4.0	4.0	10.5	1.9	2.6	**23.0**
Cost $M/km (without seismic)	4.1	6.9	15.4	7.2	4.8	**8.2**
Cost $M/km (with seismic)	7.0	6.9	15.4	7.2	6.9	**9.3**

Table 4.5 Citywide Dike Upgrade Cost Summary

Item	Queensborough	Downtown (including Poplar Landing Tie-in Dike)	Braid Industrial Area	West Industrial Area	Total
Dike Length (m)	6490	2485	2290	1360	**12625**
Construction $M	55.9	20.5	25.9	17.7	**120.0**
Seismic $M	28.7	2.5	1.2	1.1	**33.5**
Total $M	84.6	23.0	27.1	18.8	**153.5**
Cost $M/km (without seismic)	8.6	8.3	11.3	13.0	**9.5**
Cost $M/km (with seismic)	13.0	9.3	11.8	13.9	**12.2**

4.4 Next Steps

Prior to initiating preliminary design work for the Queensborough dike upgrades, a number of specific technical studies need to be completed. The outcome of these assessments could significantly affect dike alignments, design details, and costs. It is recommended that the City:

- Conduct a detailed seismic assessment of the dike alignment, including a "Seismic Flood Hazard Assessment" as outlined by EGBC (2021). Obtain input from the Inspector of Dikes to confirm seismic design requirements.

- Prepare a consolidated rights of way (ROW) plan showing legal boundaries and current physical location of the dike. Using the conceptual upgrade drawings as a starting point, identify additional ROW requirements and critical areas where alternative design options may be required to resolve land ownership issues.

- Assess the potential for Fraser River channel change that could lead to scour and undermining of the riprap toe and assess the adequacy of the existing riprap bank protection. Prepare plans for erosion protection improvements as may be required.

- Evaluate the cost effectiveness of alternative designs and construction phasing for upgrading the 2 km section of dike contiguous with South Dyke Road, integrating seismic design. Conduct a public information and consultation process to obtain input from landowners on both sides of the dike.

The conceptual design and costs for the Queensborough dike should be updated based on the above work. Similar studies are needed to advance the preliminary design for a new Downtown Waterfront dike. These could be combined with the Queensborough work (e.g. seismic assessments and Fraser River channel change) or could be addressed separately at a later date.

Preliminary design work for the Poplar Landing Tie-in Dike should be coordinated with planning of the 1400 Quayside Drive housing development. Design and construction of the Tie-in Dike could proceed independently of long-term flood protection improvements along the Waterfront Esplanade.

5 DIKE INSPECTIONS AND OPERATION AND MAINTENANCE MANUAL

The annual dike inspection and report is a primary dike safety tool and combined with an up-to-date Operation and Maintenance Manual is essential for effective dike operation and maintenance. Subsections 5.1 to 5.5 provide information on the purpose of dike inspections, provincial requirements, available guidelines and resources, plus recommendations on how to improve the City's dike inspection reporting for the Queensborough Dike. The City's previous inspection reports (2013 to 2020) were reviewed. Although NHC staff are generally familiar with the Queensborough Dike, the scope of work did not include a formal dike inspection and preparation of a dike inspection report.

The existing Operation and Maintenance Manual for the Queensborough dike was prepared in 1979 as part of the dike upgrading project completed under the Fraser River Flood Control Program. However, many changes have been made to the dikes and adjacent lands over the past 40 years and a completely new manual is needed. As part of this Floodplain Management Strategy Update, Section 5.5 describes the preparation of a draft template of a new manual (included in Appendix E) and the assembly of relevant information that should be considered for inclusion in the appendices to a new manual.

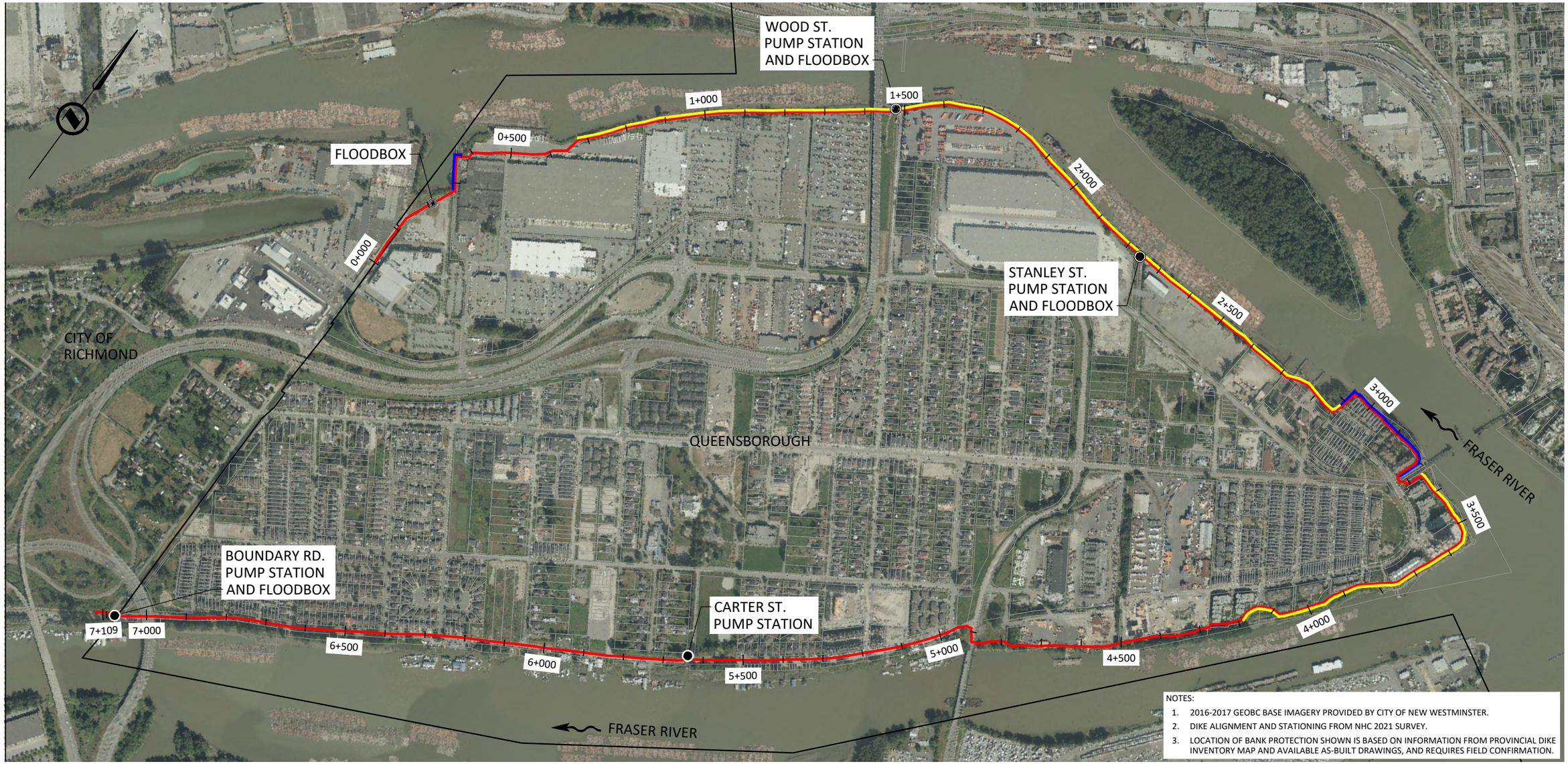
5.1 Purpose of Dike Inspections, IOD Requirements and Resources

A regular program of dike inspection can identify potentially critical conditions and facilitate maintenance in advance of high-water periods. Effective dike safety management, as documented by annual inspection reports, lends confidence that the diking system will perform up to its design limits in the next flood event. Considering the importance of inspections, the Inspector of Dikes (IOD) requires that all diking authorities in British Columbia conduct annual inspections and submit the inspection reports in a standardized format. The most recently available IOD Annual Dike Inspection Letter and Dike Inspection Checklist (2021) are included in Appendix E.

The provincial “Flood Protection Works Inspection Guide” (MELP, 2000) provides a comprehensive description of dike inspection methods and the various types of issues that can affect dike safety. The Dike Safety Section has also provided dike inspection training sessions, typically involving a combination of in-class and field instruction over 1 to 2 days.

What makes an effective dike inspection report? The key elements include:

- A reference plan showing dike chainages that can be used to accurately identify the location of dike segments and any observed problem sites (**Figure 5.1** provides an overview plan of the dike with chainages, however a more detailed scale plan would be useful).
- Detailed sketches, photos and descriptions of observed issues, with comments on how these problems might impact dike safety, plus description of remedial actions required.
- A summary of maintenance/repair work completed in the past 12 months and the maintenance/repair work planned for the next 12 months.
- References and documentation of relevant changes over the past year – i.e. a description of construction work near, or on the dike, dike surveys, changes to pump stations, consultant reports etc.
- Confirmation that the most recent dike crest survey is accurate and that it reflects any changes to the dike.
- Completion of the inspections and reports by trained and knowledgeable staff that are familiar with the design of the dike and the types of issues to look for.



NOTES:

1. 2016-2017 GEOBC BASE IMAGERY PROVIDED BY CITY OF NEW WESTMINSTER.
2. DIKE ALIGNMENT AND STATIONING FROM NHC 2021 SURVEY.
3. LOCATION OF BANK PROTECTION SHOWN IS BASED ON INFORMATION FROM PROVINCIAL DIKE INVENTORY MAP AND AVAILABLE AS-BUILT DRAWINGS, AND REQUIRES FIELD CONFIRMATION.

PLAN VIEW
1:10,000

LEGEND:

- PERMANENT DIKE
- BANK PROTECTION - RIPRAP
- FLOODWALLS

0 100 200 500m

SCALE = 1:10,000

Corporation of the City of NEW WESTMINSTER

nhc northwest hydraulic consultants
30 Gostick Place
North Vancouver, BC
Canada V7M 3G3
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

REVISIONS		
0	2022-08-11	ISSUED FOR REPORTING

DRAWING INFORMATION	
DATE	11 Aug 2022
DESIGNED BY	DWM/ARV
DRAWN BY	KEH
CHECKED BY	NJP
SHEET SIZE	B (11" x 17")

CITY OF NEW WESTMINSTER
QUEENSBOROUGH DIKE

GENERAL ARRANGEMENT

PROJECT NUMBER	3006287
DRAWING NUMBER	3006287-10-002
SHEET NUMBER	1
REVISION	0

Filename: \\mainfile-van\Projects\Active\3006287 New West Flood Strategy\96 CAD\02_Production\000_Figures\3006287-10-IFR-FIG-NewWestFRP-Queensborough_Protection-ROC.dwg, 2022-08-11 11:54:53 AM

5.2 Description of the Queensborough Diking System

A brief description of the diking system can help inspection staff to understand the characteristics of the dikes and determine where special dike inspection efforts should be focused.

The 7 km long Queensborough Dike was reconstructed and upgraded in the late 1970's as part of the 1968 to 1994 Fraser River Flood Control Program. The design crest level was based on a flood profile developed in 1969 representing the 1894 flood of record, plus 0.6 m freeboard. Subsequent hydraulic modelling developed a new "official" provincial design profile for the estimated 1894 flood (NHC, 2008). More recent modelling as presented elsewhere in this report, provides a very similar historic 1894 flood profile for the Queensborough reach (NHC, 2019). While the 1969, 2008 and 2019 profiles for the historic flood of record have significant variations in other locations, the differences in all three profiles along the Queensborough dike are less than 0.2 m. Except for long term settlement of the dike crest or other changes associated with land development, most sections of the dike constructed over 40 years ago still have at least nominal freeboard relative to more recently modelled flood levels, without consideration of sea level rise and climate change.

