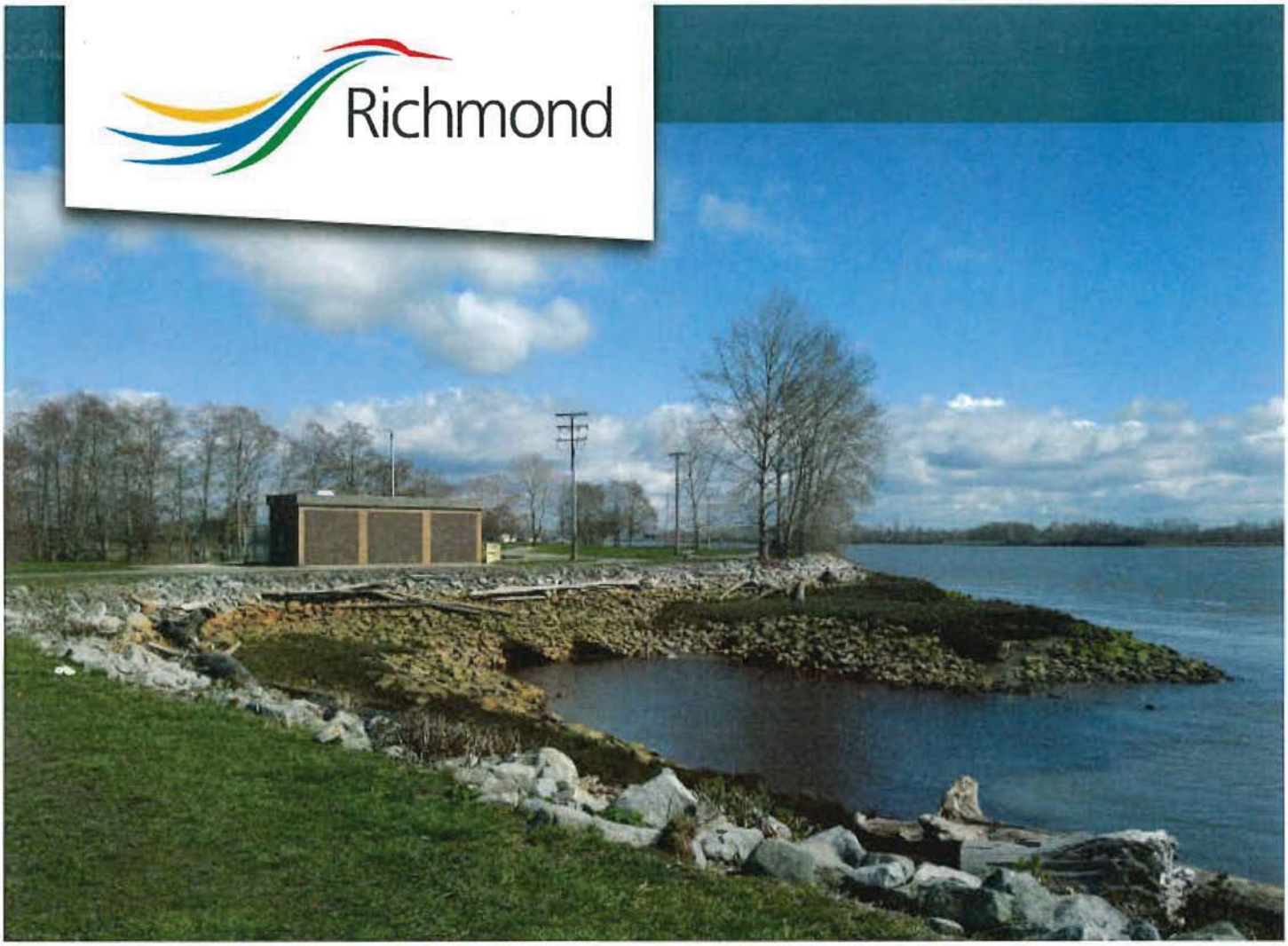
Richmond









Draft Report

Richmond Dike Master Plan - Phase 3

November 2018
KWL File No. 0651.110-300

Submitted by:

KERR WOOD LEIDAL
consulting engineers

Contents

Executive Summary i

1. Introduction 1-1
1.1 Background 1-1
1.2 Purpose and Objectives 1-2
1.3 Approach and Methodology 1-2
1.4 Report Format 1-3
1.5 Project Team 1-3

2. Existing Conditions 2-1
2.1 Reaches and Major Features 2-1
2.2 Land Tenure 2-7
2.3 Infrastructure 2-7
2.4 Habitat 2-8

3. Options Assessment 3-1
3.1 Design Considerations 3-1
3.2 Design Criteria 3-7
3.3 Alternative Upgrading Strategies 3-10
3.4 Options and Concepts 3-12
3.5 Stakeholder Engagement 3-24
3.6 Options Evaluation and Selection 3-24
3.7 Cost Opinions 3-32

4. Implementation Strategy 4-1
4.1 Pre-design Measures 4-1
4.2 Construction Sequence 4-1
4.3 Prioritization 4-2

5. Reach Summary Sheets 5-1
Reach 1: Gilmore West 5-1
Reach 2: Gilmore Crown Packaging 5-4
Reach 3: Gilmore East 5-7
Reach 4: Shellmont West 5-10
Reach 5: Shellmont Deas Dock 5-13
Reach 6: Highway 99 5-16
Reach 7: Fraser Lands 13140 Rice Mill Road 5-19
Reach 8: Fraser Lands Fraser Wharves 5-22
Reach 9: Fraser Lands Riverport Way 5-24
Reach 10: Fraser Lands Port Metro Vancouver (PMV) 5-26
Reach 11: Fraser Lands Lafarge 5-28
Reach 12: East Richmond 5-30
Reach 13/14: Hamilton/Boundary 5-33

6. Recommendations 6-1

Report Submission

References

Figures

Figure 1-1: Dike Master Plan Phase Locations 1-4
Figure 1-2: Dike Master Plan Phase 3 Reaches 1-5
Figure 2-1: Existing Land Tenure 2-12
Figure 3-1: Fraser River Flood Elevations 3-14
Figure 3-2: Option 1 - Separated Dike and Road: Raise Dike and Road, Extend Land-side 3-15
Figure 3-3: Option 2 - Riverbank Dike: Raise Dike Only and Extend Land-side 3-16
Figure 3-4: Option 3 - Superdike: Raise Land Behind the Dike 3-17
Figure 3-5: Option 4 - Road Dike: Raise the Existing Dike Within the Road (Interim Option) 3-18
Figure 3-6: Option 5 - Setback Sheetpile Wall (Interim Option) 3-19
Figure 3-7: Option 6 - River-side Sheetpile Wall (Interim Option) 3-20

Tables

Table 2-1: Phase 3 Reaches and Features 2-2
Table 2-2: Phase 3 Pump Stations and Reach Locations 2-7
Table 2-3: Environmental Values 2-10
Table 3-1: Ideal Dike Design Principles and Considerations 3-2
Table 3-2: City of Richmond ESA Type Management Objectives 3-5
Table 3-3: Design Criteria Summary 3-7
Table 3-4: Flood Levels and Dike Crest Elevations 3-9
Table 3-5: Proposed Alternative Seismic Performance Criteria 3-10
Table 3-6: High-level Dike Upgrading Strategies 3-11
Table 3-7: Dike Upgrading Options 3-12
Table 3-8: Space Limitations and Access Issues 3-21
Table 3-9: Recommended Dike Upgrading Options (Phase 3) 3-27
Table 3-10: Reach-by-Reach Summary of Habitat Impacts 3-29
Table 3-12: Summary of Construction Costs ($ in Millions) 3-33
Table 3-13: Summary of Costs for Interim Measures ($ in Millions) 3-33
Table 4-1: Priority by Reach 4-2

Appendices

Appendix A: Plans and Sections for Lulu Island Dike Master Plan – Phase 3
Appendix B: Richmond Dike Master Plan Landscape Concepts and Dike Typologies
Appendix C: Geotechnical Engineering Analysis Report (Thurber)

Executive Summary

The City of Richmond uses a Dike Master Planning program to guide future dike upgrading projects, and to ensure that land development adjacent to the dike is compatible with flood protection objectives. The program includes 4 phases for the 49 km of the Lulu Island perimeter dike that is within Richmond, plus another phase for Sea Island, Mitchell Island, and Richmond Island. The goal is to raise the dikes to allow for 1 m of sea level rise plus 0.2 m of land subsidence, and to allow for further upgrading in the future. The ultimate goal is to provide the City with a world class level of flood protection to keep pace with the rapidly growing community that relies on the dikes.

Dike Master Plan Phase 3 covers approximately 20 km of the Lulu Island perimeter dike along the Fraser River, on the south side of the island between Gilbert Road and Boundary Road. The dike within Phase 3 crosses through a variety of land uses, including roads, parks, and industrial land. Challenges along the dike alignment include conflicts with roads, drainage channels, utilities, and industrial development. There are also challenges with residential and commercial development outside the dike, and liquefiable soils beneath the dike. There are opportunities to construct at least some dike works through redevelopment, and to create linked trail networks for a full trail loop around Lulu Island.

This report describes existing conditions, develops an ideal vision for dike upgrading, presents design criteria, identifies options for dike upgrading, and presents recommended dike upgrading options that appropriately address the challenges. This work can be used as a basis for design of dike upgrading projects, recognizing that site-specific refinement of recommended options will be required in some areas. This work can also be used to assist with land use planning activities along the dike corridor. The main features of the recommended options to dike upgrading in Phase 3 are described below.

- Raise the dike crest to allow for 1 m of sea level rise plus 0.2 m of land subsidence. West of Nelson Road, the raised dike crest would be 4.7 m (CGVD28). East of Nelson Road, the raised dike crest would increase to 5.1 m at Boundary Road. The plan also allows for longer term upgrading to accommodate a further 1 m of sea level rise (i.e. 2 m of sea level rise).
- Widen the dike on the land side rather than into the Fraser River.
- Move Dyke Road inside the dike to facilitate short-term and long-term dike upgrading. This will require the road to be reconfigured and reconstructed, with some additional need for land tenure. Moving the road will allow removal of utilities within the dike.
- Raise the relocated Dyke Road to the dike crest elevation. This will facilitate driveway access over the dike to riverside properties. It will also be compatible with the desire to raise land inside the dike.
- Pursue individual industrial site strategies depending on the existing rights and agreements, the urgency of the works, and opportunities for redevelopment for each site.
- Replace the drainage channels immediately inside the dike with storm sewers and swales. This will improve dike stability, and will provide some of the land needed to relocate Dyke Road.
- Raise land and roads immediately inside the dike (during redevelopment) to improve seismic resilience. This will also improve liveability by allowing residents to look down over the water.
- Improve pedestrian and cyclist safety by constructing a separate multi-use path along the dike. This would be consistent with the City Parks vision for a perimeter trail system.
- Construct the south section of a secondary dike near Boundary Road.

It is also recommended that the City prepare a comprehensive implementation plan for dike upgrading that incorporates the elements of the Phase 3 Dike Master Plan, and the elements of the other Dike Master Plans.

To address habitat compensation issues associated with dike upgrading, it is further recommended that the City consider development of a habitat banking program that could provide effective large-scale compensation.

1. Introduction

Flood protection in Richmond is guided by the City's 2008-2031 Flood Protection Management Strategy which includes a comprehensive suite of measures including structural measures (e.g., dikes and pump stations), non-structural measures (e.g., flood construction levels), and flood response and recovery plans.

Dike Master Plans are critical components of the City's 2008-2031 Flood Protection Management Strategy, and are used to guide the implementation of long-term dike upgrades.

The City of Richmond (City) has retained Kerr Wood Leidal (KWL) to prepare the Richmond Dike Master Plan Phase 3.

Phase 3 covers the south-eastern portion of the Lulu Island perimeter dike from No. 2 Road to Boundary Road (City of New Westminster). Figure 1-1 presents the extent of the City's Dike Master Plan phases. Figure 1-2 shows the reaches of the Phase 3 Dike Master Plan.

1.1 Background

Richmond has a population of about 220,000 and is situated entirely on islands within the overlapping Fraser River and coastal floodplains (Lulu Island, Sea Island, Mitchell Island, Richmond Island, etc.). The City's continued success is due in part to its flat, arable land and its strategic location at the mouth of the Fraser River and on the seashore. The low elevation of the land and its proximity to the water comes with flood risks.

Lulu Island is the most heavily developed part of Richmond. Lulu Island is bounded by the Fraser River and the Strait of Georgia, and is subject to flood risks from the Fraser River and the sea. Lulu Island is also subject to other flood-related hazards, including dike breach, seismic effects, extreme rainfall, wave action, and river instability. The typical natural ground elevation is in the range of 1 m to 2 m as shown on Figure 1-1.

The cornerstone of the Lulu Island flood defenses is a 49 km long perimeter dike. Internal drainage is provided by an integrated system of channels and storm sewers that drain to 39 pump stations / floodboxes. Richmond occupies over 90% of Lulu Island. The balance of Lulu Island (the upstream end) is occupied by the Queensborough neighbourhood of the City of New Westminster.

As Richmond is fully situated within the river/coastal floodplain, there is no option to locate development out of the floodplain. The continued success of the City depends on providing a high level of structural and non-structural flood protection measures. Without continued improvements, the flood risk within the City would progressively rise as a result of rising flood levels (due to sea level and climate change), subsiding land, and increasing development.

The 2008-2031 Flood Protection Management Strategy guides the City's flood risk reduction activities across the City's organizational structure and across the spectrum of structural and non-structural flood protection measures.

The Lulu Island perimeter dike is the most critical structural flood protection measure, and improvement of this asset is identified as the priority action in the Flood Protection Management Strategy.

1.2 Purpose and Objectives

The purpose of the Dike Master Plan is to guide the implementation of dike upgrades and provide a starting point for the City to work with proposed developments adjacent to the dike. The master plan defines the City's preferred and minimum acceptable dike upgrading concepts.