The dike includes four pump stations:

- Wood St. pump station and floodbox
- Stanley St. pump station and floodbox
- Carter St. pump station
- Boundary Rd. pump station and floodbox

Extensive commercial and residential development combined with landfilling adjacent to the Queensborough dikes over the past few decades has resulted in much of the diking system (approximately 95% of the 7 km length) being relatively low in height with gentle landside slopes (i.e. the design flood level is less than 1.5 m higher than the ground level at the landside dike toe). Landfilling has generally made these sections of the dike safer with respect to potential seepage and stability issues, especially for moderate flood levels.

However, significant sections of higher dike remain. Most notably, the dikes immediately adjacent to and including the four pump stations are very high with the design flood levels being 3 to 4 m higher than the water levels in the drainage canals. Therefore, additional dike inspection effort is required for the higher dike sections, including the pump station structures, flood boxes and adjacent dike fills.

The 4 km section of the dike between the Derwent Way Bridge and Boundary Road is comprised of South Dyke Road with marinas, float homes and other developments on the riverside. Although the roadway itself is not a concern for dike safety, any leaks or breaks in buried utilities (primarily water and sewer pipes) along the dike can lead to dike safety problems that could become evident through depressions/voids/sinkholes in the roadway, or possibly washouts. Unless carefully constructed, buried utilities passing through the dike (e.g. service connections to developments on both sides of the dike) can provide preferential seepage paths during high water events.

A significant length (approx. 3.7 km) of the riverside slope of the Queensborough dike is protected from river currents and wave action by riprap. These erosion protection works should be inspected annually and any areas of concern monitored and addressed. The construction record drawings, as provided in the O&M Manual show the locations and design details for the dike sections protected by riprap.

The Queensborough dike is located entirely within an active urban area comprised of industrial, commercial, residential, and recreational/parks land uses. Inspectors should be aware of any unauthorized construction work, excavations or encroachments on the dike or dike rights of way.

5.3 Review of Previous Inspection Reports

The City provided NHC with the City's Queensborough dike inspection reports for 2013 to 2020 (except for the 2019 report). The 7 reports utilized a consistent checklist/report format developed by the IOD. The dike was divided into 12 segments with 10 of these identified by property owner(s), land use, or developers' names. Only 2 of the segments along South Dyke Road were identified by street names or other major landmarks. No reference map was provided that showed the location of the segments.

Relatively few dike safety issues and concerns were reported. These included:

Casino Site segment:

- a bank erosion site - same description in all reports from 2013 to 2020, except that the 2020 report noted that a consultant was retained, and remedial work was being planned for 2022

Queensborough Industrial Park/Lowes segment:

- settlement at the bulkhead wall behind the old dock (in all reports from 2013 to 2020)
- trees in or near dike (in all reports from 2013 to 2020)
- erosion site east of the old dock (2020 report, City to remediate in 2022)

Wal-Mart segment:

- trees in or near dike (in all reports from 2013 to 2020)

Beedie Lands segment:

- a sinkhole was noted and photographed (in the 2020 report)

Anthem Properties (formerly Star Shipyard):

- description of dike configuration with closure sections (2013 to 2017 reports)
- description of temporary dike measures and permanent dike plans (2018 and 2020 reports)

5.4 Recommendations to Improve Inspection Reporting

Based on the review of the previous inspection reports and given the characteristics of the Queensborough dike, the City should consider the following recommendations:

1. Utilize the most recent inspection reporting form provided by the IOD (see Appendix E).

2. Provide a map/plan of the dike showing the dike segments, chainages and major landmarks that can be used to accurately locate observation sites. Avoid use of local property names.
3. Identify, document, and address any unauthorized construction work, excavations or encroachments on the dike or dike rights of way. To enable reporting on possible encroachments, prepare a consolidated ROW plan showing legal boundaries and current physical location of the dike.
4. Where possible, locate observation sites by GPS coordinates.
5. Inspection reports should be signed by inspection staff (allows follow-up if questions arise, possibly months or years later).
6. Photos should be current. If an issue is a longer-term problem, then the value of photos is to monitor changes over time.
7. The City's reports do not include any specific observations/inspections of the appurtenant works (the four pump stations, flood box inlets/outlets, flap gate condition etc.). As the adjacent dikes and pump station structures/conduits through the dike are the most vulnerable locations in the Queensborough dike, any observations of slumping, cracks, settlement etc. could be critical to preventing a dike failure. A photographic record of these dike sections and appurtenant structures (free of vegetation) could be useful.
8. Bank protection (riprap) should be inspected at low water, by boat where necessary. If problem sites are observed a specific bathymetry survey may be required. Vegetation control on the dike slopes should be sufficient so that the rock can be visually inspected (MELP and DFO, 1999)
9. If bank erosion problems are observed, then the inspection report should provide a plan view and cross-section sketch showing the dike and setback distance of the eroding areas from the toe of dike (if any). Photos should clearly show the bank erosion and if possible, the dike crest and slopes in relation to the erosion problem. Consider monitoring by survey if bank retreat is suspected.
10. Dike inspection staff should take advantage of any training opportunities that may be offered by the Province and become familiar with the O&M Manual, and particularly the record drawings. Where possible, the City should identify two or three staff to provide continuity in inspections from year to year and to ensure knowledge transfer to new staff as needed.

5.5 Draft Operation and Maintenance Manual Template

A Draft Operation and Maintenance Manual Template is included in Appendix E. This document can be considered as a rough first draft of a manual for the Queensborough Dike. It is largely based on the template provided by the Province of BC Dike Safety Program: "Operation & Maintenance Manual for New Work (PDF)" available at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/dike-management/operation-maintenance

Much of the content of the provincial template has been revised to address the specific issues associated with the Queensborough dikes. However, further work is required to complete the manual

text and to locate, organize and/or develop information, reports, drawings etc. to complete the Appendices. An itemized list of the work required is summarized in **Table 5.1**.

Table 5.1 Further Work and Information Needed to Complete Operation and Maintenance Manual

O&M Manual	Further Work and Information Needed
O&M Manual main text	The O&M Manual in Appendix E is a draft template for the Queensborough Dike system. Further work and review are required.
O&M Manual Appendices	**Further Work and Information Needed**
A.1 – A.7 Fundamental Information	Template only; missing information to be filled in
A.9 SROW Agreements	ROW information is incomplete and outdated. • Update ROW information: create plan drawings illustrating current ROW's and Dike alignments. • Land acquisition analysis for dike upgrades
B.1-B.2 Flood Protection Works	Template only; missing information to be filled in
B.3 History of Dike Improvements B.4 Future Proposed Modifications to Flood Protection Works	Incomplete; Requires a table or write up
B.5 Flood Protection Works Civil Design Reports	Missing all civil design reports
B.6 Flood Protection Works Geotechnical Design Reports	Appendix is incomplete. Need to include reports such as Advisian (2019) for Anthem Properties Site at 41 and 175 Duncan St.
C.1 – C.4 Pump Stations	Missing all civil and some of the geotechnical design reports for the pump stations. Other supplemental reports could be missing as well.
D.1 Construction Completion Records D.2 Flood Control Work As-Built Drawings	Appendix may be incomplete; thorough review of available as-builts required.
D.3 Pump Station & Floodbox As-built Drawings D.4 Riprap specifications	Incomplete; Drawings and Specifications are missing
E.1 Past Flooding Events Record E.2 Hydrometric Records & Streamflow Gauges	Template only; missing information to be filled in
F Environment & Habitat Reports	Possibly incomplete; thorough review of available reports required.
G.1 – G.4 Inspection of Flood Protection Works	Template only; missing information to be filled in
H.1 Routine Maintenance Activity Summary H.2 Troubleshooting Guide	Template only; missing information to be filled in
I.1 Summary of emergency Conditions and Repair	Template only; missing information to be filled in
I.2 Emergency Response Plan	Incomplete; City's updated response plan needs to be added when available.
J.1 List of Benchmarks Established in Queensborough Area for the O&M of the Flood Control Works	Partially available in Appendix 5 of 1979 O&M. Requires update and review.

The suggested content for each of the manual's Appendices is provided in the list at the end of the Draft Template. Some of the reports, documents and drawings to be included in these appendices were readily available as part of the Floodplain Management Strategy Update project. These materials have been organized into an indexed digital folder (provided separately).

6 FLOOD RESPONSE PLAN

Preparation and implementation of a flood response plan is a critical and effective flood management measure when integrated with other actions including regulation of floodplain development and construction and maintenance of structural works (dikes). Every year, the City of New Westminster (the City) prepares for and implements flood response activities in advance of and during the spring freshet. Much of the information in the City's current plan was developed in advance of the increased freshet flood potential in 2007 and 2012. The following sections and maps provide background on Fraser River flooding and an update to the technical basis for the City's flood response activities. These activities include the monitoring of river forecasts and gauges, placement of temporary works, dike and foreshore inspections and patrols, and evacuation planning.

6.1 Fraser River Flood Levels and Forecasting

The timing, duration and rate of rise of Fraser River water levels are important factors for flood response planning. Although hydrograph shapes can vary significantly from year to year, including multiple peaks corresponding to changing weather, freshet flood levels at the Mission gauge typically reach their highest level between about mid-May to early July. In the 1948 flood, the flood level at the Mission gauge remained within 0.2 m of the peak level for about two weeks, giving ample time for dikes to become fully saturated and subject to seepage flow conditions.

Given a sustained period of warm weather over an average (or greater) snowpack, or with heavy rainfall, the river can rise very quickly. From examination of several Fraser River Mission gauge hydrographs, a conservative assumption for planning would be to allow for a maximum 0.5 m rise per day at Mission due to extreme heating and/or heavy rain. In this scenario, the Mission gauge could potentially rise from about 6 m (bankfull flow – an approximate threshold of flooding of low lying un-diked areas in the Fraser Valley) to over 8 m (major flood conditions) in a minimum of 4 to 5 days. A more likely rate of rise would be half this rate, or about 10 days to go from bank full to major flooding conditions.

The Provincial River Forecast Centre (RFC) provides critical information each spring to support Fraser River freshet response. This information includes:

- The Snow Survey and Water Supply Bulletin - issued monthly from January to May, the April 1st Bulletin provides a full discussion of spring flood risk potential.
- Hydrological Model Forecasts (WARNS and CLEVER models) – these models are updated daily and provide daily average discharge flows for various gauge locations on the Fraser and major tributaries. These forecasted flows plus tidal levels provide the input to a Lower Fraser River hydraulic model used to predict water levels.
- Lower Fraser River Water Level Forecasting (output from a Lower Fraser River hydraulic model as briefly described below).
- High Streamflow Advisories, Flood Watch and Flood Warnings – issued for specific regions or locations.

The Lower Fraser River Water Level Forecasts provide a primary tool during the response phase. Over the past several years, the Province of BC has operated a one-dimensional hydraulic model that extends from Hope to Richmond. The model utilizes Danish Hydraulic Institute MIKE 11 software. With forecasted flow inputs from the RFC's hydrologic model(s) and tidal predictions, this hydraulic model is used to forecast water levels at approximately 75-gauge locations along the Lower Fraser. Lower Fraser water level forecasts have typically been provided when the Mission gauge is forecast to rise to about 5.5 to 6 m.

The RFC web page publishes forecasted water levels for five gauges located in New Westminster:

- CNW Winvan - staff gauge in the Braid Industrial area – maintained by the City
- CNW Quayside – staff gauge – maintained by the City
- CNW Fraser River Pile and Dredge – staff gauge on the North Arm – maintained by the City
- Carter PS – staff gauge on Annacis Channel in Queensborough – maintained by the Province
- CHS New Westminster (Canadian Hydrographic Service gauge 07654) – continuous recording gauge located at Westminster Quay

The locations of the above gauges are shown in **Figure 6.1**.



Figure 6.1 Fraser River water level gauges in New Westminster

While the water level predictions are currently published as 10-day forecasts, the reliability of the forecasts can diminish significantly beyond only a few days as they are dependent on the reliability of the weather forecasts. Nonetheless, the water level predictions provide a useful basis for planning, particularly if potentially extreme weather (e.g. excessive heat and/or precipitation) is forecasted.

An example water level forecast and a map showing the entire Lower Fraser Gauge Network is available online (see links at the end of this report). (Note: in the past, the levels have been published in the older CGVD28 datum; therefore, if this practice continues, a factor of 0.11 m should be added to approximately convert levels to CGVD2013 at locations in New Westminster.)

6.2 Non-Freshet High Water Events

In addition to Fraser River freshet flooding, it is useful to briefly compare the water levels and severity of two other sources of flooding. Both of the non-freshet events described below have significantly less potential for flood impacts on the City than a major Fraser River freshet flood.

6.2.1 High Winter Ocean Levels Combined with an Atmospheric River Event and High Flows on the Lower Fraser River

Storm surge events can significantly increase ocean levels above the predicted high tidal levels. For example, the Winter Historic 0.2% AEP ocean level at the mouth of the Fraser (without future sea level rise) has been estimated to be 2.88 m CGVD2013 (NHC, 2019). Moderately high flows can also occur on the Fraser in winter, as recently seen in November 2021, when Mission gauge reached 5.67 m CGVD2013. Although the coincidence of extreme ocean levels and high winter flows on the Fraser would be rare, the water levels at Westminster Quay could conceivably reach 3.0 m CGVD2013 (from the hydraulic modelling used to generate **Table 6.1**, present day - without sea level rise).

Given the land elevation profiles shown on the Mitigation Boundary Freeboard Maps (see Section Non-Freshet High Water Events below), a level of 3.0 m CGVD2013 would be below the threshold of flooding for both Queensborough and Waterfront. However, the Braid Industrial area might experience minor flooding in this type of extreme winter storm surge and atmospheric river event.

6.2.2 Brunette River High Flows

Metro Vancouver has recently completed a floodplain mapping study of the Still Creek - Brunette River drainage area (NHC, 2021). The hydraulic modeling shows that the 0.2% AEP present day flood can impact a low-lying area east of Brunette Avenue in the vicinity of the Braid Street railway crossing.

Potential impacts from the present-day 0.2% AEP Brunette River flood are significantly less than from the present day 0.2% AEP Fraser River freshet. However, with consideration of increased flows due to climate change and land use effects, the study showed that more areas are potentially subject to Brunette River flooding.

6.3 Areas of City at Risk from Fraser River Floods

6.3.1 Detailed Inundation Maps

The City lies partly within the Fraser River floodplain; roughly 170 ha along the north bank, comprised mainly of the Waterfront and Braid Street Industrial areas, and 350 ha in Queensborough. Appendix A

presents maps that show the extent and depths of flooding for the entire City corresponding to various flood scenarios, including dike breaching and climate change effects.

Appendix F includes the following additional inundation maps that show the pattern of flooding in more detail:

- Maps 1, 2 and 3: Present Day 2%, 1% and 0.2% AEP Max. Depth Maps
- Map 4: North Arm Breach 1894 Flood – Max. Depth map for Queensborough (the 1894 flood magnitude has an estimated AEP of just under 0.2%)

For the purposes of flood response planning for the Waterfront and Braid Street Industrial areas, the present-day maximum depth maps are useful for identifying areas subject to flooding. Because the diking system in Queensborough is not overtopped by the present-day 0.2 % AEP flood, a dike breach scenario max depth map is included to provide information with respect to access/egress and evacuation planning.

6.3.2 Mitigation Boundary Freeboard Maps

Placement of temporary works to raise low sections of the foreshore and dikes can be an effective flood response measure. The City's previous flood response plans included mitigation program maps for Waterfront, Queensborough and Braid Industrial Park showing mitigation boundaries, low sections and types of temporary works to be placed; see figures 4, 5 and 6 in the City's 2012 Freshet Response Plan and Preparation Binder (City of New Westminster, n.d.). This approach was updated by comparing ground elevations along the mitigation boundaries from a recent LiDAR based DEM with the 0.2% AEP flood level profile.

The Mitigation Boundary Freeboard Maps for Waterfront, Queensborough and Braid Industrial Park are included in Appendix F. Maps 5, 6 and 7 show the ground and flood profiles and the amount of freeboard (if any) in colour coded increments of 0.3 m. The mitigation boundaries are based on those considered previously by the City, with relatively minor adjustments as described below.

Ground profiles were extracted along the mitigation boundaries using the DEM from the Fraser Basin Council 2019 Fraser River 2D flood model (NHC, 2019) and Queensborough survey data collected by NHC in May 2021. The mitigation boundary alignments were adjusted to capture ground elevations along the shoreline that define susceptibility to flooding, ensuring a good fit to top of bank and relevant high ground. Areas of high ground that could currently provide flood protection but are not considered part of a diking system were leveraged where appropriate, such as filled areas for roads, parking, trails, landscaping etc. and some building foundation walls (noted on figures where included). Following profile extraction using GIS software, results were inspected and anomalies that were determined to be artefacts of digital sampling were manually corrected to reflect interpreted ground elevations.

Ground profiles were then compared against hydraulic model results for the present-day 0.2% AEP (500-year return period) Fraser River freshet, as extracted from the FBC 2019 Fraser River 2D flood model. Mitigation boundary linework on the plan view maps was colour-coded by available freeboard. To reduce frequent changes in line colour where the profile was near the freeboard category limits, the

colour coding sensitivity was slightly reduced. Therefore, the freeboard indicated by colour coding may vary by +/- 0.05 m from calculated freeboard.

6.3.3 Flood Levels in New Westminster in Relation to Mission Gauge and Ocean Levels

The FBC 2019 Fraser River 2D flood model can be used to relate flood levels at the New Westminster CHS gauge (located near the Fraser River Discovery Centre at New Westminster Quay) to water levels at the Mission gauge and the ocean level (**Table 6.1** and **Figure 6.1**) The model simulation was based on a rising limb hydrograph, with concurrent combinations of Fraser River water levels at Mission and ocean levels run to populate the table. This table can be used to roughly estimate the flood level at the Quay that would result from forecasted Mission and ocean tide levels.

Mission and ocean tide levels can both be monitored from publicly accessible real-time gauge data (see links at the end of this report). As previously noted, during the freshet, the Provincial water level forecasts provide specific water level predictions for the Mission gauge and the gauges located at the Braid St Industrial Park, New Westminster Quay, Fraser River Pile and Dredge and at the Carter St Pump Station in Queensborough.

Table 6.1 Lookup table relating Fraser River stage in New Westminster to water level in Mission and ocean tide level

Stage at New Westminster CHS Gauge (07654)
(m CGVD2013 [1])

		Water Level at Mission WSC Gauge 08MH024 (m assumed datum [2] / m CGVD2013)			
		5.8 / 6.0	6.8 / 7.0	7.8 / 8.0	8.8 / 9.0
Ocean Level (m CGVD2013)	1.5	2.3	2.7	2.9	3.4
	2.0	2.6	3.0	3.3	3.7
	2.5	3.1	3.2	3.6	3.9
	3.0	3.4	3.5	3.9	4.1

Notes:
1. Water levels at CHS Gauge 07654 are reported in chart datum. To convert chart datum at CHS Gauge 07654 to CGVD2013, subtract 1.16 m.
2. Real time water levels at Mission are reported by Environment Canada in assumed datum.
3. During high flows, the peak water level at the Braid Industrial Park is approximately 0.3 m higher than at the CHS Gauge.

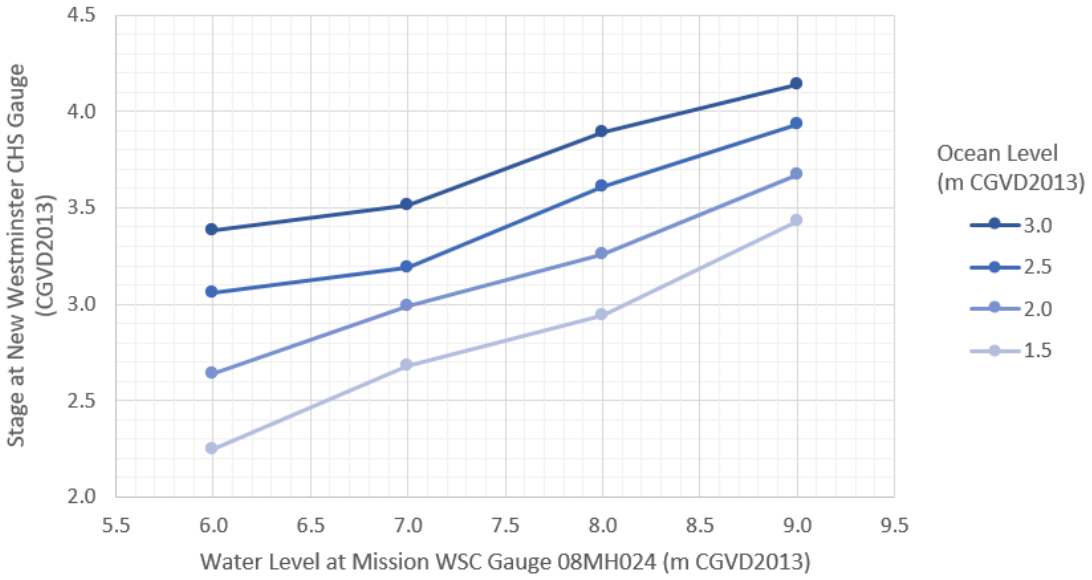


Figure 6.2 Plot showing relation between water levels in New Westminster and Mission for various ocean tide levels

The estimated water levels at New Westminster are approximate and actual values may vary from those provided above. For hydraulic model limitations, please refer to the hydraulic modelling report (NHC, 2019). The model assumes a fixed riverbed whereas the channel may change due to scour and sediment deposits during a large flood. Debris depositions may locally impact water levels. Predicted astronomical tide levels do not include storm surge. The stage-discharge relationship at Mission is unstable due to gradual degradation, likely as a result of past dredging activity in the Lower Fraser River.

The following points provide some context for the ocean level heights in **Table 6.1**.

- A level of 1.5 m CGVD2013 would correspond to a very common high tide (Higher High Water Mean Tide for the CHS Point Atkinson Gauge 07795 is approx. 1.4 m CGVD2013).
- An ocean level of 2.0 m CGVD2013 would correspond to a very high tide plus a small residual (Higher High Water Large Tide for Pt Atkinson is approx. 1.9 m CGVD2013).
- An ocean level of 2.5 m CGVD2013 could result from a significant storm surge on top of a high astronomical tide.
- A level of 3.0 m CGVD2013 would be a very extreme high ocean level.
- As noted previously, the Winter Historic 0.2% AEP ocean level at the mouth of the Fraser, without future sea level rise, has been estimated to be 2.88 m CGVD2013 (NHC, 2019).

Table 6.2 provides flood levels at Mission corresponding to a range of Annual Exceedance Probability (AEP) events, as generated by the FBC 2D model (NHC, 2019).

Table 6.2 Approximate Flood Levels at Mission for a Range of Flood Magnitudes

Flood Magnitude	Mission Gauge Level (m, assumed datum)	Mission Gauge Level (m CGVD2013)
Present Day 2% (1:50) AEP	7.3	7.5
Present Day 1% (1:100) AEP	7.7	7.9
Present Day 0.2% (1:500) AEP	8.6	8.7
Historic 1894 Flood	8.7	8.8

6.4 Flood Mitigation with Placement of Temporary Works

As general objectives, it is proposed that:

1. temporary works should be in place at least one week before flood levels could rise to within a few tenths of a metre of overflowing the lowest sections of foreshore and impacting vulnerable sites; and
2. for years when temporary flood mitigation is required, the works should be installed to provide 0.6 m freeboard above the 0.2% AEP flood profile, where feasible and cost effective.

The proposed freeboard of 0.6 m provides a factor of safety against uncertainty in both predicted flood levels and assessed ground elevations, as well as a nominal allowance for wave action.

Based on the mitigation boundary maps/profiles and interpolation of the values in **Table 6.1**, a set of trigger levels are proposed in **Table 7.1**. These trigger levels are based on water levels at Mission that result in stage at New Westminster approaching the first overflow elevations of the mitigation boundaries and serve as a rough guide for the timing of placement of temporary works. Using the 7-to-10-day Provincial Lower Fraser River Water Level Forecasts, and assuming the works can be placed within the forecast period, installation of the works should commence when the trigger levels are predicted. For locations where longer lead times are required, the placement timing may have to be advanced.