The Dike Master Plan facilitates the City's annual dike upgrading program by providing critical information for the design of dike upgrades, including:

- general design concept;
- alignment;
- typical cross-section (conceptual design);
- footprint and land acquisition and tenure needs;
- design and performance criteria;
- infrastructure changes required for dike upgrading;
- operation and maintenance considerations;
- environmental features and potential impacts;
- social and public amenity considerations;
- guidance for future development adjacent to the dike; and
- guidance on interaction with other structural flood protection measures (e.g. secondary dikes).

The Dike Master Plan is intended to guide dike upgrading over the next 20 to 30 years.

Other flood protection measures, including non-structural measures, are identified in the City's 2008-2031 Flood Protection Management Strategy.

1.3 Approach and Methodology

The Dike Master Plan has been developed using a 5-step approach presented and described below.



Define: Confirm Dike Master Plan objectives and design/performance criteria.

Understand: Collect and compile relevant information, including spatial data and background reports from the City and several other parties (City of New Westminster, provincial regulators, the port, etc.).

Assess: Develop dike upgrading options and identification of constraints and potential impacts. Desktop and field review of options with City staff to identify preferred options.

Consult: Present to and gather feedback from council and stakeholders on preferred options.

Refine: Develop the master plan informed by consultation and review by the City.

The scope for the Dike Master Plan includes the following main tasks:

- goals and objectives development;
- background data collection and review;
- design criteria development and identification of constraints;
- options development and review;
- site visits;

- drainage impacts assessment;
- desktop habitat mapping and impacts review;
- geotechnical assessment;
- public amenity review;
- stakeholder consultation; and
- report preparation.

1.4 Report Format

This report is organized as follows:

- The executive summary provides a high-level overview of the master plan and key features;
- Section 1 introduces the master plan context and process;
- Section 2 documents the existing conditions;
- Section 3 documents the options development and assessment, and presents the recommended options;
- Section 4 is a compilation of 2-page summary sheets highlighting existing conditions and key features of the preferred option for each reach; and
- Section 5 provides implementation strategy, including costs, phasing, and coordination; and
- Section 6 provides general and reach specific recommendations for next steps and implementation.

Appendix A provides figures showing conditions along the existing dike alignment, and the preliminary design footprint for of the recommended upgrading options discussed in Section 3.

1.5 Project Team

The KWL project team includes the following key individuals:

- Colin Kristiansen, P.Eng., MBA – Project Manager;
- Mike Currie, M.Eng., P.Eng., FEC – Senior Engineer and Technical Reviewer;
- Sarah Lawrie, M.A.Sc., P.Eng. – Project Engineer;
- Laurel Morgan, M.Sc., P.Eng., P.E. – Drainage Engineer;
- Daniel Brown, B.Sc., B.Tech., BIT – Project Biologist; and
- Jack Lau - GIS/CAD Analyst.

This report was primarily written by Sarah Lawrie. The report was reviewed by Mike Currie and Colin Kristiansen.

Thurber Engineering Ltd. (Steven Coulter, M.Sc., P.Eng.) provided geotechnical engineering services and Hapa Collaborative (Joseph Fry, BCSLA) provided landscape architecture services.

The project was guided on behalf of the City by:

- Lloyd Bie, P.Eng. – Manager, Engineering Planning;
- Corrine Haer, P.Eng. – Project Engineer, Engineering Planning; and
- Pratima Milaire, P.Eng., PMP - Project Engineer, Engineering Planning.

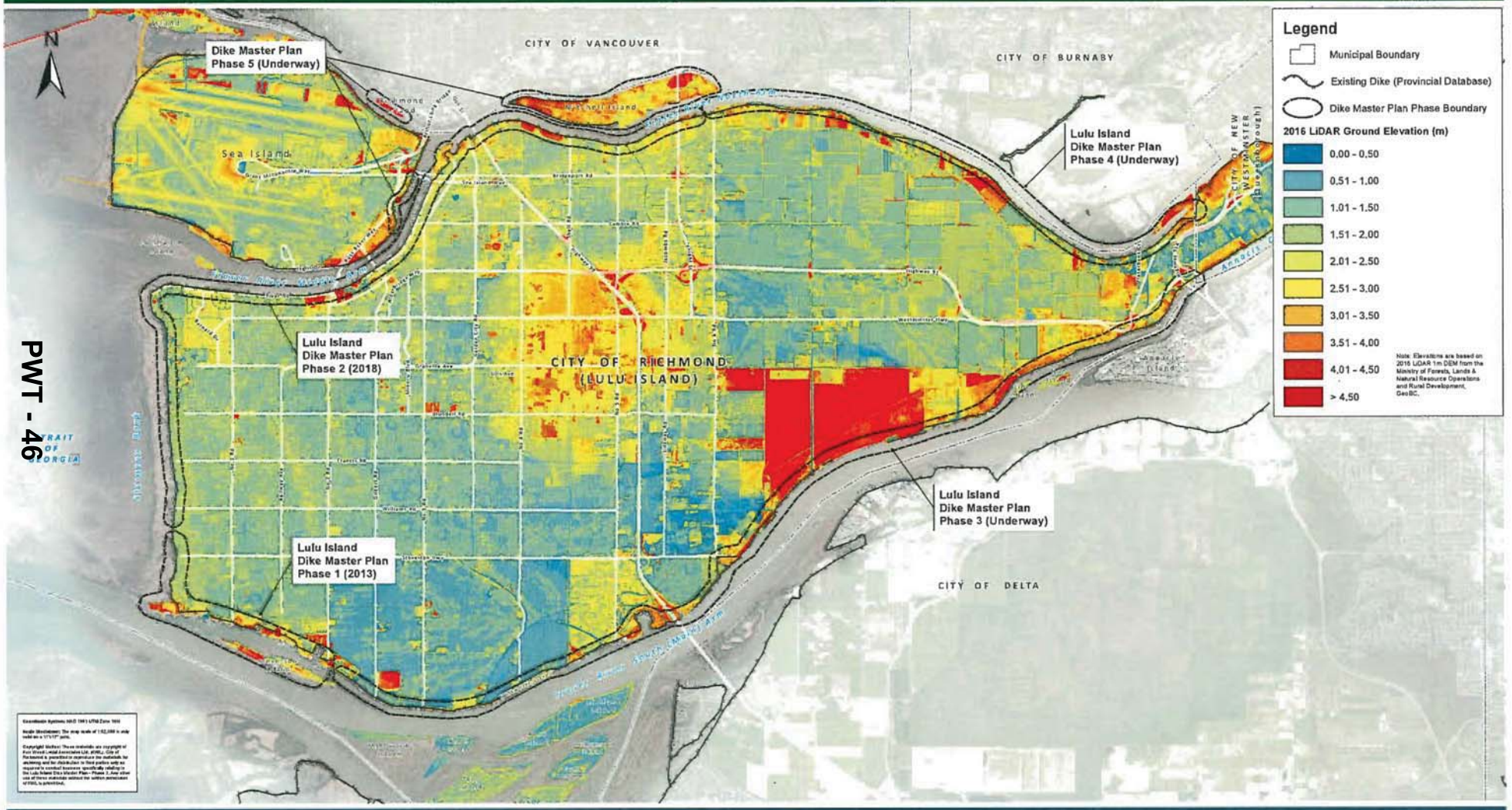
Many additional City staff contributed to the project during workshops, site visits, and in reviewing draft report materials.

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City of Richmond

Lulu Island Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



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Dike Master Plan Phases

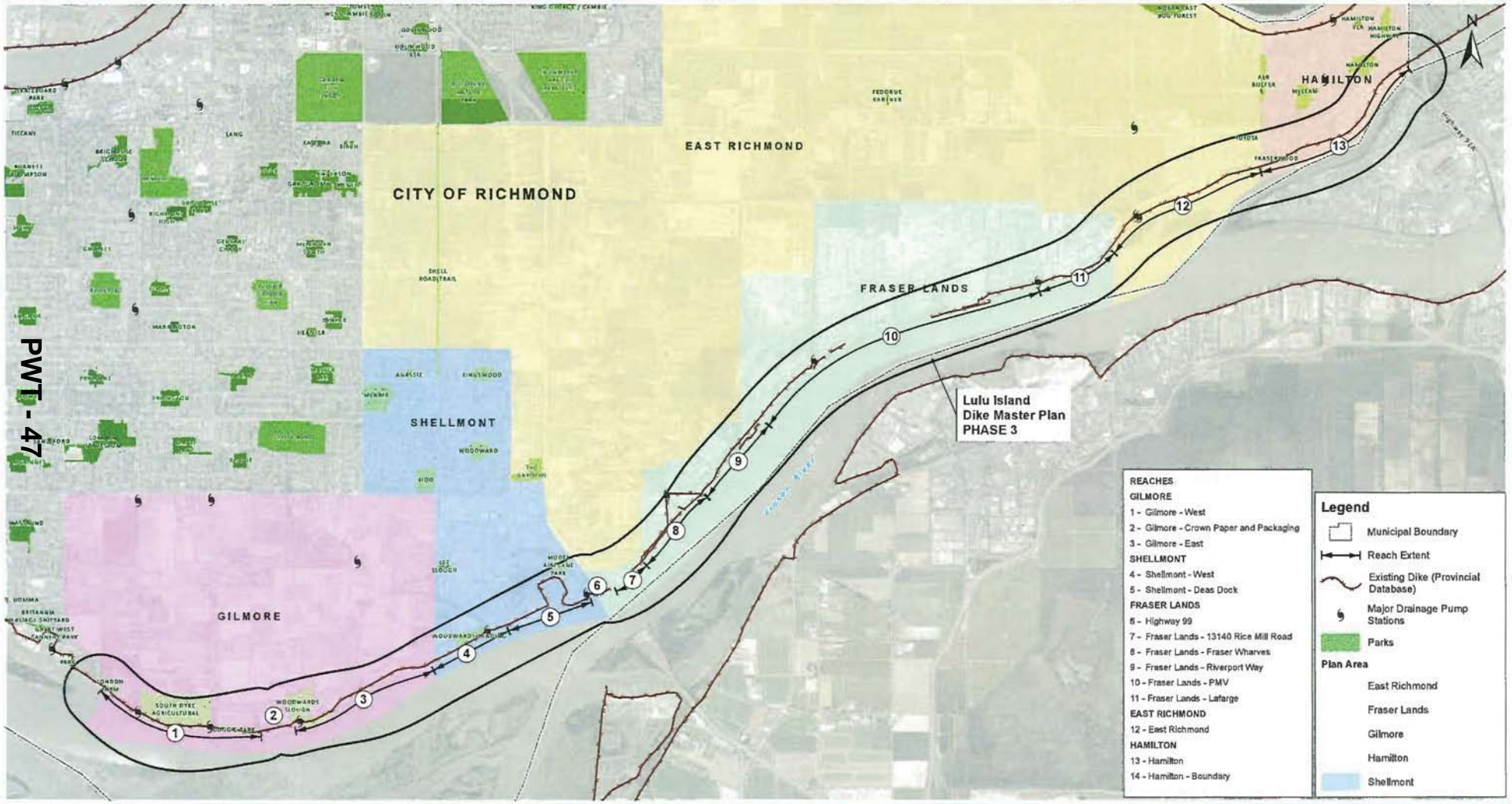
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Figure 1-1

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City of Richmond
Lulu Island Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



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Dike Master Plan Phase 3 Reaches

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Figure 1-2

2. Existing Conditions

This section summarizes the options development process undertaken, including the following components:

- review of existing conditions;
- design considerations;
- upgrading strategies; and
- preferred options and concepts.

2.1 Reaches and Major Features

The dike in Phase 3 is characterized as a dike in the road alignment (predominantly in Dyke Road), a dike through park space and a dike through industrial lands. A variety of land uses, structures and infrastructure are located on either side of the road/dike.

Space is limited in the road corridor presenting unique challenges for the master plan. City staff has identified road safety, including pedestrian and cyclist safety, as an important consideration for the Dike Master Plan.

In the active works yards and port facilities, space can be limited and industrial activities, such as the need for river access and site grading constraints due to specialized machinery, present unique challenges for the master plan. City staff has identified access for dike maintenance and inspection as an important consideration for the Dike Master Plan.

Land uses adjacent to the dike in Phase 3 comprise industrial, agricultural, and single and multi-family residential. The setback between the river bank and the dike varies from more than 15 m to none where the edge of the dike/road is the river bank and riprap bank protection is in place.

There are marine-based industries in Phase 3, including shipbuilding and repair, barge on/off-loading, port facilities, tour operations, and marinas. These operations typically require access to the river over the dike, or they are set outside of the dike and are unprotected.

There are residential settlements on the river-side of the dike. Finn Slough heritage community is a residential community situated on the river, outside of the protection of the dike (Reach 3). And, a recent townhome development (23740 and 23580 Dyke Road, Reach 13) is on the river, outside of the protection of the dike.

Phase 3 has been subdivided into 14 reaches with relatively uniform conditions. Reach extents are presented on Figure 1-2.

Table 2-1 describes the existing conditions and features of each reach. It is anticipated that these defined reaches can be subsequently used for dike upgrading implementation phasing.