Table 6.3 Proposed Forecasted Trigger Levels for Placement of Temporary Works

Area	Vulnerable Location	Threshold Water Level that Could Initiate Flooding	Equivalent Trigger Level at Vulnerable Location (from Table 3.1)	Forecasted Trigger Level at Mission Gauge
Braid Industrial Park	Near Sta 1+200 in Area A (east of Capilano Way and along Bypass Channel)	3.0 m	2.9 m [3]	**6.0 m**
Waterfront	Sta 0+050 to 0+460 (near Kruger Products)	3.1 m	2.6 m	**6.0 m**
	Waterfront Esplanade and Quay	3.5 m	3.0 m	**7.0 m**
Queensborough	Furness Street	3.7 m	3.2 m	**7.5 m**

Notes:
1. All elevations provided in CGVD2013 datum.
2. Assumed peak ocean level = 2.0 m which is conservative.
3. A 0.3 m adjustment has been added to allow for the typical river gradient between the Quay and the Braid Industrial Park area.

While the mitigation boundary maps provide an indication of existing freeboard and vulnerability, an important next step for the City is detailed planning of the temporary flood protection works to be placed. In some locations, mitigation works may only be required between buildings and landscaping, tying into those features for flood protection. In other locations, the actual height of temporary works may exceed what is indicated by freeboard on the maps and profiles due to practical considerations that require placement to differ from the mitigation boundary alignments.

6.5 Dike and Foreshore Monitoring

The Queensborough dikes and various sections of the mainland foreshore (i.e. Waterfront Esplanade) should be monitored during high river flow conditions. For all areas, City staff should look for evidence of potential erosion or scour, and any impacts from floating debris. The Provincial Dike Patrol Guidelines and Flood Protection Works Inspection Guide (see links section) provide guidance on the frequency of patrols and how to identify conditions that might jeopardize dike safety.

Much of the diking system in Queensborough is comprised of relatively low earth dikes with extensive landfill on the landside. Unless very high-water levels occur (i.e. approaching the freeboard zone), dike patrols should focus inspections on sections of dikes that are approximately 1.5 m or higher relative to the adjacent land elevations. Special attention should also be given to frequent inspections and monitoring of the dikes immediately adjacent to and at the four major pump stations. The dikes at these locations are typically 3 to 4 m high relative to the drainage canal water levels. Seepage and/or stability issues at these locations can occur at flood levels well below design flood levels.

6.6 Evacuation Planning and Flood Impacts on Access

Maps 3 and 4 in Appendix A indicate the potential extents of flooding and possible road closures that could affect evacuation requirements and timing. The animation videos provided to the City with NHC's June 24, 2021 Modelling and Mapping Report give additional insight on how the progression of flooding might be affected by tides and timing of the Queensborough dike breach. Actual flooding patterns would depend on many factors (i.e. storm drainage system details) not included in the 2D model.

The following sections briefly discuss a few of the critical factors affecting access and evacuation planning for a large flood event for Waterfront, Braid Industrial Park (present day 0.2% AEP event) and Queensborough (North Arm Breach 1894 flood event).

6.6.1 Waterfront

If temporary mitigation works fail, key access and egress routes subject to at least shallow flooding could include:

- Stewardson Way east of 3rd Avenue
- Quayside Drive (full length, except for overpass at 3rd Avenue)
- Front Street west of 6th Street
- A section of Columbia Street near the intersection with 10th Street

Disruption of normal access to the densely populated Waterfront residential area should be anticipated. However, given the shallow flooding of most of the above roads, emergency vehicle access may be possible, depending on drainage at low tide.

Because of City floodproofing requirements over the past few decades, very few actual living units would be flooded as the habitable areas of buildings have been required to be elevated above Flood Construction Levels. However, below grade parking areas and possibly some building foyers and elevators, or other equipment may be impacted. Emergency planners should check the critical design levels for each building against the recently modelled flood levels (i.e. the present day 0.2% AEP modelled water surface level is 3.5 m CGVD2013 at Rialto Court and 3.6 m CGVD2013 at the Quay) to identify which buildings might be vulnerable to at least some flood impacts.

6.6.2 Braid Industrial Park

If temporary mitigation works fail, or are overtopped, possible road flooding could include:

- Braid Street access flooded to depth of over 1 m.
- Canfor Avenue flooded east of the Brunette River bypass channel.
- Brunette Avenue may be subject to shallow flooding with possible closure for a short section just south of Braid Street.

The Spruce Street access would not appear to be inundated by the 0.2% AEP flood level. Because of the non-residential land use, the City could control access for the businesses and property owners in the area on an as needed basis.

6.6.3 Queensborough

The approximately 7.3 km long perimeter Queensborough dike is generally high enough to prevent an overtopping failure during a 0.2% AEP flood event under present-day conditions. However, given the possibility of larger floods and that dikes can breach catastrophically due to other failure mechanisms (e.g. uncontrolled seepage, embankment instabilities, and river erosion) the City should prepare an evacuation plan. The plan would need to be implemented when a dike failure (through any mechanism) is assessed to be probable and/or imminent. With a population of more than 8,700 people (2016 census) and with much of the residential area being subject to 1 to 3 m depth of flooding, an effective evacuation plan is critical for public safety.

Map 4 in Appendix A shows maximum flood depths over the areas and roads that could be affected by a hypothetical dike breach near the Stanley Street pump station on the Fraser River North Arm during a recurrence of the 1894 flood magnitude. Except for Port Royal homes and recent landfilled developments near South Dyke Road (i.e. those homes constructed on fill above approx. 3.5 m) most residential properties would be surrounded by flood water and unsafe to occupy.

All normal access and egress routes would be disrupted following a dike breach. These include:

- Queensborough Connector (Hwy 91A) with shallow flooding of the approaches to the Annacis Channel and North Arm (Queensborough) Bridges.
- Ewen Avenue – deep flooding.
- Boyd Street to Westminster Highway – deep flooding.
- Derwent Way north of the Derwent Way Bridge to Annacis Island.

Due to extensive landfilling, there is relatively safe, high ground at Port Royal. It may be feasible to establish a temporary emergency egress route from Port Royal to the Derwent Way Bridge along the perimeter dike alignment.

Evacuation timing and decision making is complex and depends on many factors. Evacuation alerts and orders should be issued when there are any specific assessments indicating a probable or imminent dike breach, or when the Fraser River is forecast to exceed the nominal capacity of the diking system (i.e. less than 0.6 m freeboard for the 0.2% AEP flood). Possible evacuation alert trigger levels would be when the Mission gauge is forecast to reach 8.7 m and the New Westminster CHS gauge is forecasted to reach 3.6 m CGVD2013.

6.7 Future Freshet Response Plan Updates

To remain current, the technical basis for the freshet response plan as outlined in this report should be reviewed every few years, or whenever significant changes occur with respect to both the flood hazard and/or the vulnerability of key areas in the City. These factors would include:

- increased Fraser River flows and/or ocean levels based on better climate change predictions
- hydraulic modeling improvements
- any dike upgrades introduced
- changes in grade along the mitigation boundary due to landfilling, development or subsidence
- changes in provincial flood forecasting information and gauge reporting locations
- experience gained during future large flood events.

6.8 Useful Links

1. Sample Lower Fraser River Water Level Forecasting Report
2. Map of Existing Gauge Network on the Lower Fraser River
3. Water Survey of Canada Real Time Data Mission Gauge
4. Canadian Hydrographic Service (CHS) Point Atkinson
5. Canadian Hydrographic Service (CHS) New Westminster
6. Provincial Dike Patrol Guidelines
7. Provincial Flood Protection Works Inspection Guide

7 INTEGRATED FLOODPLAIN MANAGEMENT AND OTHER NON-STRUCTURAL MITIGATION MEASURES

7.1 Integrated Flood Management and Non-Structural Mitigation Measures

The risk and impacts of flooding can be mitigated by several different approaches including structural measures such as dikes, and non-structural measures such as land use management and emergency planning, response, and recovery. In recognition that each approach by itself has limitations, the integration of a combination of mitigation activities is needed to minimize flood risk.

For example, dikes can provide years of flood protection benefits, but can fail through defects or exceedance of design criteria. Effective flood warning, response and recovery are essential to public safety and reducing social impacts, but the emergency response will not prevent much of the property damage. Land use management has limitations too, given that retreat from floodplain lands is usually neither practical nor desirable. While much historic floodplain development may remain vulnerable to

flood damage, raising and "floodproofing" new development, where feasible, can greatly reduce future flood damage costs and public safety concerns.

Non-structural mitigations include land use policies and public education to reduce the consequence of a flood by reducing the exposure, reducing the vulnerability, and increasing the resiliency to flooding. These measures include establishing limitations, restrictions, and requirements on land use, such as limits on what type of development occurs on flood prone lands, establishing no-build setbacks from the riverbanks and dikes, and defining minimum elevations for new construction (i.e. flood construction levels - FCLs). Non-structural flood mitigation measures also include public education, to increase awareness of the local flood risk and the role and value of individual preparations.

Non-structural mitigations influence community behaviour and actions. This is in contrast to structural mitigations (e.g. dikes, flood reservoirs, by-pass channels, dredging etc.) which are intended to influence the physical flood. If broadly applied over the long term, non-structural flood management can be the most effective and the least costly mitigation to limit or reduce flood risk.

The non-structural measures reviewed in this section of the report focus on floodplain land use management, i.e. development planning, building regulations, public education and related measures with respect to flooding from the Fraser River. Emergency response planning information is provided in Section 6. Stormwater management information is discussed in Section 8 and Appendix H.

7.1.1 The Context - Changing Flood Hazards and Need for a Long-Term Strategy

The land use planning tools and floodplain development regulations currently employed by the City are based on historical flood information and guidelines provided over the past few decades by the Province of BC. While the effects of climate change are highly uncertain both in timing and magnitude, these effects have now become critical factors that must be considered in the development of a long-term floodplain management strategy.

The Year 2100 design flood levels described in Section 2 of this report incorporate the potential for a 35% increase in Fraser River flood flows combined with sea level rise of one metre. Provincial Guidelines (MFLNRORD, 2018) also recommend that, "Land use adaptation strategies as set out in Official Community Plans (OCPs) and Regional Growth Strategies (RGSs) should allow for sea level rise to the Year 2200 and beyond" and over this time period to plan for two metres of sea level rise, relative to the Year 2000.

The City is located in the Fraser River estuary where peak flood levels depend on the combined effects of river flows and sea levels. Updated Year 2100 Flood Construction Levels (FCLs) for the downtown based on the above criteria are more than 1 m higher than current bylaw levels. Allowing for a Year 2200 sea level rise of 2 m for long-term planning as per the provincial Guidelines could increase the FCLs in the downtown by approximately an additional 0.5 m.

Higher and wider dikes to mitigate the impacts of rising flood levels plus the need to address the seismic vulnerability of dikes also has significant implications for foreshore development. Upgrading existing dikes and new dikes will require more space, and/or very costly floodwall structures.

The City of New Westminster's Floodplain Management Strategy is being developed within the context of two regional planning initiatives:

A. **The Metro 2050 Regional Growth Strategy** (Metro Vancouver, 2022) states that Metro will mitigate flood risks with respect to Metro's extensions of regional infrastructure and designation of areas for intensive population growth. This document also states that member jurisdictions will:

"support climate change adaptation including:

- monitoring storm water, flooding, and sea level rise impacts on agricultural land,
- implementing flood construction requirements for residential uses"

"include policies that minimize risks associated with climate change and natural hazards in existing communities through tools such as heat and air quality response plans, seismic retrofit policies, and flood-proofing policies"; and

"adopt appropriate planning standards, guidelines, and best practices related to climate change and natural hazards, such as flood hazard management guidelines…"

B. **The Lower Mainland Flood Management Strategy** is being developed by the Fraser Basin Council (FBC) and its partner organizations. The City is a member of the Joint Program Committee (JPC) for Integrated Flood Hazard Management facilitated by the FBC, which guides and supports the development of the Lower Mainland Flood Management Strategy. This initiative is currently in Phase 2, and while the "Strategy" itself is not yet complete, the study work to date has developed many useful products that can support the City's work, such as the 2D hydraulic model used to estimate the design flood levels at various locations in the City (NHC, 2019).

7.1.2 Section Outline

The relationship between land development and vulnerability to flood hazards in each part of the City's floodplain areas varies and, therefore, a different combination of mitigation approaches may be needed. The following section (Subsection 7.2 briefly describes the flood vulnerability, land use and development potential for Queensborough, Downtown, Braid Industrial Area and the West Industrial Area.

Section 3 describes a number of non-structural measures, current City requirements and possible improvements. The final section (Sub-section 7.4) provides recommendations on the non-structural measures to be included in the City's updated Floodplain Management Strategy.

7.2 City Floodplain Development Characteristics

7.2.1 Queensborough

Queensborough comprises the upstream, eastern part of Lulu Island, bounded by Annacis Channel and the North Arm of the Fraser River; all its area of 303 hectares lies within the natural floodplain of the Fraser River. Since the early 1990's several former industrial sites in Queensborough have been transformed into residential and commercial areas. The population has grown steadily from about 2000 people in 1991 to nearly 10,000 people today (8,700 people in the 2016 Census).

As part of the 2014 Queensborough Community Plan review, the Land Use Designation Map development capacity was estimated to provide enough homes for up to 14,825 residents by 2041 (City of New Westminster, 2014). Current and future residential construction includes redevelopment of homes on small, existing residential lots as well as larger subdivision developments that may include both single family and multifamily structures.

In addition to mitigation of flood risk by dikes, the Province of BC has encouraged floodproofing of new residential development in floodplains since the mid 1970's, primarily by elevating the habitable floor space within a building to the Flood Construction Level. Residential construction to the full FCLs recommended by the Province has been very challenging within the older residential areas of Queensborough, given the historic subdivisions into small residential lots, the low natural grades relative to the flood levels, and the soft organic foundation soils. The recent large subdivision developments, particularly on former industrial lands such as Port Royal in the eastern part of Queensborough, have generally been able to achieve floodproofing standards.

The Port of Vancouver, which is a federal agency, has a degree of planning jurisdiction along the waterfront through ownership of a substantial amount of water lots and waterfront property. This may impact the layout of future foreshore land development including the alignment and design of upgraded perimeter dikes.

Given Queensborough's ongoing population growth and floodplain development, consideration of non-structural mitigation measures should be a high priority.

7.2.2 Downtown

The Downtown area includes the Fraser River foreshore and floodplain areas extending downstream from the Patullo Bridge to the eastern end of Quayside Drive at Poplar Landing. **Figure 7.1** is "Schedule E Floodplain Boundary" from the Downtown Community Plan 2010, with updates to 2020, (City of New Westminster, 2010), and **Figure 7.2** shows maximum flood depths from the HECRAS 2D hydraulic model projected for the Year 2100 0.2% AEP flood (NHC, 2019). The floodplain zone is relatively narrow in the upstream section but widens out further downstream to a maximum width of about 400 m, where it extends beyond Columbia Street to the edge of the hill slope.

Existing high density residential development in the Downtown floodplain area is comprised of mid-rise and high-rise multi-family buildings. With the exception of the Poplar Landing site at the downstream

end, most of the foreshore lands have already been developed or are under construction (i.e. Pier West). However, there is considerable re-development potential in the floodplain areas north of the railway corridor, in areas that are designated "Mixed-Use High Density" on the Community Plan Land Use Map **Figure 7.3**.

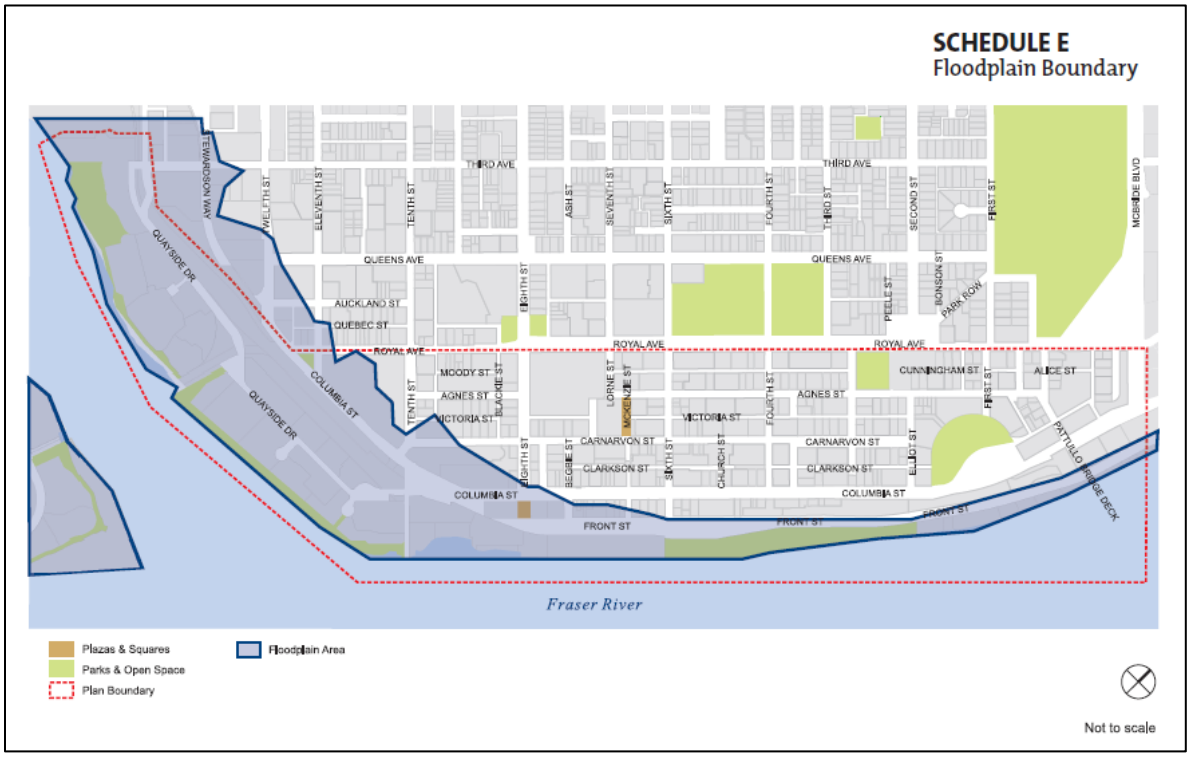


Figure 7.1 Floodplain Boundary from Downtown Community Plan 2010

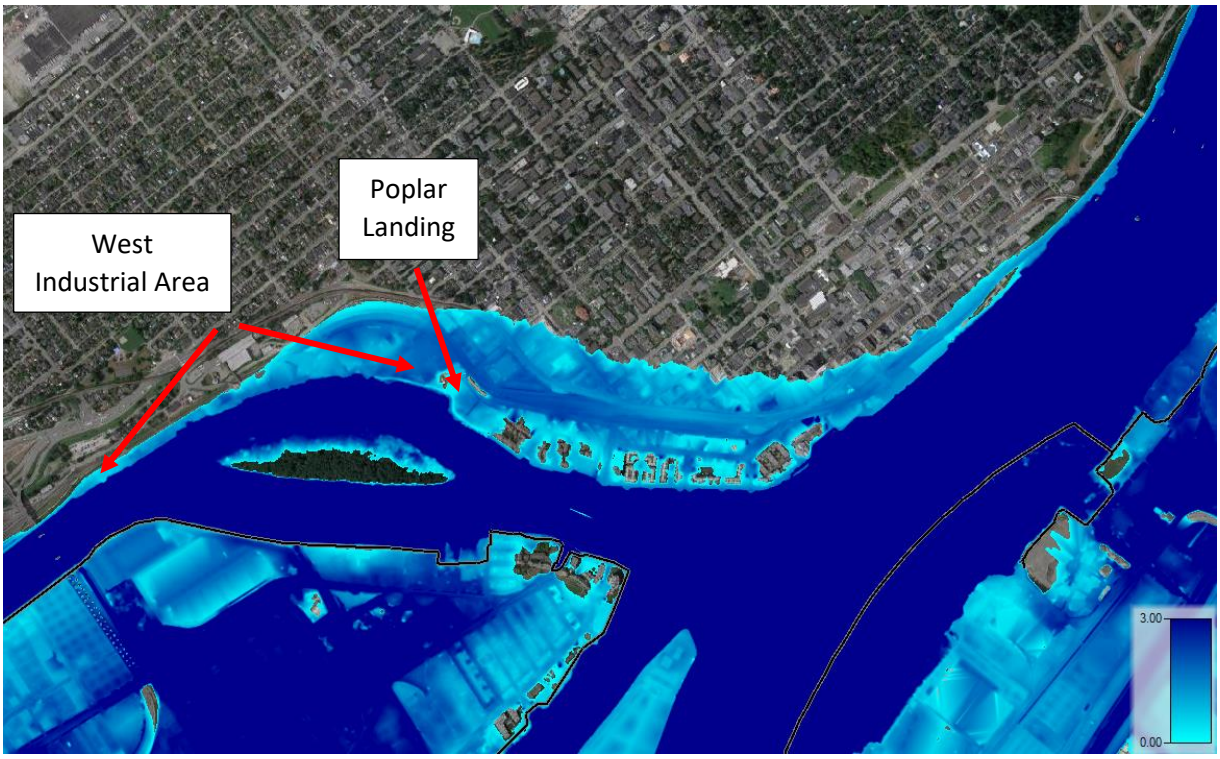


Figure 7.2 Maximum Depths for the Year 2100 0.2% AEP Flood in the Downtown and West Industrial Areas

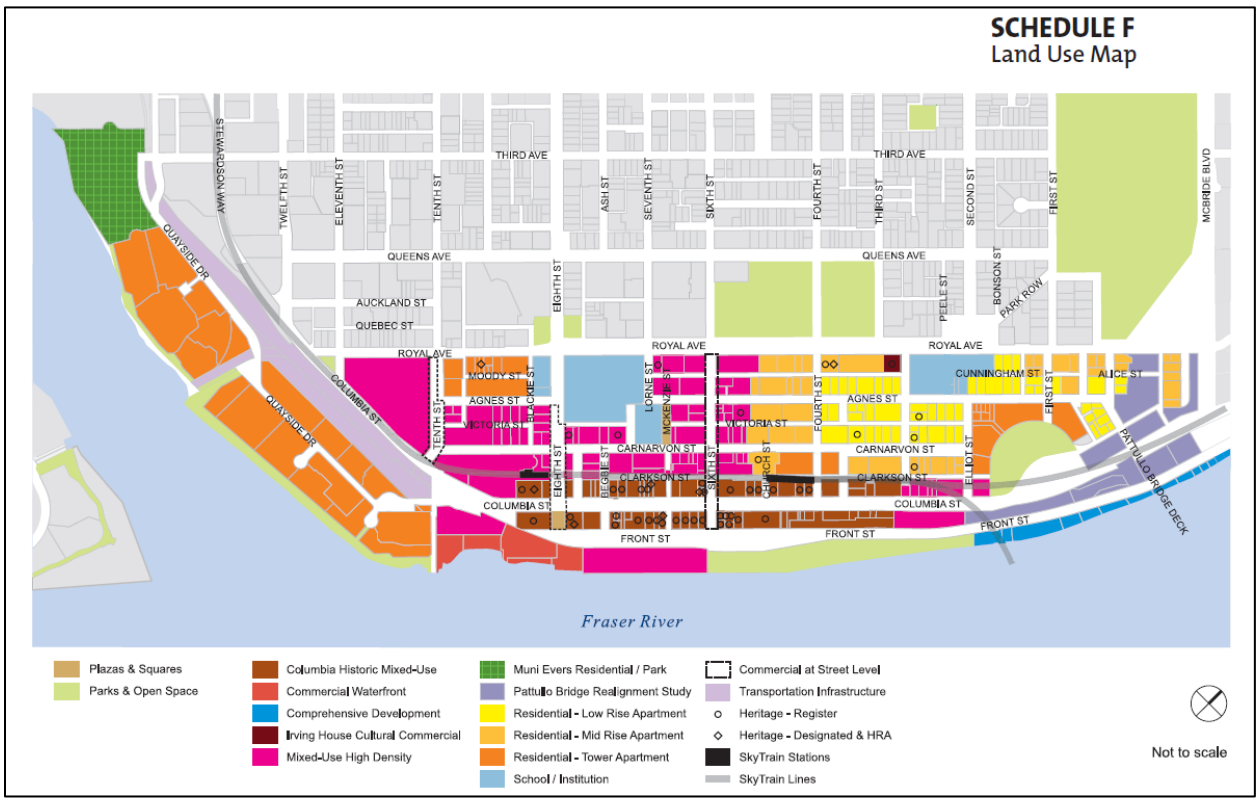


Figure 7.3 Land Use Map from Downtown Community Plan 2010

7.2.3 Braid Street Industrial Area

The Braid Street Industrial Area is in the floodplains of both the Brunette River and the Fraser River near the Coquitlam border. The City's Official Community Plan (OCP) shows continued industrial land use in this area, but notes that the industrial use would benefit from transportation access and infrastructure improvements (City of New Westminster, 2017). The area has no permanent dike protection. However, road and building elevations in the floodplain have historically been partially raised by fill, so potential depths of flooding are relatively shallow with respect to historic 1894 flood levels.