Table 2-1: Phase 3 Reaches and Features

Reach # and Name	Extent / Length	Existing Dike Alignment	Major Features
1 – Gilmore West	No. 2 Road to Crown Packaging (2.7 km)	Dyke Road Dyke Trail Dog Park (trail)	• Dike in road with utilities • Habitat, trail, and park amenities on water side • Farms, residences, and channels on land side • London Heritage Farm, a historical site featuring a 19th-century farmhouse and barn, is located on the landside of the dike at approximate chainage 68+500. Dike upgrades need to protect this area without impacting the existing structures • South Dyke Trail runs along the crest of the dike from No. 2 Road to No. 5 Road • No. 3 Road Pier, a public amenity on the water side of the dike, at chainage 67+400 • Lulu Island Waste Water Treatment Plant is located approximately 200 m inland of the dike at chainage 68+100 • Dike upgrade project between Gilbert Road and No. 3 Road under construction 2018 (approximate chainage 68+100 to 67+300) • Fish habitat compensation site at the base of Gilbert Road • Drainage channel along the landside toe of the road/dike • Gilbert Road South pump station • No. 3 Road South pump station
2 – Crown Packaging	66+500 to 66+150 (350m)	Adjacent to the River Riverside of Crown Packaging	• Active industrial site and barge facility with restricted maintenance access • Rail and road access issues limit options to go around the site • Property is leased to Crown Packaging with 18 years left on the lease • Restricted City maintenance access • Dike crest elevation is approximately 2.75 m to 3.5 m • Crown Packaging operates a large cardboard production plant on the site (60 to 65 m from top of bank) • Rail line is located on the property (below the dike crest elevation) with rail access from the east

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Reach # & Name	Extent / Length	Existing Dike Alignment	Major Features
3 – Gilmore East	Crown Packaging to Shell Road (1.75 km)	Dyke Road	• Dike in road with utilities • Habitat and Finn Slough on water side • Farms and residences on land side • Woodwards Slough pump station • South Dyke Trail runs along the crest of the dike from No. 2 Road to No. 5 Road • Drainage channel on the land side adjacent to the existing road/dike • Large, newly built homes and farm structures (barns etc.) near the toe of the existing dike/road
4 – Shellmont West	Shell Road to No. 5 Road (1 km)	Dyke Road	• Dike in road with utilities • Industrial/commercial buildings and parks on land side • South Dyke Trail runs along the crest of the dike from No. 2 Road to No. 5 Road and provides connection to the Horseshoe Slough Trail • Woodward's Landing park space • Horseshoe Slough pump station • Existing drainage channel along the landside toe of the road/dike • Habitat, trail, and park amenities on water side
5 – Shellmont Deas Dock	No. 5 Road to Rice Mill Road (1 km) (1.6 km of dike)	Adjacent to the River	• Port facilities under redevelopment • Active marine work yard and shipyard facilities with restricted maintenance access • Rail and road access issues limit options to go around the site • Active redevelopment activities • Mainland Sand and Gravel have an agreement with the City to maintain a given elevation of the material to provide flood protection (not a defined dike structure on the site) • Fish habitat compensation site (plantings along Deas Dock area) • BC Ferries, Deas Pacific Marine, have a flood response plan for high water events

Reach # and Name	Extent / Length	Existing Dike Alignment	Major Features
			• Mainland Sand and Gravel have an agreement with the City to maintain a given elevation of the material to provide flood protection (not a defined dike structure on the site) • Fish habitat compensation site (plantings along Deas Dock area) • BC Ferries, Deas Pacific Marine, have a flood response plan for high water events
6 – Highway 99	Rice Mill Road (250 m)	Adjacent to the River	• Dike in road • Peace Arch (Hwy 99) pump station • Flood protection needs to integrate with the George Massey Tunnel • Unique risks associated with having a tunnel under the dike
7 – Fraser Lands – 13140 Rich Mill Road	Rice Mill Road to Fraser Wharves (500 m)	Adjacent to the River	• Active industrial site, dock and barge facility with restricted maintenance access • Rail and road access issues limit options to go around the site • Fish habitat compensation site (plantings on the river-side of the property) • Dike crest elevation ranges from less than 3 m to up to 3.5 m
8 – Fraser Lands Fraser Wharves	Fraser Wharves to Steveston Hwy (1 km)	Adjacent to the River	• Active ship to land car unloading facilities • Habitat on water side with limited or no community access • Near-term potential redevelopment • Active redevelopment activities • No. 6 Road South pump station
9 – Fraser Lands Riverport Way	Steveston Hwy to Williams Road (1 km)	Adjacent to the River	• Dike in road with utilities and dike trail • Residential and commercial development • Some recently constructed improvements challenging to raise • Redevelopment offers opportunity to raise site (superdikes) and provide community amenities • Fish habitat compensation site in front of the Riverport Way development

Reach # and Name	Extent / Length	Existing Dike Alignment	Major Features
10 – Fraser Lands Port Metro Vancouver	Williams Road to Nelson Road (3.5 km)	Adjacent to the River	• PMV development, barge facilities, dredged material and construction material stockpiles on extensive high ground due to historic landfill • Stability concerns due to proximity to narrow section of river with deep dredging • Development offers opportunities for creating superdike improvements and raising the land behind the dike • Opportunities for dike material stockpile areas, and increased public amenities • Three (3) Fish habitat compensation sites: front face of the loading area in the Port, and two (2) intertidal areas near No. 8 Road • City-owned property along the waterfront provides recreational opportunities • No. 7 Road South pump station • Nelson Road South pump station
11 – Fraser Lands Lafarge	Nelson Road to Dyke Road (1.5 km)	Adjacent to the River	• Active industrial site and barge facility with restricted maintenance access • Rail and road access issues limit options to go around the site • Dike upgrade project under construction 2018
12 – East Richmond	Dyke Road to Fraserwood Way (1.8 km)	Dyke Road	• Dike in the road with utilities • Commercial development on land side • Existing drainage channel along the landside toe of the road/dike • Marinas with access over dike on water side • Shelter Island Marina and Boatyard needs low gradient access across the dike for the Travelifts to haul out or launch boats • East Richmond Trail and Fraserwood Trail run along the dike crest, or adjacent to the road from No. 9 Road to Boundary Road • Ewen Road Irrigation pump station
13/14 – Hamilton/Boundary	Fraserwood Way to Boundary Road	Fraserwood Way Dyke Road	• Dike in the road with utilities • Commercial development on land side • Existing drainage channel along the landside toe of the road/dike

Reach # and Name	Extent / Length	Existing Dike Alignment	Major Features
	(1.7 km)		• Marinas and float homes with river access over the dike on both the land side and river side • East Richmond Trail and Fraserwood Trail run along the dike crest, or adjacent to the road from No. 9 Road to Boundary Road • Final 500 m of dike is set back on the land side of Fraserwood Way (Fraserwood Trail) and road and buildings are on the river side of the dike • Townhome complex at 23740 and 23580 Dyke Road outside of the dike • Fish habitat compensation site on either side of the Queensburough Connector • Highway 91 and City of New Westminster dike interface

2.2 Land Tenure

The majority of the existing dike footprint is located within the City's road dedication, on a right-of-way, or on City-owned land parcels. However, there are several areas where the existing dike footprint encroaches onto private property or where space is very limited such that any upgrading would encroach onto private property.

The existing land tenure in Phase 3 is presented on Figure 2-1 and in more detail in Appendix A.

2.3 Infrastructure

There are considerable infrastructure and utilities associated with the existing dike corridor in Phase 3. In addition to the road that runs along the top of the dike for much of the reach, there are also watermains, sanitary mains and forcemains, drainage channels, and storm mains that run parallel to the dike, predominantly at the landside toe. This infrastructure will need to be moved to accommodate any increases to the dike footprint.

There are nine (9) pump stations that cross through the dike in Phase 3. The pump stations and the associated reach are summarized in Table 2-2. The condition of the pump stations was not assessed as part of preparing the master plan.

Table 2-2: Phase 3 Pump Stations and Reach Locations

Pump Station	Reach
Gilbert Road South	1
No. 3 Road South	1
Woodwards Slough	3
Horseshoe Slough	4
Peace Arch (Hwy 99)	6
No. 6 Road South	8
No. 7 Road South	10
Nelson Road South	10
Ewen Road Irrigation	12

There are a number of parks and public spaces associated with the existing dike (Table 2-3). The dike crest provides recreation opportunities and connection for the public to the waterfront. The South Dyke Trail runs along the crest of the dike from No. 2 Road to No. 5 Road (Reaches 1 through 4), with a short detour around Crown Packaging (Reach 2). The South Dyke Trail provides connection to inland trails, including the Horseshoe Slough Trail.

The East Richmond Trail and Fraserwood Trail run along the dike crest, or adjacent to Fraserwood Way and Dyke Road, from No. 9 Road to Boundary Road (Reaches 12 and 13).

In addition to the official City parks and trails, there are portions of the dike which is City-owned land and is used by the public as an unofficial trail and recreational area (Reach 10).

Table 2-3: Phase 3 Parks and Reach Locations

Park Name	Reach
No. 2 Road Pier/London's Landing	1
Gilbert Beach	1
London Heritage Farm	1
Dyke Trail Dog Park	1
No. 3 Road Waterfront Park / No. 3 Road Fishing Pier	1
Woodward's Landing	4

2.4 Habitat

Methodology

A desktop review was conducted to the ecological setting along and adjacent to the length of proposed dike upgrades. The Phase 3 study area includes the existing dike and adjacent land or intertidal area on the south side of Lulu Island between Princess Lane and Boundary Road and is split into 14 reaches. Spatial data were used to identify overlap of known environmental values with the Phase 3 study area, which will inform development of the detailed design for dike improvements.

Spatial data reviewed in the desktop study includes:

- Fraser River Estuary Management Program mapping (FREMP 2012, 2007) mapping used to identify riparian and intertidal habitat types and quality;
- iMapBC web application (iMapBC 2017);
- Richmond Interactive Map web application (City of Richmond 2018) and
- City of Richmond aerial photographs (Richmond Interactive Map 2017).

The location and extent of high quality Fraser River riparian and intertidal habitat was identified to inform development of dike upgrade options and their potential impacts. FREMP habitat polygons were assigned the following categories: high quality riparian, high quality intertidal, or other. Deciduous tree woodland polygons were categorized as high quality riparian habitat because these communities provide cover and nutrients to fish using nearshore habitat. Mud, sand, and marsh polygons were categorized as high quality intertidal habitat because of the foraging and nesting habitat they provide for bird species and the foraging, egg deposition and rearing habitat they provide for fish species. Aquatic and riparian habitat on the land side of the existing dike was identified and mapped using the Riparian Area Regulation buffer layers from the Richmond Interactive Map (City of Richmond 2018) and interpretation of recent aerial photography (City of Richmond 2017).

Fish and Aquatic Habitat

High quality intertidal and riparian habitat is present in 12 of 13 Phase 3 reaches on the Fraser River side of the dike. This important habitat provides forage and cover habitat as well as a staging area for anadromous salmonids transitioning from saltwater to freshwater. Conversely, armoured sections of shoreline on the Fraser River side of the existing dike are present in Reaches 1, 2, 3, 7, 8, 9, 11, and 12. These sections provide limited habitat value and construction here would have less of a negative impact on fish.

On the land-side of the dike, drainage channels are present in 7 of 13 reaches (Reaches 1, 3, 4, 5, 10, 12, 13). These channels provide low to moderate quality aquatic and riparian habitat for fish and amphibians.

Seven fish habitat compensation are present in the Phase 3 study area. Completed between 1979 and 2004, these projects included the creation of intertidal marsh habitat to compensate for damage to habitat elsewhere. The reaches where these habitat compensation projects are located are listed in Table 2-4.

Wildlife and Terrestrial Habitat

Terrestrial habitat types in Phase 3 include deciduous tree woodland, tall shrub woodland, low shrub woodland, and vascular plant meadow, as well as uncategorized sections (e.g. paved lots; FREMP 2007). These habitat types have potential to provide nesting habitat to migratory birds in all reaches of Phase 3. Orthoimagery review identified potential raptor nesting trees in all reaches of the Phase 3 study area.

The internal drainage channels that are mentioned above and are present in six of the thirteen reaches of Phase 3 (Reaches 1, 3, 4, 10, 12, and 13) are likely used by native amphibian species as breeding habitat as well as by fish species. It is possible that additional amphibian habitat is present in small ponds or channels along the dike that were not identified in the desktop review.

Species and Ecological Communities at Risk

No known occurrences of terrestrial wildlife species at risk are present in the Phase 3 study area but several occurrences exist nearby, on islands in the Fraser River or on the river banks across from Richmond. It is possible that individuals of these species also occur on the Richmond side of the Fraser River. The Lower Fraser River population of White Sturgeon (*Acipenser transmontanus* pop. 4) is known to occur in the Fraser River next to the dike. Mapped critical habitat for at-risk species is not present within 500 m of the study area.

FREMP mapping (2007) shows the presence of intertidal marsh communities in eight of thirteen reaches of the Phase 3 study area (Reaches 1, 2, 3, 8, 9, 10, 12, and 13). Many of these communities in British Columbia are considered at-risk (i.e. Blue-Listed; special concern, or Red-Listed; threatened, or endangered). No ecological communities at-risk are shown in either the study area on BC iMap (2017), but it is likely that some are present in the Phase 3 study area.

Table 2-4 presents the findings of the desktop review on a reach-by-reach basis and separates Fraser River side results from land-side results.

Table 2-4: Environmental Values

Reach #	Location	Environmental setting (organized by inland side and shoreline side of existing dike)	Construction Constraints	Construction Opportunities	FREMP Habitat Types	Known Species at Risk Occurrence Near Dyke Alignment	Potential Raptor Nesting Trees	Potential Migratory Bird Nesting Habitat	Existing Habitat Compensation Sites Present
1 Gilmore - West	Land Side	• Most of reach bordered by low-quality fish-bearing, and amphibian habitat drainage channel • Moderate quality deciduous woodland, tall shrub woodland, and meadow present on inland bank of drainage channel	Drainage channel full length of reach	East end of reach, dike is set back from watercourse	Deciduous tree woodland Tall shrub woodland Meadow	Henderson's Checker-mallow (*Sidalcea hendersonii*) Joe-pye Weed (*Eutrochium maculatum var. bruneri*) Vancouver Island beggarticks (*Bidens amplissima*) White Sturgeon (Lower Fraser River population) (*Acipenser transmontanus* pop. 4)	Y	Y	Project: Lulu Island Sewage Treatment Plant Outfall Replacement Year Created:1993
	Fraser River Side	• Western third of reach is bordered by high quality marsh and mudflat habitat • Middle third of reach is low quality habitat armoured bank • Eastern third of reach has narrow strip of marsh habitat	High quality habitat at west end	Existing dike is set back from the shoreline in portions of this reach	Marsh Meadow Mudflat				
2 Gilmore - Crown Paper	Land Side	• Paved parking lot	Private property	n/a	Unvegetated	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	N
	Fraser River Side	• Armoured bank with small area of high quality riparian deciduous treed woodland habitat	Small area of high quality habitat	n/a	Marsh Meadow				
3 Gilmore - East	Land Side	• Drainage channel bordering agricultural fields along entire length of reach (Potential amphibian breeding habitat • Fish species presence not recorded)	Drainage channel bordering dike	n/a	Meadow Low shrub woodland Deciduous tree woodland	Flowering Quillwort (*Lilaea scilloides*) White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	N
	Fraser River Side	• Habitat in West quarter of reach is low quality (landscaped grasses and walking trails, set back from armoured slope) • Middle section adjacent to Gilmour Slough, (records of threespine stickleback and carp) • Habitat on banks of Gilmour slough is high quality marsh • Riparian habitat on south side of Gilmour slough is high quality (tall shrubby woodland)	Gilmour slough (high quality habitat) bordering dike	Dike is set back from shoreline at west end	Meadow Marsh Deciduous tree woodland Mud flat				
4 Shellmont - West	Land Side	• Low quality habitat, walking path and maintained lawn at east and west end of reach • Drainage channel adjacent to middle of reach (Threespine stickleback, amphibian habitat)	Drainage channel in middle of reach	Absence of watercourses in east and west ends	Deciduous tree woodland Meadow	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	N
	Fraser River Side	• Very West end of reach is set back from Fraser River • High quality marsh habitat in Fraser River in east half of Reach	High quality riparian habitat at west end. Marsh at east half	Low quality riparian habitat in middle third	Deciduous tree woodland Sand Meadow				
5 Shellmont - Deas Dock	Land Side	• Mostly paved, some low quality herbaceous habitat present	n/a	Low quality habitat and absence of watercourses along full length	Meadow Unvegetated	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	Project: Richmond Plywood Year Created: 1989
	Fraser River Side	• Dike is set back approx. 100 m from High Quality marsh habitat in west half of reach • High quality mudflats and marsh bordering dike in east third of reach	High quality habitat at east end	absence of riparian habitat on east side of bay dike is set back from riparian habitat on west end	Sand Meadow Mud flat				
6 Highway 99	Land Side	• Low quality gravel parking lots	n/a	Low quality habitat along full length	Deciduous tree woodland	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	N
	Fraser River Side	• High quality deciduous tree riparian woodland, mostly at west end	High quality riparian habitat	n/a	Deciduous tree woodland				
7 Fraser Lands - 13140 Rice Mill Road	Land Side	• Some deciduous trees, but mostly paved of buildings	Private property, buildings Some trees at east end	Mostly low quality paved	Meadow Unvegetated	Pointed Rush (*Juncus oxymeris*) White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	Project: Ocean Fisheries Limited Year Created: 1987
	Fraser River Side	• Low quality habitat armoured slope or pier	Pier	Low quality riparian habitat	Meadow Unvegetated				

PWT - 57

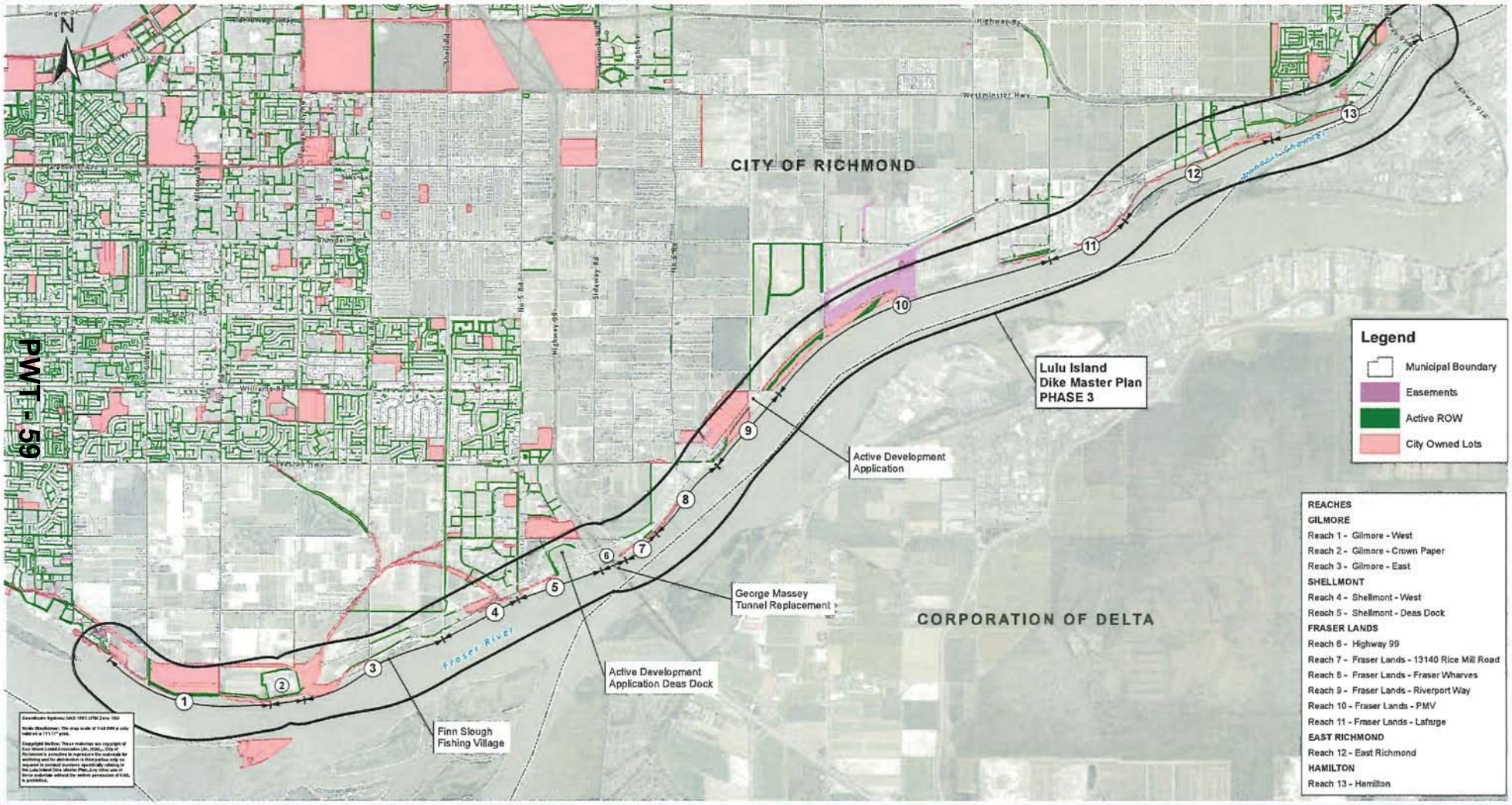
Reach #	Location	Environmental setting (organized by inland side and shoreline side of existing dike)	Construction Constraints	Construction Opportunities	FREMP Habitat Types	Known Species at Risk Occurrence Near Dyke Alignment	Potential Raptor Nesting Trees	Potential Migratory Bird Nesting Habitat	Existing Habitat Compensation Sites Present
8 Fraser lands - Fraser Wharves	Land Side	• Paved Parking Lot, some low quality shrub habitat between dike and pavement	n/a	Low quality habitat along full length	Meadow Unvegetated	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	N
	Fraser River Side	• High quality deciduous treed riparian habitat in east half and small patch in west half-armoured slope and pier in middle of reach	Dike is mostly set back from high quality riparian habitat	Low quality habitat in middle of reach and at far east end	Meadow Deciduous tree woodland Marsh				
9 Fraser Lands - Riverport Way	Land Side	• Maintained lawn or gravel lot, low quality habitat	Private property	Low quality habitat along full length	Meadow Unvegetated	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	Project: Legacy Park Lands Year Created: 2003
	Fraser River Side	• High quality deciduous forest riparian habitat in middle of reach • Low quality habitat armoured bank at east and west ends	High quality riparian habitat in middle of reach	Low quality riparian habitat at east and west ends of reach	Meadow, deciduous tree Woodland marsh Unvegetated				
10 Fraser Lands - PMV	Land Side	• Drainage channel at east end (Stickleback, amphibian habitat) • Paved lots at east and west ends • Large, seasonally flooded area in middle of reach (Potential for overwintering habitat creation)	Drainage channel at east end flooded area in middle of reach	Sections of low quality habitat at west and east ends	Meadow Tall shrub woodland	Three-flowered (*Waterwort Elatine rubella*) White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	Project: Barge Facility Year Created: 2003 Project: Fraser Richmond Landfill Compensation Sites (2) Year Created: 1979
	Fraser River Side	• Large areas of high quality riparian forest, intertidal marsh along full length of reach	Large areas of high quality riparian habitat intertidal marsh along full length of reach	n/a	Deciduous tree woodland Marsh Sand bar Meadow				
11 Fraser Lands - Lafarge	Land Side	• Low quality habitat paved lots and buildings	Private property	Low quality habitat, absence of watercourses	None (Paved)	Three-flowered (*Waterwort Elatine rubella*) White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	N
	Fraser River Side	• Some high quality forested riparian habitat at east end • Low quality habitat armoured bank at west end	High quality habitat at east end of reach	Low quality armoured bank at west end of reach	Meadow Deciduous tree woodland Sand				
12 East Richmond	Land Side	• Drainage channels adjacent to dike at east and west ends of reach (amphibian habitat) • Low quality habitat paved or maintained lawn in middle of reach	Drainage channel at east and west ends	Paved or maintained lawn in middle of reach	Meadow Low shrub woodland Deciduous tree woodland Unvegetated	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	N
	Fraser River Side	• High quality habitat mud flats at middle and east end of reach • Deciduous treed woodland high quality habitat at west end of reach	High quality habitat along almost full length of reach	Small section of low quality armoured bank in western portion of reach	Deciduous tree woodland Meadow Mud flat Marsh				
13/14 Hamilton/Boundary	Land Side	• Drainage channels at very west end and in middle of reach (amphibian habitat) • Low quality paved or landscaping shrubs at west end of reach habitat • High quality shrubland habitat at east end of reach	Drainage channel at very west end and in middle of reach	Low quality habitat in west end of reach	Meadow	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	Project: Former Queensborough Shipyard Restoration Year Created: 2004
	Fraser River Side	• High quality mud flats and marsh at west end of reach • Patches of high quality marsh and riparian deciduous woodland along east end of reach • Small patches of unvegetated low quality habitat along reach	High quality habitat at west end of reach	Small patches of low quality habitat	Deciduous tree woodland Marsh Mudflat Meadow Sandbar				

PWT - 58

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City of Richmond
Lulu Island Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



PWT - 59

Project No. 651-110
Date October 2018
Scale 1:40,000
500 250 0 500 m

Existing Land Tenure

DRAFT
Figure 2-1

3. Options Assessment

This section summarizes the options development process, including the following components:

- design considerations and design criteria;
- upgrading strategies;
- upgrading options and concepts; and
- recommended options for implementation

The next version of the draft report will include a summary of external stakeholder engagement results.

3.1 Design Considerations

This section summarizes the main themes and issues that have informed the development of upgrading strategies and options for Phase 3.

Dike Performance, Maintenance, and Upgrading

Dike performance, maintenance, and upgrading are the most important design considerations for the Dike Master Plan.

The following themes define the ideal vision for dike upgrading:

1. **Level of Protection:** The City's 2008-2031 Flood Protection Management Strategy sets a target level of protection for structural measures. The City is presently developing an updated flood protection management strategy that will have an even more ambitious flood protection level target. The level of protection translates to a hazard-based design flood scenario to be incorporated into the Dike Master Plan. At this time, the proposed design flood scenario for the Lulu Island perimeter dike is the 500-year return period flood event (0.2 % annual exceedance probability, AEP) with climate change allowances including 1 m of sea level rise. However, the Dike Master Plan should be flexible to accommodate a future change in the design flood scenario.
2. **Form and Performance:** The preferred form of the dike is a continuous, compacted dike fill embankment with standard or better geometry. Walls and other non-standard forms are less reliable and are not preferred. The level of performance of the dike should be in line with the significant population and assets that the dike protects. The dike should meet all relevant design guidelines of the day and in some cases, exceed guidelines to provide a higher level of performance. Dike performance can be expressed in terms of freeboard above the design flood scenario water level and factors of safety against various failure processes, including flood conditions and internal erosion (piping).
3. **Passive Operation:** Minimal human or mechanical intervention or operation should be required to achieve full dike performance. To achieve this, the dike should not have any gaps, gates, or stop log structures.
4. **Enhance Performance** (slow failure): The likelihood of a catastrophic dike failure causing significant flood damages can be reduced by design features that aim to slow down failure processes, provide redundancy, and provide time to implement emergency repairs. In general, failure can be slowed or controlled with additional setback, crest width, and armouring of the river side slope, crest, and land-side slope. Such measures can slow the impacts of river erosion, overtopping erosion, and stability failures. Increased monitoring approaches and technology may also be helpful.

5. **Post-earthquake Protection:** The dike should provide adequate protection following a major earthquake until permanent repairs can be implemented. In general, this means avoiding dike conditions where a major earthquake would result in a sudden and full failure of the dike cross-section into the river, referred to as a 'flow-slide failure'. Other conditions where the dike crest settles, but still provides sufficient freeboard and factors of safety until repairs can be conducted may be tolerable. In general, increased crest width, crest elevation, and setback from the river may be undertaken to help achieve adequate post-earthquake protection. In some cases, improved seismic performance will also require ground improvement and densification works.
6. **Future Upgrading:** Uncertainty in climate change, particularly sea level rise timing, may require the City to further upgrade the dike sooner or higher than anticipated by current guidelines and policies. Sufficient space should be reserved under secured land tenure for future upgrading based on standard geometry. Conceptual design is provided for design flood levels which incorporate 1 m of sea level rise, and proof-of-concept design is provided for design flood levels which incorporate another 1 m water level increase for further climate change impacts (i.e. 2 m of sea level rise).

Some specific design considerations related to the above principles are presented in Table 3-1.