With consideration of climate change effects, the Year 2100 floodplain as projected by the HEC-RAS2D hydraulic model (NHC, 2019) would extend a short distance (50 to 100 m) northwest of Brunette Avenue and includes some lands currently designated for residential and mixed use **Figure 7.4**.

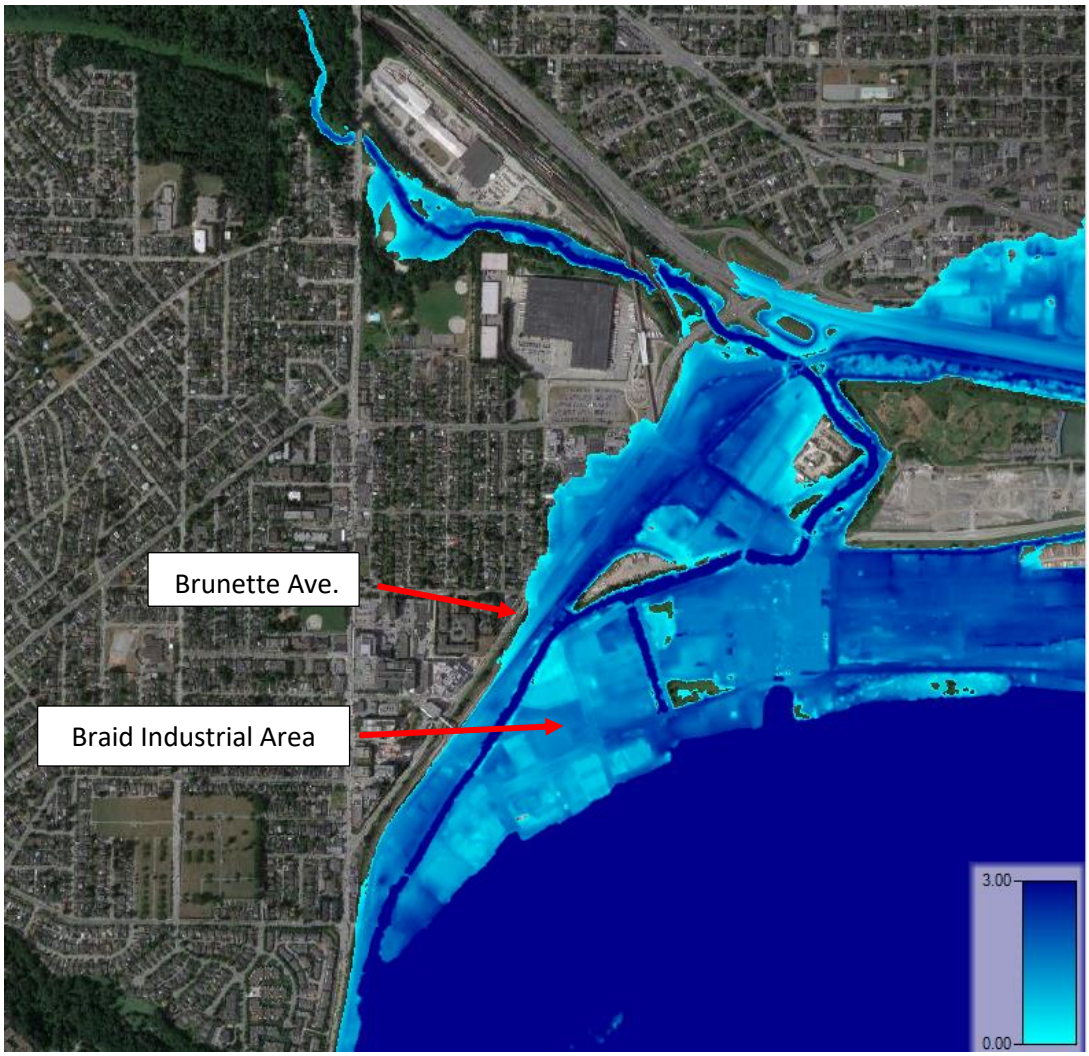


Figure 7.4 Maximum Depths for the Year 2100 0.2% AEP Flood in the Braid Street Industrial Area

7.2.4 West Industrial Area

The West Industrial Area (also known as the North Arm North Industrial area) is located west and downstream of Poplar Landing. The City's OCP shows continued industrial land use in this area, and notes that this type of riverfront industrial land that enables water-dependent industry is relatively scarce in Metro Vancouver. The area consists of the Kruger Products site west of Poplar landing plus a narrow strip of land extending almost to the Queensborough bridge. Except for a section of an emergency dike constructed in the spring of 2007 near Poplar Landing, the area is not protected by dikes.

The Year 2100 flood extents are very similar to the historic floodplain boundary given that the terrain rises steeply north of the railway track corridor **Figure 7.4**.

7.3 Non-Structural Flood Mitigation Measures and Relevance to the City

7.3.1 Planning and Building Regulation Tools and Guidelines

From the mid 1970's to 2003 the BC Ministry of Environment reviewed and approved municipal OCP floodplain policies, floodplain subdivisions and floodproofing bylaws, and established FCL's for specific locations. The legislative changes in 2003 gave municipalities the full responsibility to adopt and administer floodplain development regulations without provincial review or approval. However, local governments are still required to give consideration to provincial guidelines i.e. the "Flood Hazard Area Land Use Management Guidelines" May 2004, as amended in 2018 to address sea level rise (MFLNRORD, 2018) (referred to below as the "Guidelines").

As the types of hazards, historic development and future development potential in each floodplain area are unique, the specific regulatory mechanisms may vary. The Guidelines also provide a number of exemptions from full floodproofing, but give the general direction:

> "Local governments should consider broad flood hazard management tools to ensure that future land use will be planned and buildings constructed in a manner that will reduce or prevent injury, human trauma and loss of life, and to minimize property damage during flood events."

Because the City is located within the Fraser River estuary, the Fraser River freshet flood profile is significantly impacted by sea level rise, and therefore, the Amendment to Sections 3.5 and 3.6 of the Guidelines (MFLNRORD, 2018) is relevant. Year 2100 FCL's for "heavily populated and built-up areas" should be based on the 0.2% (1:500) AEP flood, 1 m of sea level rise and an allowance for regional subsidence. For areas protected by dikes, Section 3.6 and Appendix 1 of the Amendment indicate that relaxation of FC'Ls may be appropriate where the local government has adopted a long -term flood protection strategy, but subject to the following cautionary advice:

> "Relaxation of FCL requirements for new development in the protected area and intensification of development through subdivision of land has significant long-term implications. The future reliance on the sea dikes and consequences of dike failure will

> increase as development occurs and sea level rises. Therefore, the extent of work required to establish a successful long-term dike upgrading program is demanding and costly. This approach should only be undertaken where the extent of community development in the floodplain justifies the high cost and level of effort."

In addition to the provincial Guidelines, which encourage the adoption of prescriptive regulations such as Floodplain Bylaws or Development Permit Area requirements, current provincial legislation enables local governments to require a developer to provide a report, certified by a professional engineer or geoscientist, to establish floodplain development recommendations and requirements. Engineers and Geoscientists of BC has prepared professional practice guidelines entitled "Legislated Flood Assessments in a Changing Climate in BC" with an overall objective for professionals to provide consistent and comprehensive flood assessment reports (EGBC, 2018). The need for site specific flood assessments by Qualified Professionals (QPs) may be appropriate for large complex developments, or for developments in areas where other regulations and flood mitigation measures are not sufficiently defined.

Floodplain development planning and regulation can be implemented through several tools that include:

- Official Community Plans – policy statements and hazard schedules identifying flood prone lands.
- Rezoning and Subdivision approval requirements – Approving officers have considerable scope in establishing site specific flood management conditions.
- Building Regulations – usually implemented through Floodplain Bylaws or Development Permit Area (DPA) requirements (within DPAs as identified in OCPs).
- Flood Hazard Assessments by QPs for large, or complex new developments (e.g. as per EGBC guidelines).
- Floodplain Maps.

Floodplain maps and the related technical reports provide the basis for planning and regulatory requirements (e.g. at minimum, they define the extent of the floodplain and flood levels for a specified magnitude flood). The Province of BC was historically involved in floodplain mapping, but the program ended in the mid 1990's before maps could be completed along the Lower Fraser River. Although senior governments have recently provided limited funding for flood risk studies including floodplain mapping, the Province has not established mapping standards and does not review and approve maps.

APEGBC (APEGBC, 2017) has prepared professional practice guidelines that outline best floodplain mapping practices, but these guidelines are not prescriptive with respect to mapping standards, such as the required AEP of the design flood, freeboard requirements, or how to account for climate change effects.

Given the current hazard management legislative framework in BC, the City has considerable latitude in deciding what planning policies and regulatory requirements are the most appropriate and effective for each floodplain area. The FCLs adopted for new building construction in specific areas also may vary (i.e. be lower) from levels defined by floodplain mapping depending on the land use, the type of

development, dike protection and policies established within an integrated floodplain management strategy.

7.3.2 Current Floodplain Development Regulations and Possible Improvements

Goal 5 of the Queensborough Community Plan (City of New Westminster, 2014): "Queensborough effectively protects against and manages incident of flooding" is supported by four policies:

> "Policy 5.1: Manage the dikes so that they continue to be the primary defence against flood events.
>
> Policy 5.2: Apply the Flood Construction Level (FCL) regulation to new development as a secondary flood protection measure.
>
> Policy 5.3: Minimize the impacts of the Flood Construction Level (FCL) regulation on the aesthetics and functionality of buildings.
>
> Policy 5.4: Use emergency management processes to help minimize impacts to the community from a flood event."

Policies 5.2 and 5.3 with respect to FCLs are currently being implemented through a Natural Hazard Development Permit Area and through provisions in Zoning Bylaw No 6680 (City of New Westminster, 2001, 2017). The minimum FCLs (CGVD28 datum) are shown in **Figure 7.5**. The FCLs apply to all new building construction in Queensborough except for a number of minor exemptions (e.g. small additions to existing buildings, park buildings etc.) and do not apply to industrial buildings on parcels not adjacent to a dike.