Table 3-1: Ideal Dike Design Principles and Considerations

Design Principle	Ideal Design Principles and Considerations
Level of Protection	• Based on 2008-2031 Flood Protection Management Strategy • Currently proposed: 500-year return period (0.2% AEP) with climate change allowances as per provincial studies
Form and Performance	• Continuous, compacted dike fill with standard or better geometry • Crest elevation and adequate freeboard • Factors of safety for stability • Minimal infrastructure within the dike corridor • Adequate bank protection or setback
Passive operation	• No gaps, gates, or stop logs • Passive monitoring (e.g. SCADA water levels)
Enhance Performance (slow failure)	• Wide dike crest • Armoured river-bank slope to resist erosion • Paved/armoured crest and/or land-side slope to resist overtopping • Wide setback from the river
Post-earthquake Protection	• No loss of full dike geometry into the river ("flowslide failure") up to a return period to be determined • Adequate post-earthquake freeboard and stability until repairs • Wide dike crest and/or wide setback from the river
Future upgrading	• Space and tenure for upgrading (standard or better geometry) • Avoid need for future infrastructure relocation or land acquisition

Road Safety and Access

The safety of drivers, cyclists, and pedestrians using Dyke Road, Fraserwood Way and the dike trail system in south Richmond is a significant consideration in Phase 3. City transportation engineering staff were consulted during the master plan development to provide input on dike upgrading concepts that will also improve road safety. The City's preferred concept for Dyke Road is to provide wider vehicle travel lanes and separated multi-use paths, which may be located on the dike crest. Preferred travel lane and multi-use path widths are documented in the design criteria in Section 3.2.

Vehicle access to the properties located on both sides of Dyke Road is also a significant consideration. Dike raising alignments will impact driveway access for both residential and commercial landowners. Land use on these properties includes industrial / port-related uses, residential, and agricultural. As such, a variety of vehicles, including semi-trailer trucks, need safe access from Dyke Road to these properties. Currently, these properties are generally at grade with or slightly below the road and access is provided via asphalt or gravel driveways.

Driveway access was considered in options development by identifying several access upgrading concepts including upgrading driveways, land filling to raise sites to the dike / road level, and providing vehicle parking at the dike / road level.

Land Raising and Acquisition

Land acquisition is an important consideration for the development and evaluation of dike upgrading options. In many areas, the existing dike corridor is confined on both sides by private property with no room for expansion of the dike footprint.

The figures in Appendix A present the overlap between the proposed dike footprint and private property for select upgrading options discussed in Section 3. This overlap can be used to produce a land acquisition plan.

In some locations, an alternative to land acquisition may be to raise private property lots up to the dike elevation to create a much wider land raising platform (similar to recent developments along the Middle Arm (e.g. Olympic Oval). The active redevelopment activities through the Fraser Lands (Reaches 7 – 11) offer opportunities for land raising to create so-called "superdikes".

Industrial Operations and River Access

South Richmond (Phase 3) is an important industrial area in the City. Existing industrial operations and river access for marine operations is an important consideration for developing and evaluating the dike upgrading options. In particular, landowners and leaseholders at Crown Packaging (Reach 2), Mainland Sand and Gravel (Reach 5), BC Ferries Richmond (Reach 5), Canadian Fishing Company (Reach 7), Fraser Wharves ship-to-land car unloading facilities (Reach 8), Port Metro Vancouver (Reach 10), Lafarge (Reach 11), Shelter Island Marina and Boatyard (Reach 12), and various small marine operations (Reach 12 and Reach 13).

In these locations, alternative dike geometries may be considered in the interim until redevelopment allows for land acquisition or land raising activities.

Internal Drainage System

As with any diked area, drainage for the interior protected area must be integrated with the flood protection measures such that the protected area does not experience flooding due to conflicting functions between the drainage of water from the interior area and prevention of flooding from water exterior to the dike system.

There are several smaller drainage channels and drainage pipes located at the landside toe of the existing dike providing local surface drainage for the area. As part of any upgrades, the existing drainage channel along the landside toe will need to be moved out of the proposed dike section or replaced with a pipe and inlets for local drainage. Additionally, the existing drainage pipes located within the proposed dike section may need to be relocated or upgraded to accommodate the proposed dike section.

The existing intakes and outfalls for the pump stations may need to be modified or extended and the pump station piping should be reviewed to consider structural impacts of the preferred dike section.

Tie-in with City of New Westminster Dike

The Phase 3 dike needs to tie into the City of New Westminster portion of the Lulu Island perimeter dike.

Approximately 500 m of the current dike in the boundary area is set back from Dyke Road so that the road and riverside townhomes (23740 and 23580 Dyke Road) are outside of the protection of the dike. The dike then ties back into the road at the Boundary Road and continues as part of South Dyke Road in the City of New Westminster.

Coordination between the City and the City of New Westminster is needed to confirm the dike tie-in design at the boundary.

Potential Future Secondary Dikes

The City's 2008-2031 Flood Protection Management Strategy identifies potential secondary dike concepts which are important considerations for Phase 3, including the proposed mid-island dike and the proposed Richmond-New Westminster boundary dike. The purpose of these secondary dikes is to limit flood damages by creating flood cells on Lulu Island which would contain flooding to smaller areas and prevent complete flooding of the island if dike breaches were to occur.

The Phase 3 Dike Master Plan has been developed to allow tie-ins with the possible mid-island dike and the proposed Richmond-New Westminster boundary dike. The possible mid-island dike is not addressed because it is linked to changes to the George Massey Tunnel and the tunnel's potential replacement. It is understood the City is also considering the implementation of both of these proposed dikes through gradual land raising through development as opposed to a dedicated dike corridor. The City's 2008-2031 Flood Protection Management Strategy provides additional information regarding potential future secondary dikes.

Environmental Considerations

The City's Official Community Plan (OCP) bylaw (2011) includes an Environmental Management Strategy (ENMS) that identifies ecologically important areas in the City's Ecological Network (EN). These areas include Environmentally Sensitive Areas (ESAs) and Riparian Management Areas (RMAs), and EN components (hubs, sites, and corridors, shoreline, city parks).

ESAs are designated as Development Permit Areas (DPAs) with specific restrictions and guidelines for development controlled through a review and permitting process (HB Lanarc-Golder and Raincoast Applied Ecology 2012). There are five ESA types, based on habitat, each with specific management objectives. These are summarized in Table 3-2 and more detailed guidelines can be found in HB Lanarc-Golder and Raincoast Applied Ecology (2012). According to Richmond's OCP dike maintenance is exempt from development permits in ESAs. However, the guidelines provide useful direction that can be used to minimize impacts to these areas and provincial and federal legislation (see below) still applies to these areas.

RMAs are setbacks that were implemented in accordance with the Provincial *Riparian Areas Protection Act* and act as pre-determined Streamside and Protection Areas (SPEAs) under the Act. They extend 5 m or 15 m back from the top of bank of the City's channelized watercourses and are to remain free from development unless authorized by the City (City of Richmond, 2017). RMAs are present in 10 of 13 Phase 3 reaches (Reaches 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13).

Hubs, sites, and corridors are components of the City of Richmond's EN, which are not specifically afforded protection, but often overlap ESAs and RMAs, which are protected. These components are present in 11 of 13 reaches of Phase 3 (Reaches 1, 2, 3, 4, 5, 6, 8, 9, 10, 12, and 13).

Dike upgrade options will consider the potential impacts to these areas.

Table 3-2: City of Richmond ESA Type Management Objectives

ESA Type	Reaches Where Present	Management Objectives
Intertidal	All	• Prevent infilling or direct disturbance to vegetation and soil in the intertidal zones • Maintain ecosystem processes such as drainage or sediment that sustain intertidal zones
Shoreline	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12	• Preserve existing shoreline vegetation and soils, and increase natural vegetation in developed areas during development or retrofitting
Upland Forest	1, 10, 12, 13	• Maintain stands or patches of healthy upland forests by preventing or limiting tree removal or damage, and maintaining ecological processes that sustain forests over the long term
Old Fields and Shrublands	None	• Maintain the extent and condition of old fields and shrublands, while recognizing the dynamic nature of these ecosystems • Preservation should recognize the balance between habitat loss and creation with the overall objective of preventing permanent loss of old fields and shrublands
Freshwater Wetland	3, 4	• Maintain the areal extent and condition of freshwater wetland ESAs by preserving vegetation and soils, and maintaining predevelopment hydrology, drainage patterns, and water quality
		Source: (HB Lanarc-Golder and Raincoast Applied Ecology 2012)

Fish Habitat and Offsetting

Fish and aquatic habitat is protected by the federal *Fisheries Act*. Under the Act, *serious harm to fish* must be authorized by the Minister of Fisheries and Oceans and Impacts that cannot be avoided or mitigated must be balanced through offsetting. Offsetting plans are negotiated on a case-by-case basis and may require consultation with aboriginal groups and the Province. Offsetting options include habitat restoration, enhancement, habitat creation (or a combination of the three) and must be proportional to the loss caused by the project. The area of offsetting may need to be increased to account for uncertainty of effectiveness and time lag between impacts and offsetting. Often, the offset area is equal to an area greater than that of the impacted area.

Wildlife Considerations

Migratory birds, their eggs, and active nests are protected by the *Migratory Birds Convention Act* and appropriate measures must be taken to avoid incidental take. The most effective and efficient of these measures includes scheduling vegetation clearing outside of the migratory bird nesting season. If this is not possible, bird nest surveys can be completed immediately prior to vegetation clearing to identify active nests and delay vegetation clearing until the nest is no longer active.

The nests of Bald Eagles, herons and other raptors (both active and inactive) are protected under the Provincial *Wildlife Act*. It is also prohibited under the *Wildlife Act* to harm an active bird nest, birds, and their eggs. The detailed design stage for dike upgrading should attempt to avoid the removal of trees where bald eagle nests are located.

Native amphibian species are likely use the drainage channels at the toes of the land side of the dike. These species are protected by the provincial *Wildlife Act* and detailed design should consider potential impacts to these species.

Public Realm and Ecological Enhancement

The dike is a major existing public realm feature providing a variety of recreation opportunities. The Dike Master Plan provides an opportunity to significantly enhance the public amenity of the dike system. Additionally, the dike upgrading provides an opportunity to enhance ecological value through the landscaping treatments that will define the dike surface and edges.

Appendix B presents a suite of landscape concepts prepared by landscape architects at Hapa to supplement the Dike Master Plan. These include landscape design principles, an overall network connectivity concept for the Lulu Island perimeter dike trail, and design toolkits for ecological enhancement and public realm features. Additionally, the Appendix B presents a suite of landscape concepts to supplement the upgrading options presented in Section 3.6.

3.2 Design Criteria

This section describes the main design criteria used in the Dike Master Plan.

Table 3-3 presents a summary of the criteria and is followed by additional discussion. The criteria are presented in terms of both what is the minimum acceptable level and the preferred level.

Table 3-3: Design Criteria Summary

Item	Value and Description	
	Minimum Acceptable	Preferred
Proposed Dike Crest Elevation	4.7 m CGVD28 downstream of Nelson Road 4.7 m CGVD28 to 5.0 m CGVD28 between Nelson Road and Boundary Road	
Future Dike Crest Elevation (for proof-of-concept design)	5.5 m CGVD28 downstream of Nelson Road 5.5 m CGVD28 to 6.0 m CGVD28 between Nelson Road and Boundary Road	
Geometry and Stability	4 m wide crest with dike fill core 3H:1V land-side slope 3H:1V river-side slope (or 2H:1V with riprap revetment) Retaining walls minimized Sheetpile walls acceptable only with minimum 4 m wide dike fill core behind wall No standalone flood walls Meet minimum geotechnical factors of safety	Meets or exceed provincial dike standard and City dike standard
Land Tenure	Registered standard right-of-way	Dike located on City-owned land
Infrastructure in Dike	Crossings designed with seepage control Locate parallel infrastructure to land-side away from dike core	No infrastructure in dike
Vegetation on the Dike Slopes and Crest	Minimize shrubs and trees on the dike crest and slopes Operation and maintenance procedures need to deal with excessive vegetation	With overwide dike, it may be appropriate to allow for some relaxation of vegetation guidelines
Land Adjacent to Dike	Land is raised as much as is practical	Land is raised to meet or exceed dike crest elevation

Item	Value and Description	
	Minimum Acceptable	Preferred
Seismic Performance	Minimum 3.2 m CGVD28 post-earthquake dike crest elevation and maintain dike core integrity	No damage to dike from earthquakes up to a return period to be determined
River-side Slope and Setback	2H:1V bank slope with riprap revetment	>10 m setback between river top of bank and dike river-side slope toe 3H:1V river-side bank slope with acceptable vegetation
Crest Surfacing and Land-side Slope Treatment	Crest surfacing: 150 mm thick road mulch Land-side slope treatment: hydraulically seeded grass	Meet or exceed provincial dike standard and City dike standard Consider paved crest and land-side slope vegetation/armouring to add robustness against overtopping
Dyke Road Design Width	From river-side to land-side: 0.5 m allowance for barrier 0.6 m min horizontal clearance Two 3.7 m travel lanes 0.6 m min horizontal clearance 0.5 m allowance for barrier Total width: 9.6 m	From river-side to land-side: 4.0 m multi-use path 0.5 m min horizontal clearance 0.5 m allowance for barrier 0.6 m min horizontal clearance Two 3.7 m travel lanes 0.6 m min horizontal clearance 0.5 m allowance for barrier 2.0 m pedestrian walkway Total width: 16.1 m

Dike Crest Elevation

At this time, the Province has not established a Fraser River flood profile and dike design profile that considers sea level rise and climate change. It is understood that the Fraser Basin Council's Lower Mainland Flood Management Strategy project may produce a recommended future flood profile. The most recent available flood profile information is provided in the Province's 2014 study of climate change and sea level rise effects on the Fraser River flood hazard.

The designated flood profile for developing the master plan is proposed as the maximum of the following flood scenarios:

- 500-year return period coastal water level with 1 m of sea level rise (no wave effects); and
- 500-year return period freshet with moderate climate change impacts and 1 m of sea level rise.

Figure 3-1 shows the estimated flood profile water levels (in CGVD28 vertical datum, excluding freeboard) along the river in the study area. As shown on the figure, the coastal flood scenario governs from the ocean upstream to approximately Nelson Road.

Dike crest elevations are derived by adding freeboard and an allowance for land subsidence to the flood level. Table 3-4 presents the components that sum to the proposed dike crest elevation.

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	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)[1]	3.8		4.2	4.6
Wave Effects Allowance	None			
Freeboard (m)	0.6			
Land Subsidence Allowance (m)	0.2			
Dike Crest Elevation[2] (m)	4.6		5.0	5.4

Notes:
1. From (BC MFLNRO, 2014).
2. 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).

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

Seismic Performance guidelines

The current provincial seismic performance criteria for dikes are generally difficult to meet without costly and impractical ground improvement works. Additionally, the guidelines are considered very conservative in some situations because they require performance under extremely rare scenarios. For example, the guidelines require dikes to maintain 0.3 m freeboard in the event of a 10-year return period flood occurring following a 2,475-year return period earthquake which has a probability of 0.004% in a 1-year period. This is significantly rarer than the design event for the dike crest elevation (500-year return period event has a 0.2% annual exceedance probability). It is understood that the Province is conducting a review of the current criteria and associated guidelines.

An alternative seismic performance approach that focuses on failure mechanisms and post-earthquake level of protection is proposed, subject to any higher-level direction that may be forthcoming in the ongoing Richmond 2008-2031 Flood Protection Management Strategy Update. The alternative criteria are presented in Table 3-5.

Table 3-5: Proposed Alternative Seismic Performance Criteria

Criteria	Description / Value
Failure Mechanisms	Flowslides (resulting in full loss of dike cross-section into the river or channel) are not acceptable up to a return period to be determined (e.g. 2,475-year return period)
Maximum post-earthquake overtopping probability	0.2% Annual exceedance probability Calculate probability through comparison of various post-earthquake dike crest elevations and future flood levels + 0.3 m freeboard Assume a minimum 1-year exposure period for dike repairs, or longer if local site conditions warrant. In general, this results in a minimum post-earthquake dike crest elevation of 3.2 m which corresponds to the governing scenario of an average annual maximum coastal water level (1.9 m) with 1 m of sea level rise occurring within 1 year of a 475-year return period earthquake.

This approach would make the service level of the dike in a seismic scenario consistent with the service level for the dike crest elevation which is set based on a 500-year return period flood or a 0.2% annual exceedance probability.

For the coastal design dike crest elevation of 4.7 m CGVD28, this approach would allow for up to 1.5 m of vertical settlement, as long as core dike integrity is maintained.

The length of time between earthquake and dike repair will be a critical assumption for analysis to support this approach. The City may wish to specify consistent assumptions through the Dike Master Plan to ensure consistent analyses. For example, reconstruction of a dike that has failed into the river channel following a flowslide failure from an extreme earthquake may take up to 2 years or more, whereas more straightforward compaction and raising of a settled dike could be done in less than a year after an earthquake.

In addition, it should be noted that meeting the seismic performance criteria through increasing the dike crest elevation and crest width, as opposed to ground densification, has the added benefit of increasing the level of protection against flood events.

3.3 Alternative Upgrading Strategies

Several high-level dike upgrading strategies, summarized in Table 3-6, were considered to inform the development of specific options for the Dike Master Plan.

Table 3-6: High-level Dike Upgrading Strategies

Strategy	Advantages	Disadvantages
Road Dike *Raise road to dike crest elevation*	• Smaller footprint • Wider crest (more robust) • Smaller impacts to habitat	• Operation and maintenance challenges • Infrastructure within dike • High cost to raise dike in the future • Possible conflicts with recreational cyclists/pedestrians and vehicles – recreational users may need to be rerouted along inland routes
Separated Dike and Road *Conventional dike adjacent to road*	• Operation and maintenance separated from road • No infrastructure within dike	• Larger footprint and impact to infrastructure and habitat
Raise River-side Dike *Conventional dike along riverbank*	• Minimize footprint	• Limited space • Impacts to Fraser River riparian and intertidal habitat and drainage channel side riparian and aquatic habitat • Reduced seismic performance • Erosion hazard
Fill River-side Dike *Build into river to achieve conventional dike*	• Less impacts to existing development and on-shore infrastructure	• Impacts to Fraser River riparian and intertidal habitat • Reduced seismic performance • Erosion hazard
Setback Dike *Realign significantly away from river*	• Increased seismic performance • Reduced erosion hazard • Increased opportunities for riparian and intertidal habitat enhancement	• Increase in unprotected development • High infrastructure impacts • High cost to construct new dike alignment • Would result in 2 dikes (existing and setback) to maintain
Land Raising ("superdike") *Raise development and roads adjacent to dike*	• Wider crest (more robust) • Reduced grading issues (after implementation) • Less impacts to raise a dike in the future	• Timing and phasing depends on development • High cost to raise large lots with low density land use • Grading and access issues for water-oriented developments • Impacts to Fraser River riparian and intertidal habitat and drainage channel side riparian and aquatic habitat

3.4 Options and Concepts

Through a series of meetings and site visits with City staff, the high-level upgrading strategies have been narrowed down to a set of options and concepts for each reach.

The main options developed for Phase 3 Dike Master Plan include:

- Option 1: Separated dike and road (Figure 3-2): raise dike and road, extend land-side;
- Option 2: Riverbank dike (Figure 3-3): raise dike only and extend land-side; and
- Option 3: Superdike (Figure 3-4): raise land behind the dike.

In addition to the above long-term options, additional interim options are being considered for areas where there is not enough space to build a standard dike and/or current operations at the site preclude the landowner from constructing a standard dike. These options are intended to function as temporary measures until the land behind the dike can be raised to an appropriate level, or leaseholders and landowners change, and the site can be redeveloped. These interim options are:

- Option 4: Road dike (Figure 3-5): keep the dike within the road footprint and raise the road and associated dike, extend land-side;
- Option 5: Setback sheetpile wall (Figure 3-6): raise the dike with sheetpile retaining wall behind existing development to minimize footprint and allow for access to the water;
- Option 6: Riverside sheetpile wall (Figure 3-7); raise the dike with sheetpile retaining wall along the riverside to minimize footprint

Table 3-7 presents a summary of the options for each reach. Appendix B includes landscape concepts prepared by Hapa associated with the cross-section options.

Table 3-7: Dike Upgrading Options

Reach # and Name	Options
1 – Gilmore West	• Option 1: Separated dike and road • Option 2: Riverbank dike • Option 3: Superdike
2 – Crown Packaging	• Option 2: Riverbank dike • Option 3: Superdike *Site-specific interim options:* • Option 6: Riverside sheetpile wall • Combined with site grading and Option 2
3 – Gilmore East	• Option 1: Separated dike and road • Option 2: Riverbank dike • Option 3: Superdike *Site-specific interim options:* • Option 4: Road Dike
4 – Shellmont West	• Option 1: Separated dike and road

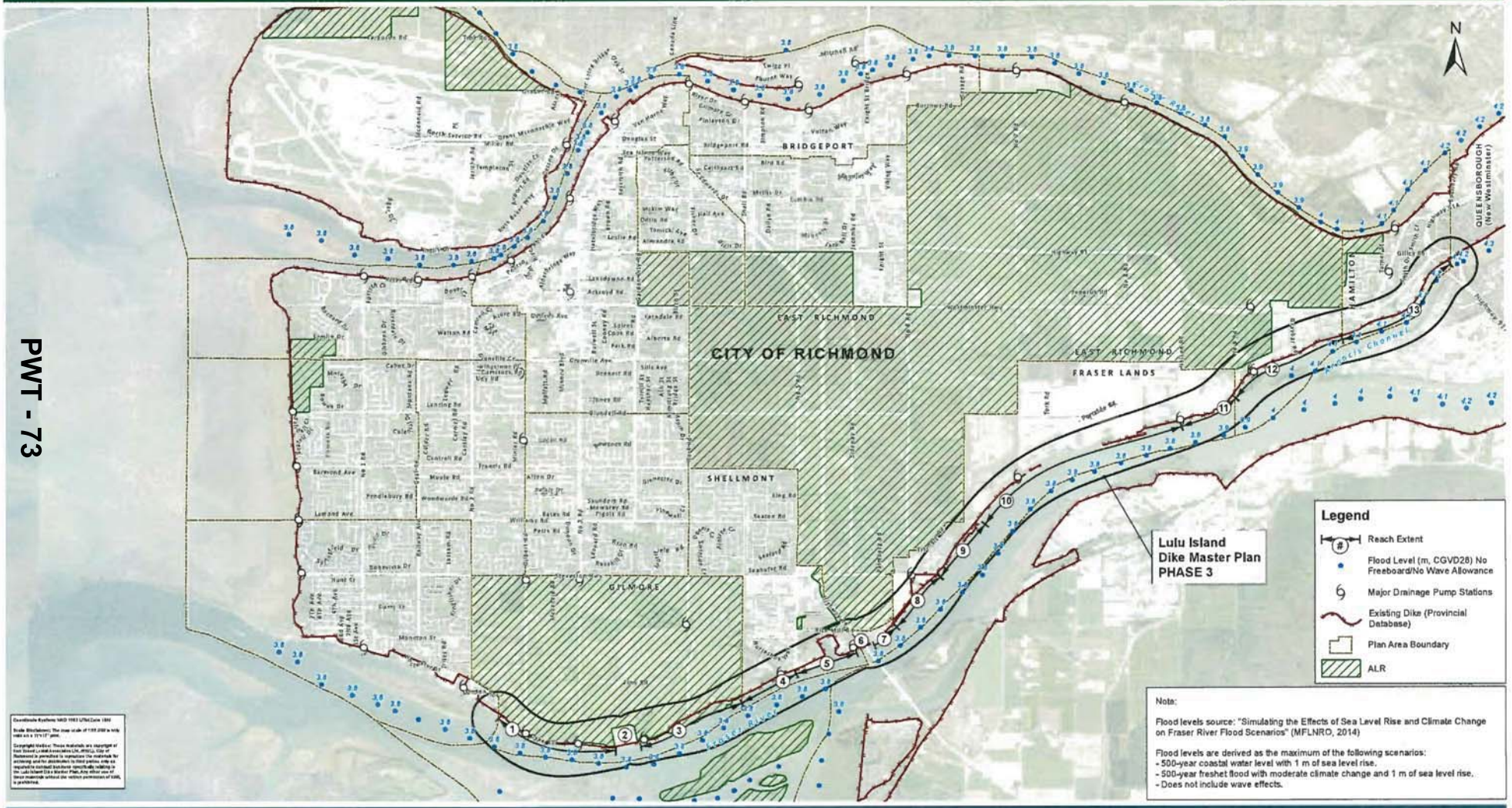
Reach # and Name	Options
5 – Shellmont Deas Dock	• Option 1: Riverbank dike • Option 3: Superdike *Site-specific interim options:* • Option 5: Setback sheetpile wall • Combined with site grading and Option 1 • Combined with site-specific flood response
6 – Highway 99	• Option 1: Separated dike and road • Option 3: Superdike • Note: the link to the potential mid-island secondary dike is not shown or addressed because it is dependent on changes to the George Massey Tunnel
7 – Fraser Lands – 13140 Rice Mill Road	• Option 2: Riverbank dike • Option 3: Superdike *Site-specific interim options:* • Option 5: Setback sheetpile wall • Combined with site grading and Option 1
8 – Fraser Lands Fraser Wharves	• Option 2: Riverbank dike • Option 3: Superdike
9 – Fraser Lands Riverport Way	• Option 2: Riverbank dike • Option 3: Superdike
10 – Fraser Lands Port Metro Vancouver	• Option 2: Riverbank dike • Option 3: Superdike
11 – Fraser Lands Lafarge	• Option 2: Riverbank dike • Option 3: Superdike
12 – East Richmond	• Option 1: Separated dike and road • Option 2: Riverbank dike • Option 3: Superdike *Site-specific interim options:* • Option 4: Road Dike
13– Hamilton	• Option 1: Separated dike and road • Option 2: Riverbank dike • Option 3: Superdike *Site-specific interim options:* • Option 4: Road Dike • Option 6: Riverside sheetpile wall around townhomes outside of the current dike
14 – Boundary	• Option 1: Separated dike and road • Option 3: Superdike • Site-specific option to include a secondary dike to tie into the higher elevations of the Hwy 91 interchange *Site-specific interim options:* • Option 4: Road Dike (tie into New Westminster's dike system at South Dyke Road)

The plan view and typical sections on a reach-by-reach basis are shown in Appendix A.