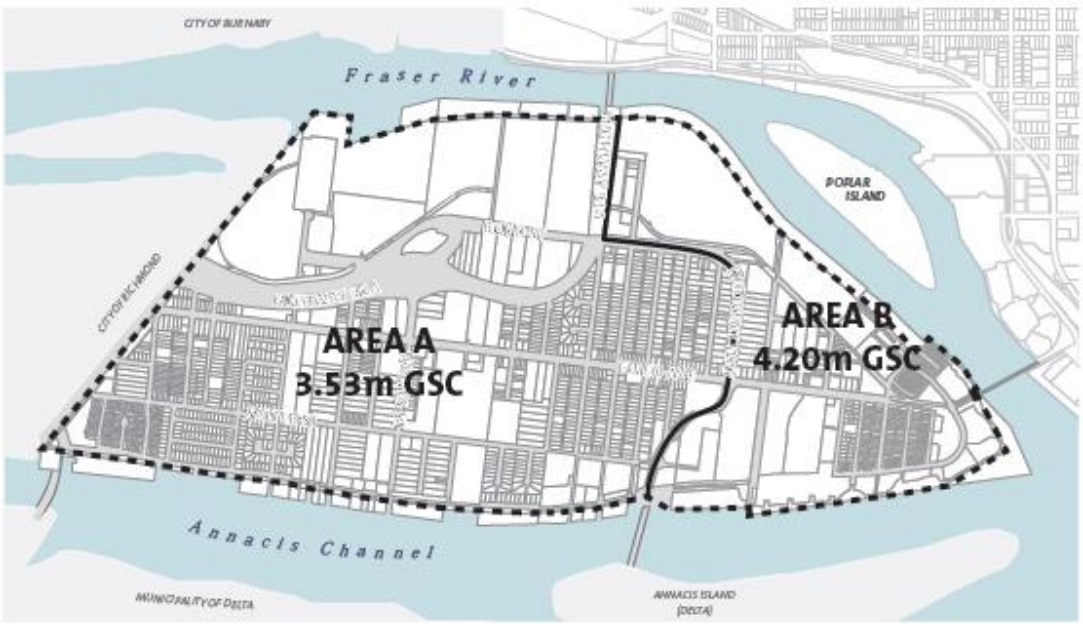


Figure 7.5 Minimum Flood Construction Levels in Queensborough (City of New Westminster, 2014) (CGVD28 datum)

The FCL for Area A in **Figure 7.5** was based on a Fraser River flood profile established by the Federal Government in 1969 and subsequent provincial advice to the City in the 1970's. A 1986 Ministry of Environment document states:

> "For ease of administration one elevation was adopted (i.e. 3.53 metres GSC) for construction protected by Ministry standard dykes and this elevation is 0.6 m less than the average Flood Construction Level. This reduced elevation was used in order to permit the construction of ground level basement homes in an area where predominantly peat soil conditions preclude the use of fill to achieve elevation in residential infill." (Ministry of Environment, 1986)

The FCL for Area 2 in **Figure 7.5** is based on the same 1969 profile but included a 0.6 m freeboard allowance. For the Queensborough area, more recent flood profiles for the historic 1894 design flood based on 1D and 2D hydraulic modelling are essentially unchanged from the 1969 profile.

Prior to implementation of the Natural Hazard Development Permit Area requirements in 2014, the City completed a review of various FCL options for Queensborough (Delcan, 2013). This study estimated how potential future flood damages and risk of loss of life could be modified by adopting lower or higher FCLs, including FCLs based on sea level rise of 1.0 m by the Year 2100 (i.e. the "Increased Level" scenario involved building all new homes to an FCL of 4.7 m CGVD28).

The analysis indicated that the "Intermediate Protection" scenario (i.e. consistently apply FCL's as per **Figure 7.5** to all new construction) would provide reduction in both flood damage and mortality. However, the effectiveness of this strategy would diminish over time with sea level rise. Given the practical limitations of implementing ever higher FCLs to match sea level rise, the analysis concluded that raising of the perimeter diking system and other dike improvements was vital for reducing flood risks.

Table 7.1 shows the current FCLs applied by the City in Queensborough vs. projected FCLs that would be consistent with current provincial Guidelines and EGBC guidance with respect to climate change effects - based on the Fraser River flood profiles developed for FBC (NHC 2019).

Table 7.1 Flood Construction Levels for Queensborough (m CGVD2013 datum)

Item	Queensborough Area A	Queensborough Area B
Current Development Permit Area FCLs	3.64	4.32
Projected Year 2100 FCL	5.3	5.8

Notes:

- Projected Year 2100 FCLs are based on 0.2% AEP levels from the HEC-RAS2D model NHC (2019) and include 0.6 m freeboard allowance.
- Queensborough FCLs include an additional regional subsidence allowance of 0.2 m for the Year 2100.
- Conversion factors from CGVD28 to CGVD2013 datum are +0.11 m for Queensborough Area A, and +0.12 m for Queensborough Area B.

The current policies and Development Permit Area flood construction requirements for new buildings in Queensborough are near the practical upper limit, and appear reasonable, given the constraints to building to higher FCLs. This limitation highlights the critical importance of the dikes as the primary defence (Policy 5.1) to the City's Floodplain Management Strategy to mitigate the impacts of climate change.

Because climate change effects have such a significant impact, Policy 5.1 should be amended to: "Upgrade and manage the dikes, considering the effects of climate change, so that they continue to be the primary defence against flood events."

Section 4 of this report outlines a proposed dike upgrading plan and Section 5recommends improvements to Dike Operation and Maintenance. However, a key constraint on dike upgrading is the lack of adequate space for wider and higher dikes. This limitation should be addressed through more detailed planning and regulation of development on parcels adjacent to dikes.

To facilitate long term dike upgrading for Queensborough plus operation and maintenance, the City should develop a "Dike Lands Plan" and implement it through planning and regulatory tools, in addition to direct negotiation and purchase from landowners. The Plan would identify the lands required and include policies and setback requirements for parcels adjacent to dikes that would enable acquisition of land and/or rights of way for upgraded dikes at the time of development approvals. Options for site redevelopment to incorporate sections of "super dike" should also be considered.

Downtown

The City's OCP (City of New Westminster, 2017) outlines several flood hazard management policies and actions.

> "Policy 6.1: Use emergency management programs to protect critical City infrastructure from hazard events.
>
> Policy 6.2: Promote community awareness and personal preparedness activities that help residents and local businesses prepare for, respond to and recover from hazard events.
>
> Policy 6.3: Protect against and minimize the impacts of sea level rise and Fraser River flooding.
>
> Policy 6.4: Ensure that buildings are designed, built, maintained and retrofitted in ways that minimize the risk of hazard impacts."

Actions identified in the OCP also include:

> "6.3c Develop and implement a new Flood Hazard Development Permit Area that clearly outlines the expectations for new development in the floodplain."

The Downtown Community Plan (City of New Westminster, 2010) states:

> "New and redeveloped buildings will be built so that no habitable space is below the appropriate Flood Construction Level as determined by a certified engineering professional."

The City's Building Bylaw No. 8125 (2019) provides the Building Official with the authority to:

> "require the owner of the land to provide a report, at the owner's expense, certified by a professional engineer with experience in geotechnical engineering, that the lands may be used safely for the use intended subject to the conditions contained in the professional engineer's report."

Bylaw 8125 (2019) also contains a reference to Floodplain Bylaw No. 5095 (1978) that specifies FCLs for the floodplain area (CGVD28 datum):

> "No building or any part thereof shall be constructed, reconstructed, moved or extended anywhere on the Lands with the underside of the floor system of any area used for habitation, business or storage of goods damageable by flood waters, lower than an elevation which would be described by an even gradient from four point one five (4.15) metres G.S.C. datum at the Queensborough Railway Bridge to four point four (4.4) metres G.S.C. datum at the Pattullo Bridge."

City staff (M. Watson, Acting Supervisor of Development Planning) advised that for areas covered by the Floodplain Bylaw, the 1978 FCL's would be the requirement. For areas covered by the downtown plan but not covered by the flood plain bylaw, the City would rely on the statement in the Downtown Community Plan, "New and redeveloped buildings will be built so that no habitable space is below the appropriate Flood Construction Level as determined by a certified engineering professional."

As a comparison with the 1978 bylaw levels, **Table 7.2** gives projected Year 2100 FCLs with reference to the Queensborough Rail Bridge and the Patullo Bridge. Given provincial and EGBC guidelines, it would be expected that site specific engineering reports would recommend higher FCLs that consider sea level rise and other climate change effects (i.e. similar to **Table 7.2**). As a recent example, landscape drawings for the Pier West development, currently under construction on the waterfront, show a finished floor elevation of 5.75 m CGVD2013 (EGBC, 2018), (Connect Landscape Architecture, 2021) which is in the range of the Projected Year 2100 FCLs in **Table 7.2**.

Table 7.2 Flood Construction Levels for Mainland (m CGVD2013 datum)

Item	Mainland (Queensborough Railway Bridge)	Mainland (Patullo Bridge)
Bylaw No 5095 (1978)	4.27	4.51
Projected Year 2100 FCL	5.5	5.8

Notes:

- Projected Year 2100 FCLs are based on 0.2% AEP levels from the HEC-RAS2D model NHC (2019) and include 0.6 m freeboard allowance.
- Conversion factors from CGVD28 to CGVD2013 datum are +0.12 m at the Queensborough Rail Bridge and +0.11 m at Patullo Bridge.

As identified in the 2017 OCP, the City may prepare detailed Development Permit Area requirements for the Downtown area. These requirements would need to consider the implications of applying Year 2100 FCLs that are 1.2 to 1.3 m higher than the 1978 bylaw FCLs.

The construction of a new diking system to protect the downtown area as outlined in Section 4 is very costly and will likely take many years to implement. Even when constructed, the diking system will remain vulnerable to failure during large seismic events and would then have to be repaired/rebuilt. Therefore, floodproofing of new development in the Downtown area should be a critical component of the City's Updated Floodplain Management Strategy.

As envisioned by the 2017 OCP, updated regulations could be implemented by new Development Permit Area requirements based on detailed floodplain maps. The technical basis for the maps should incorporate the most recent climate change research, hydraulic modelling, and provincial guidance. Updated FCLs based on future detailed floodplain mapping studies may vary from the projected Year 2100 FCL's in **Table 7.2**.

Industrial Areas

Both the Braid Street and West Industrial areas are shown as "Areas Subject to Flooding" on the Flood Hazard Map in the OCP (City of New Westminster, 2017) however, the City does not currently apply floodplain specific requirements for new building construction in these areas.

Provincial guidelines (MFLNRORD, 2018) provide for reduced FCLs for industrial uses (e.g. minus freeboard) and other special provisions. Industrial land use specific Development Permit Area requirements should be prepared to mitigate potential flood impacts on new development and to provide flexibility for future dike construction.

A further consideration is that any industrial operations that store hazardous wastes would need to comply with the provincial "Hazardous Waste Regulation" minimum siting standards for floodplain areas (BC Reg. 63/88 amended 2021). Due to the historical industrial use of these lands, there is also potential for flood events to mobilize and release contaminants from contaminated sites (Appendix I).

7.3.3 Flood Education and Increased Public Awareness

Policy 6.2 in the City's 2017 OCP states that the City intends to:

> "Promote community awareness and personal preparedness activities that help residents and local businesses prepare for, respond to and recover from hazard events."

While flood education is essential for promoting flood preparedness, it can also build support for dike upgrading. Given the high costs of diking, a high level of community support will be crucial.

As part of "Investigations in Support of Flood Strategy Development in BC", the Fraser Basin Council completed a report "Issue-B-6 Non-structural Flood Management Approaches" (NHC, 2021). This report included a comprehensive section on Flood Education Campaigns, which is included as Appendix G to this report. It is suggested that the City could utilize this information to develop effective flood education programs for both the Queensborough and Downtown areas.