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City of Richmond
Lulu Island Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



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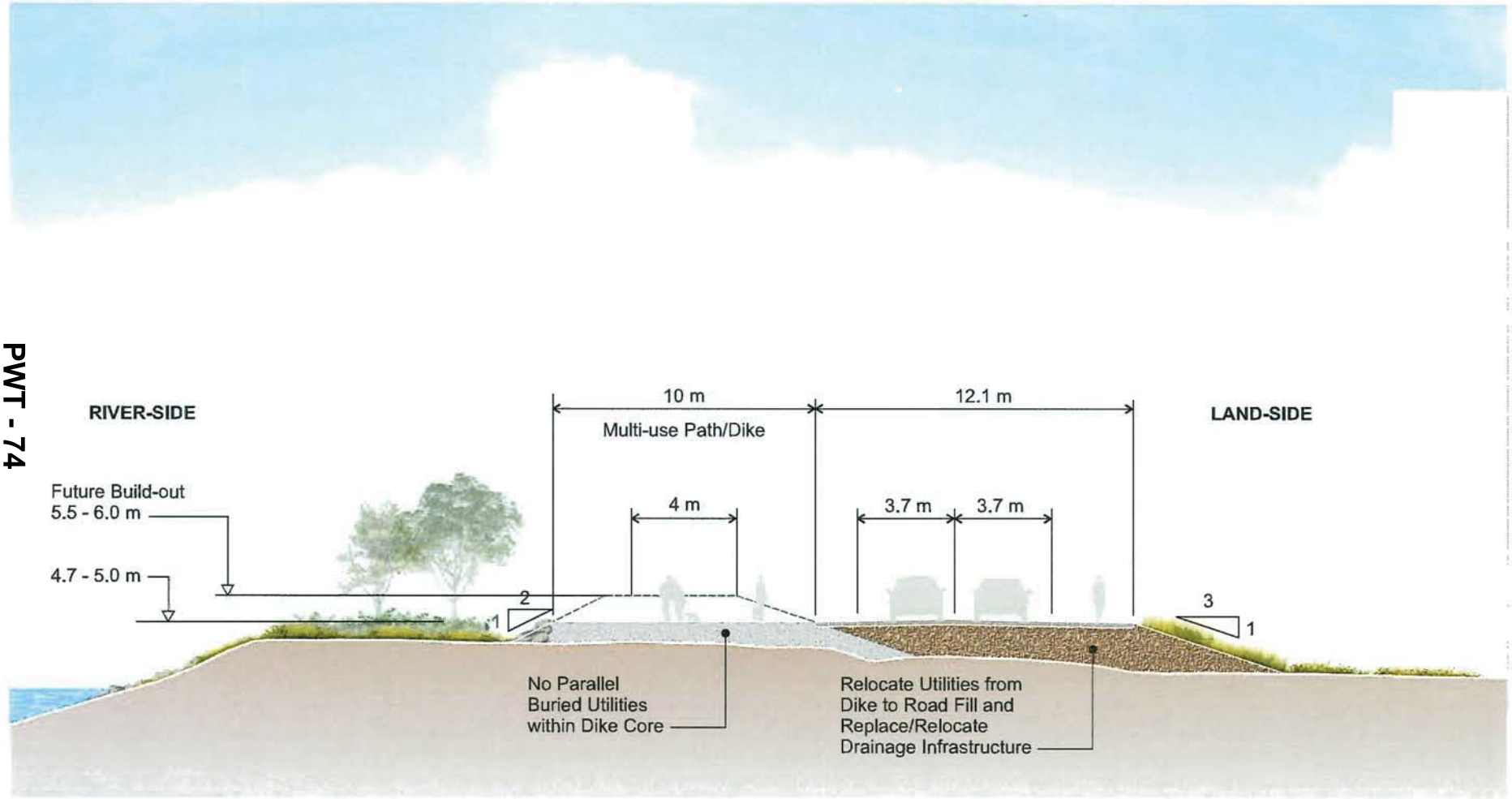
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Fraser River Flood Elevations

DRAFT
Figure 3-1

City of Richmond
Lulu Island Dike Master Plan - Phase 3

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Project No.	651.110
Date	October 2018
Scale	Not to Scale

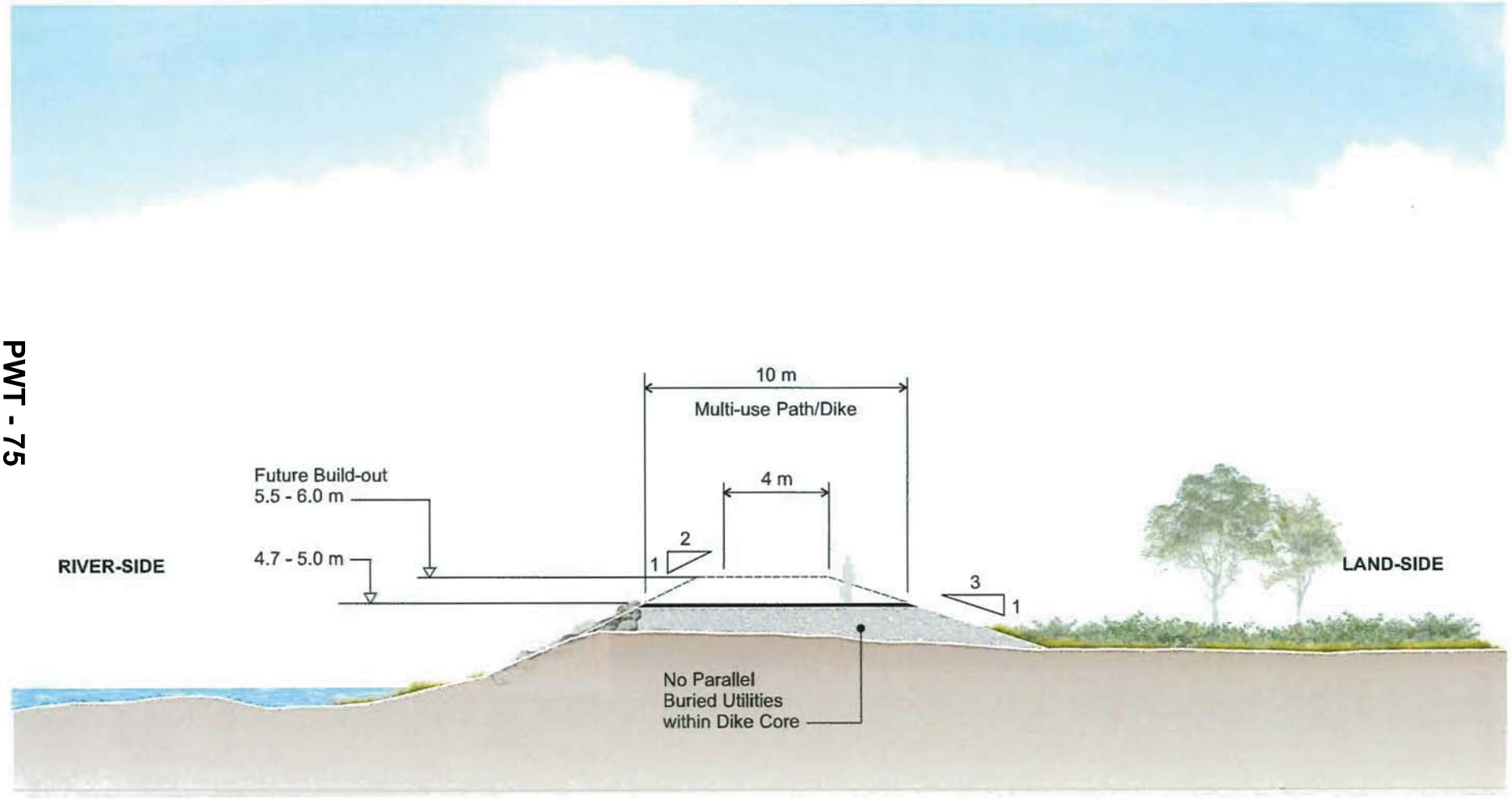
Option 1: Separated Dike and Road
Raise Dike and Road, Extend Land-side

Figure 3-2

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City of Richmond
Lulu Island Dike Master Plan - Phase 3

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Project No.	651.110
Date	October 2018
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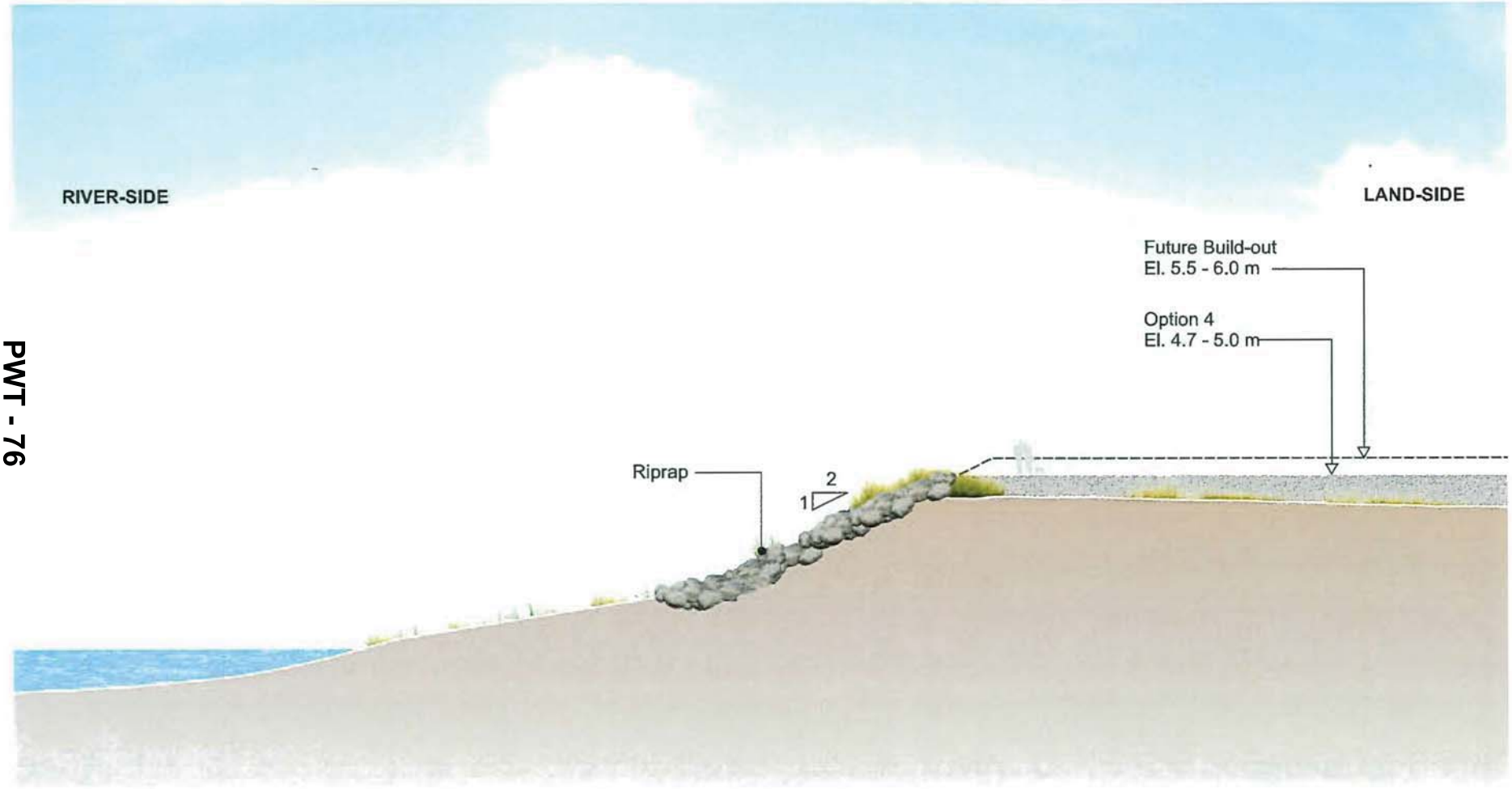
Option 2: Riverbank Dike
Raise Dike Only and Extend Land-side

Figure 3-3

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Lulu Island Dike Master Plan - Phase 3

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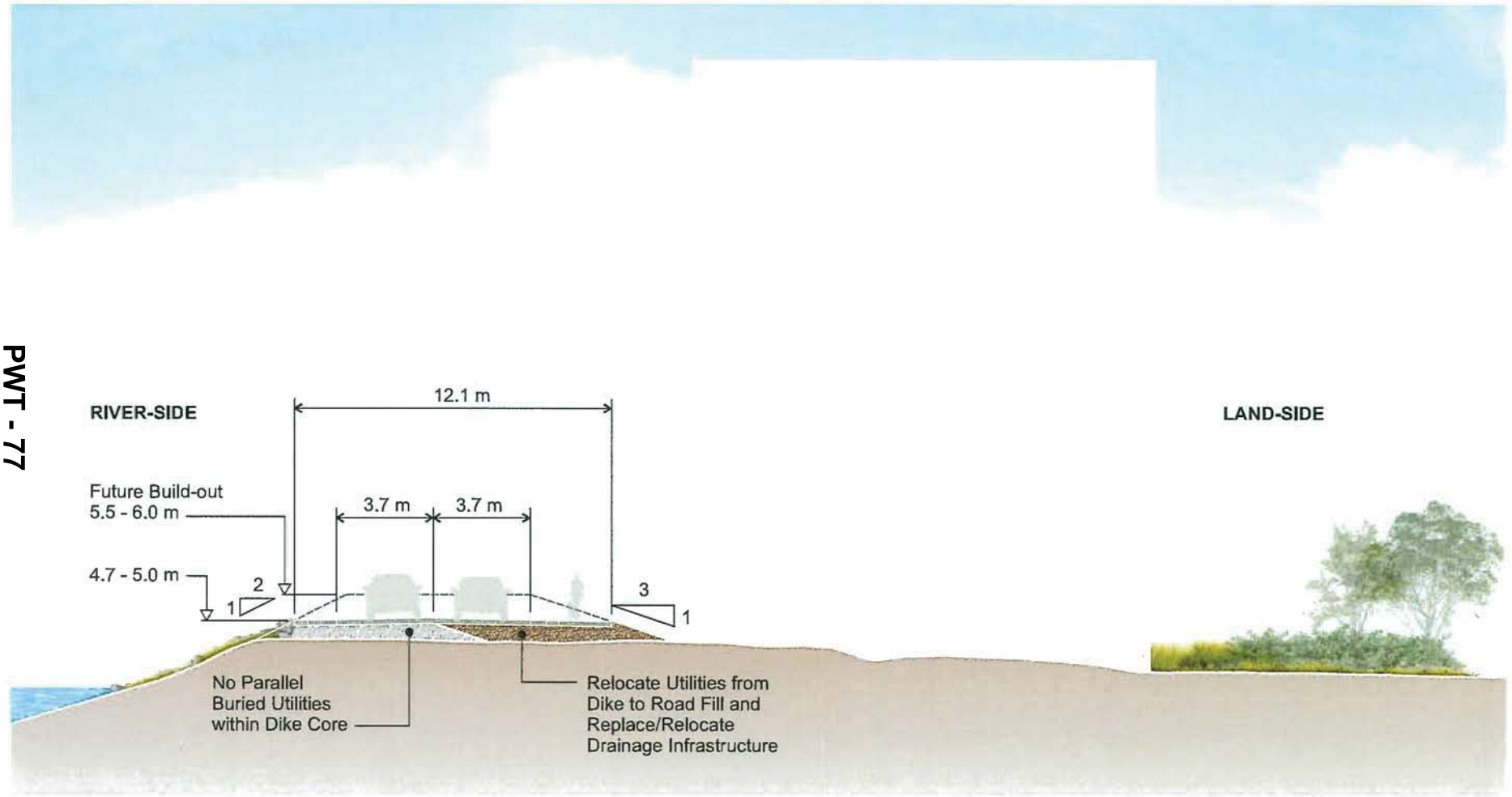
Option 3: Superdike
Raise Land Behind Dike