7.4 Non-Structural Flood Mitigation Recommendations

The following recommendations are provided with respect to non-structural flood mitigation measures:

i. Prepare floodplain maps and a comprehensive technical report for the mainland floodplain areas of the City, incorporating the most recent climate change research, hydraulic modelling, and provincial guidance. These maps will define the floodplain boundary and provide updated FCL's that reflect climate change.

ii. Establish Development Permit Areas and detailed requirements for the mainland floodplain areas based on the new floodplain maps. Particularly for downtown redevelopment, floodproofing of new construction is very important as dike completion/upgrading may take many years to implement and because the dikes will remain vulnerable to seismic damage.

iii. For all waterfront areas, ensure that new foreshore development/redevelopment facilitates dike upgrading. Prepare a "Dike Lands Plan" to identify the lands required and establish policies and setback requirements for parcels adjacent to dikes. Acquire lands or rights of way at time of regulatory approvals in addition to direct negotiation and purchase from landowners. Consider options for site redevelopment to incorporate sections of "super dike".

iv. In acknowledgement that the long-term strategy for Queensborough to mitigate impacts of climate change depends primarily on the perimeter diking system, amend Policy 5.1 in the Queensborough Community Plan to:

> "Upgrade and manage the dikes, considering the effects of climate change, so that they continue to be the primary defence against flood events."

v. Develop and implement a Flood Education Campaign to help the community prepare for a flood emergency and to build support for dike upgrading work.

8 STORMWATER AND ENVIRONMENTAL CONSIDERATIONS

This section summarizes the key stormwater and environmental considerations as they relate to the New Westminster Flood Management Study.

Stormwater

WSP has prepared a Stormwater Considerations Technical Memorandum (**Appendix H**), which includes a review of the city's current strategy for managing inland stormwater in the Queensborough area. This memorandum also includes an assessment of the capacity of existing pump stations and flood boxes that discharge stormwater to the Fraser River (WSP, 2022).

When managing stormwater in the Queensborough area, the City currently follows the guidance set out in the New Westminster City wide Integrated Stormwater Management Plan (Lanarc & KWL, 2015), the Phase 1 Queensborough Integrated Rainwater Management Plan Update (Parsons, 2017), and the 2015 Utility Master Sewer Plan (AECOM, 2017). Following the review of these stormwater management plans and the applicable as-built drawings for the Queensborough pump stations and floodboxes, WSP provided recommendations for improvement works where infrastructure was identified as deficient. The pump station and flood box capacity were analyzed using the 2050 0.2% annual exceedance probability design flood levels for the Fraser River that were modelled in the Floodplain Management Strategy Update: Hydraulic Modelling and Mapping Final Report (NHC, 2021).

According to the Stormwater Considerations memo, the Queensborough pump stations were designed to a lower Fraser River level that did not consider climate change. The recently modelled 2050 0.2% AEP flood levels are on average 600 mm higher than previously predicted. Consequently, the freeboard of the dikes at the pump stations and of all the concrete floodbox slabs are less than the required 600 mm, which could result in overtopping during a design flood event. Therefore, the assessment recommended to vertically extend the existing floodboxes so that the top of the slabs align with the new dike crest elevations.

Additionally, the increased flood levels will slightly reduce the capacity of the Queensborough pumping stations, which will result in longer pumping durations during flood events. The increased pumping demands are not expected to cause major stormwater issues; however, the City should consider replacing these pumps with a higher capacity option at the end of their design life. Further discussion of the stormwater infrastructure review and upgrade recommendations is provided in the WSP Stormwater Considerations Technical Memorandum (**Appendix H**).

Contaminated Sites

A Qualitative Assessment of Contaminated Sites for the City of New Westminster Floodplain Management Strategy Update (**Appendix I**) was conducted to assess the potential environmental impacts of known contaminated sites located within the City's floodplain (Core6 Environmental, 2022). The assessment identified the locations of contaminated sites and historical industries that have the potential to cause contamination within the municipal boundaries of New Westminster. Core6 overlaid the footprints of these existing and historical contaminated sites with the present day 2050 0.2% AEP

flood map (NHC, 2021) to illustrate which sites would be impacted by flooding (**Appendix I**). This map could be used to help inform flood risk assessments.

Results from the qualitative assessment indicated that flooding at contaminated sites can adversely impact contaminant fate and transport, which can result in environmental consequences; however, the potential effects of flooding on contaminated sites are highly complex and challenging to predict. As such, additional site-specific studies are required to understand the full impact of flooding at contaminated sites within the City's floodplain (Core6 Environmental, 2022).

Habitat Considerations

The New Westminster Floodplain Management Strategy Update Habitat Considerations Report (**Appendix J**) provides a high-level assessment of the environmental issues related to the proposed dike upgrades (GL Williams & Associates Ltd., 2022). Although the New Westminster Floodplain Management Strategy was developed to minimize encroachment into the Fraser River (e.g. dikes to be widened to the land side), flood protection improvements along the shoreline will inevitably result in habitat impacts. As such, shoreline habitats affected by flood protection upgrades will require special environmental considerations.

The Fraser River Estuary Management Program (FREMP) involved the creation of a shoreline habitat classification map (**Appendix J**) within the old FREMP jurisdiction, which includes New Westminster and Queensborough. The shoreline habitat is classified as high, moderate, or low productivity according to the relative value habitat criteria. The shoreline habitat classification map thus provides a simplified habitat value for determining which areas will be impacted the most by dike upgrading.

According to the Habitat Considerations Report, dike upgrades along the mainland will not significantly reduce habitat productivity because most of the mainland is developed and the shoreline has been classified by FREMP as low productivity with minimal habitat values. In addition, the conceptual alignment and modified dike geometry have been sited in the upland area of the mainland to avoid adversely affecting fish habitat in the Fraser River.

Queensborough has higher-quality shoreline habitat and will require a dike upgrade strategy with considerations to minimize habitat impacts. In some cases, habitat offsetting may be required, which would involve approval from DFO. A practical approach to habitat offsetting and navigating the environmental permitting process is further explained in **Appendix J**.

9 ECONOMIC ANALYSIS AND PROJECT PRIORITIZATION

The 2009 Conceptual Plan (Delcan, 2009) completed economic analyses to assess the relative priorities of implementing flood protection measures in one area of the City versus another. The 2009 study concluded that investing in flood protection improvements for Queensborough provided significantly more benefits (i.e. greater reduction in flood damage consequence costs relative to the investment) than would investment in flood protection improvements for the Mainland.

WSP Canada Inc. was retained to update the 2009 analysis with consideration to be given to climate change impacts. WSP's Technical Memorandum describing the updated analysis, using flood levels and consequence values for a Year 2050 climate change scenario, is provided in **Appendix K.** WSP's Executive Summary from **Appendix K** is provided below.

The economic analysis completed shows a business case for flood protection improvements for both Queensborough and Mainland New Westminster. The analysis shows a stronger business case for improvements to Queensborough, indicating that this section should be prioritized for flood protection improvements. The cost-benefit tables with allowances for climate change are presented in Table 9.1 below:

Table 9.1 Cost-Benefit Analysis Summary

	QUEENSBOROUGH			MAINLAND		
Level of Protection	**Investment**	**Reduction in Consequence Cost**	**Cost-Benefit**	**Investment**	**Reduction in Consequence Cost**	**Cost-Benefit**
1:100	$44.7 M	$292.5 M	6.54	$33.8 M	$58.1 M	1.72
1:200	$47.0 M	$321.5 M	6.84	$37.8 M	$64.1 M	1.69
1:500	$49.7 M	$342.7 M	6.89	$42.4 M	$67.8 M	1.60
1:1000	$51.7 M	$351.0 M	6.79	$45.7 M	$69.1 M	1.51

Notes: WSP defines "Cost-Benefit Ratio" to be the "Reduction in Total Cost" divided by the "Cost of Upgrades". The Cost-Benefit ratios shown are for the year 2050 climate change scenario.

Queensborough offers a much higher return on investment, with the highest cost-benefit ratio for protection to the 500-year return period event. For the Mainland section, the cost-benefit ratio is highest for protection to the 100-year return period event. However, it may still be practical, for planning purposes, to improve flood protection to the same return period as Queensborough (500-year) to avoid incurring the costs of phased improvements.

Based on the analysis, Queensborough should be prioritized for capital spending on flood protection.

10 RECOMMENDATIONS

This update to the City's Floodplain Management Strategy was largely prompted by the need to plan for projected climate change effects on the Fraser River flood levels and to address new requirements with respect to the seismic vulnerability of dikes. Effective mitigation of the Fraser River flood risks will require ongoing efforts by the City along with increased support from senior governments. While the effects on flood levels from sea level rise will increase over time, the current risks from large Fraser River floods are very significant and a sustained effort to implement the Floodplain Management Strategy should begin without delay.

The economic analysis concluded that dike upgrades for Queensborough should be prioritized over flood protection improvements (new dikes) for the Mainland. While this conclusion should guide major capital spending in the short term, funding of other flood mitigation activities is essential for an effective and integrated approach, and for future implementation of Mainland flood protection improvements.

Key recommendations and a brief rationale are provided below. These encapsulate the more detailed recommendations, next steps and suggestions provided in each of the individual report sections.

1) **Prepare floodplain maps for the mainland that incorporate climate change effects. Establish Development Permit Area requirements for the mainland floodplain areas based on the new mapping.**

   Given that new permanent flood protection works for the downtown and the industrial areas may take many years to implement and that these dikes will remain vulnerable to seismic events, it is critical that new developments in the mainland floodplain areas be constructed in ways that minimize flood impacts.

2) **Develop and implement a public information and flood education campaign.**

   Inform the public about the changing flood hazards and potential flood impacts, how the components of the Strategy can mitigate the risks, and what implementing the Strategy means for residents and businesses. The public will be interested in the need for new floodplain building regulations for the mainland areas, emergency and evacuation planning, what proposed dike upgrades and associated changes to shoreline linear parks/walkways will look like and the costs. This program will help to prepare the community for flood emergencies and to build support for the flood protection improvements.

3) **Monitor evolving climate change science and design criteria, update the strategy as required and adopt a phased approach, where appropriate.**

   The dike design criteria cited in this report are likely to change with better understanding of how Fraser River peak flows can be affected by changing climate and by improved modelling. To address uncertainties in design criteria, and where cost effective, adopt a phased approach to dike construction (i.e. build to Year 2050 design levels but with provisions for future raising).

4) **Prepare detailed evacuation plans for Queensborough and Downtown Waterfront Areas**

   For Queensborough there is a significant risk of loss of life in the event of a large flood event and a dike breach. This risk can be partially mitigated through development of a detailed evacuation plan. For the Downtown Waterfront area, the immediate safety hazards from a large flood may be minimal. However, disruption of normal access to the densely populated Waterfront residential area should be anticipated and addressed as part of the City's flood emergency plan.

5) To advance the preliminary designs of Queensborough Dike Upgrades and a new dike for the Downtown Waterfront, the City should complete the following work:

- Conduct a detailed seismic assessment of the dike alignment, including a Seismic Flood Hazard Assessment and confirm seismic design requirements with the Inspector of Dikes.
- Using the conceptual upgrade drawings as a starting point, identify additional ROW requirements. Prepare a Dike Lands Plan to facilitate ROW acquisition and to ensure that development approval processes leave adequate room for and facilitate dike construction, operation and maintenance.
- Assess the potential for Fraser River channel change that could lead to scour and undermining of the riprap toe and assess the adequacy of the existing riprap bank protection. Prepare plans for erosion protection improvements as may be required.
- Evaluate the cost effectiveness of alternative designs and phasing for upgrading the 2 km section of the Queensborough dike contiguous with South Dyke Road, integrating seismic design. Conduct a public consultation process.
- Coordinate preliminary design of the Poplar Landing Tie-in dike with the design of the new housing development at 1400 Quayside Drive. Proceed with construction of the Tie-in Dike as a separate project prior to Waterfront Esplanade flood protection improvements.

6) Complete the preparation of an Operation and Maintenance Manual for the Queensborough Dike and make improvements to the dike inspection program.

Section 5 and Appendix E of this report provide a draft manual template, an outline of the work required to complete the manual and specific recommendations for improving dike inspections and reporting.

7) Build on existing partnerships to increase success of funding applications.

Apply for provincial and federal funding that is and may become available for various components of the Strategy. As New Westminster and Richmond share responsibilities for the Lulu Island perimeter dike, coordinate and collaborate on dike upgrading with the City of Richmond. Continue to participate with other local governments in the Lower Mainland Flood Strategy.

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