Figure 3-4

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Lulu Island Dike Master Plan - Phase 3

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Option 4: Road Dike
Raise the Existing Dike within the Road (Interim Option)

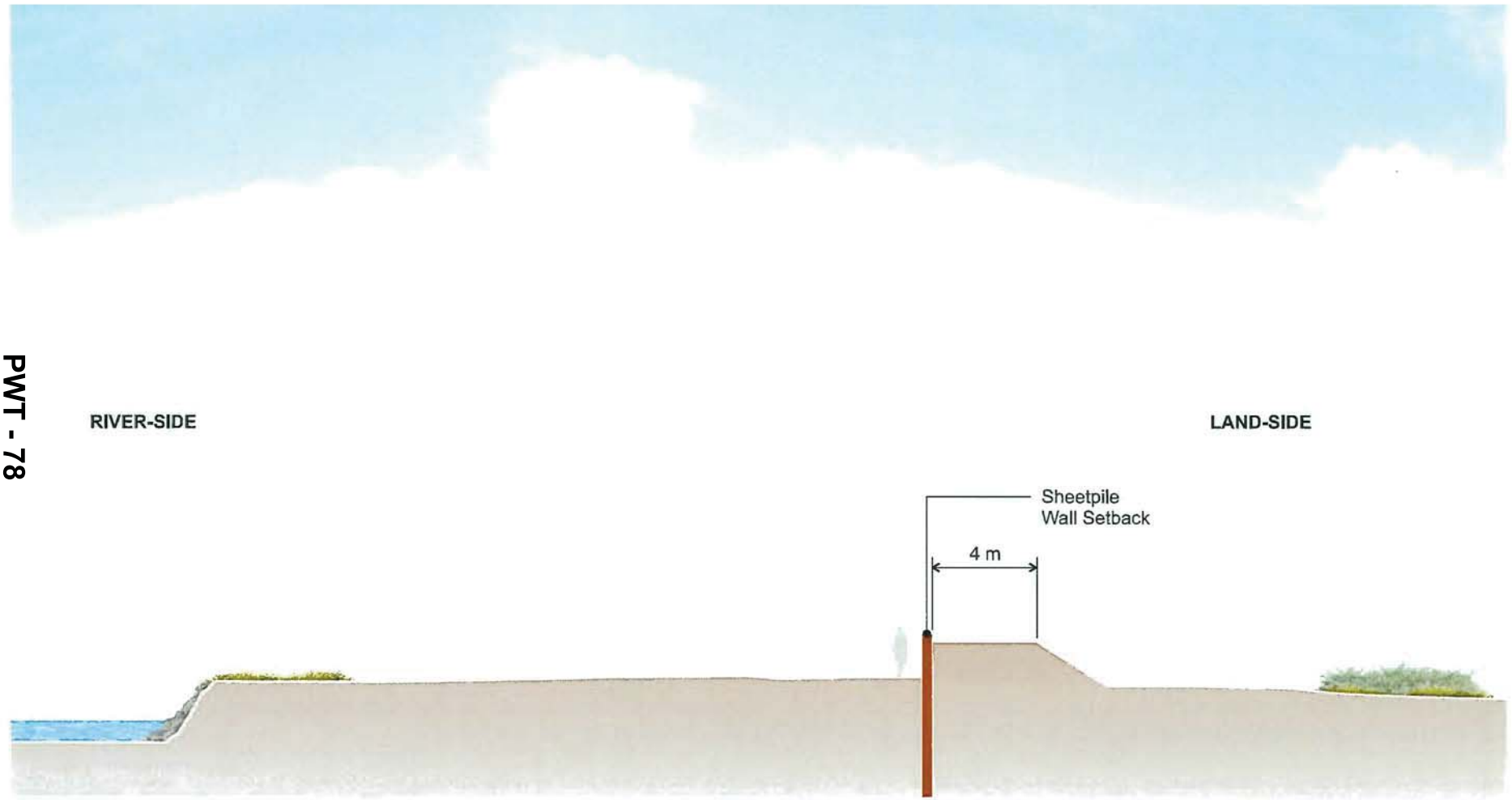
Figure 3-5

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Lulu Island Dike Master Plan - Phase 3

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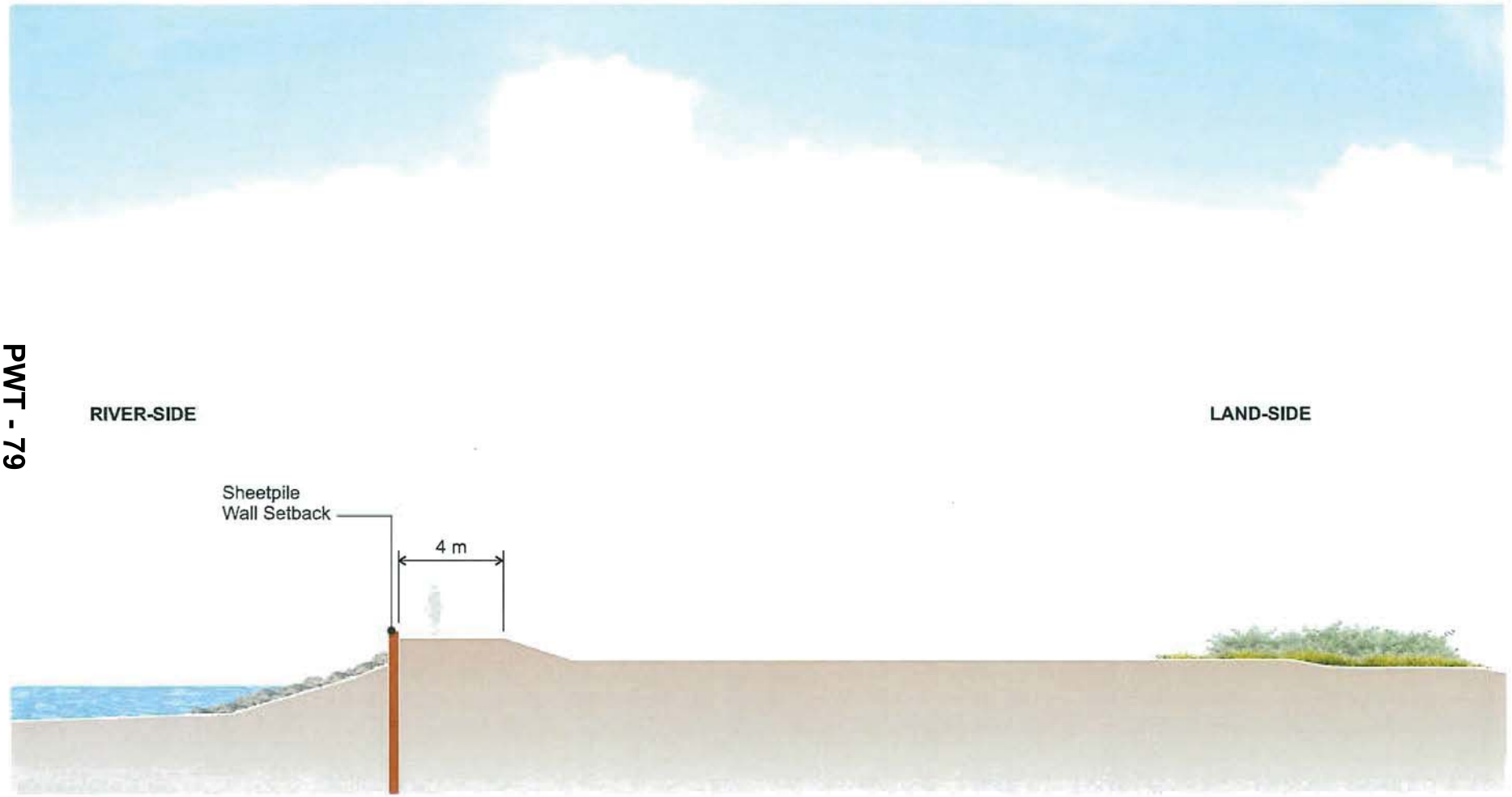
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Date	October 2018
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Option 5: Setback Sheetpile Wall (Interim Option)

Figure 3-6

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Lulu Island Dike Master Plan - Phase 3

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Date	October 2018
Scale	Not to Scale

Option 6: Riverside Sheetpile Wall (Interim Option)

Figure 3-7

Option 1: Separated Dike and Road: Separate Dike and Road, Raise Dike and Road, and Extend Land-side

The primary option developed for Phase 3 involves separating the dike and Dyke Road, raising both to the dike crest elevation, and extending the footprint of the fill towards the land-side. Figure 3-2 presents a typical cross-section for this option.

This option addresses several of the main design considerations including providing a substantially wide dike and improving road safety by separating vehicles and cyclists/pedestrians.

In some reaches, extending the footprint towards the land-side requires filling in the existing channel and replacing or relocating the drainage conveyance and storage. The preferred approach is to replace the channels with pipes. This will result in a loss of aquatic and riparian habitat and will require habitat creation, restoration, or enhancement (or a combination of the three) to be completed elsewhere to offset the loss.

Extending the footprint towards the land-side will require land acquisition where the existing corridor width is insufficient. In general, this would affect a narrow strip of land on the frontage of large lots and should be feasible to implement.

However, there are also areas on both the land-side and the river-side where the upgrade will result in access issues. The areas with the most severe space limitations and potential options to address the access issues are presented in Table 3-8.

Table 3-8: Space Limitations and Access Issues

Reach / Location / Description	Photo	Options to Address Footprint and Access
Reach 3 Finn Slough		• Steeper driveway access • Provide parking on land-side • Steeper or longer road ramps up to the new road elevation
Reach 11 Shelter Island Marina and Boatyard		• Steeper driveway access • Steeper or longer road ramps up to the new road elevation • Coordinate with industry to raise the site or to raise the ship crane and associated river access infrastructure • Raise land at time of redevelopment

Reach / Location / Description	Photo	Options to Address Footprint and Access
Reach 13 Intersection with Fraserwood Way		• Steeper or longer road ramps up to the new road elevation • Raise land at time of redevelopment
Reach 13 - Hamilton		• Steeper driveway access • Provide parking on land-side (instead of driveway down to lot) • Raise land at time of redevelopment • Steeper or longer road ramps up to the new road elevation • Managed retreat (buy-out, relocate, or do not allow redevelopment)
Reach 13 – Hamilton 23700 blk of Dyke Road		• Steeper driveway access • Provide parking on land-side (instead of driveway down to lot) • Leave existing road as a low "local road" and provide access to the new road at an intersection near Boundary Road • Managed retreat (buy-out, relocate, or do not allow redevelopment)
Note: Images from Google Street View		

Option 2: Riverbank Dike: Raise Dike, and Extend Land-Side

The primary option developed for Phase 3 where there is no road associated with the dike, is to raise the dike crest elevation and extend the footprint of fill towards the land-side. Figure 3-3 presents a typical cross-section for this option.

Extending the footprint towards the land-side will require land acquisition where the existing corridor width is insufficient. In general, this would affect a narrow strip of land on the frontage of large lots and should be feasible to implement. Extending the dike footprint to the land-side decreases the amount of Fraser River riparian and river habitat that is impacted, but may result in the loss aquatic and riparian habitat from drainage channels on the land side of the dike.

Option 3: Superdikes: Land Raising

Another option that is being considered for Phase 3 is the raising of lands behind the dike to the dike crest elevation. This creates a more robust flood protection structure and has the potential to improve site grading issues and river access constraints. The option to raise the land behind the dike is most appropriate for areas that are contemplated for short-term redevelopment.

This option will result in a loss of aquatic and riparian habitat and will require habitat creation or enhancement to be completed elsewhere to offset the loss.

Option 4: Road Dike: Raise Dike and Road, and Extend Land-side (Interim Solution)

An interim option is being considered where the existing development encroaches on the dike/road corridor such that separating the dike from the road and raising both structures is not immediately feasible. This option is to continue to have the dike in the road, while raising the road to the design dike crest elevation and extending the footprint of fill towards the land-side.

This option addresses several of the main design considerations; however, it does not allow for complete separation of pedestrians and bikes from the roadway and does not address concerns of complexities of future dike raising if the road infrastructure is integrated into the dike structure.

This option will result in a loss of aquatic and riparian habitat and will require habitat creation or enhancement to be completed elsewhere to offset the loss.

Option 5 & 6: Sheetpile Walls (Interim Solution)

Site-specific interim solutions are considered where a site is not scheduled for short-term redevelopment and site constraints such as rail lines, barge access and site grading for specialized equipment do not allow for constructing a standard dike as per the options discussed previously. Two sheetpile wall configurations (Figure 3-6 and Figure 3-7) are considered to address short-term flood protection at two sites:

- Crown Packaging (Reach 2); and
- 13140 Rice Mill Road, Canfisco (Reach 7).

For both of these sites, the sheetpile wall would bring the dike crest to the design elevation. The dike width would be narrower than the preferred options but could allow for raising the dike to an acceptable level where there is minimal room on the site for additional dike footprint. For those locations where a setback dike is constructed, the landowner would need to develop and implement a flood response plan and reasonable floodproofing measures would be required. Retaining walls should consider the need for handrails for safety, in accordance with applicable regulations. Loss of aquatic and riparian habitat may be reduced with this option.

3.5 Stakeholder Engagement

Stakeholder engagement for Phases 3, 4, and 5 of the Dike Master Plan is being completed jointly in two stages. Prior to City Council review, initial stakeholder engagement was completed that included meetings with internal City departments and government agencies. This initial stakeholder engagement allows for input from City groups on options developed, additional background, and future coordination, with the goal of informing the recommended upgrade options. Following Council review, additional stakeholder engagement is planned, which will include meetings with specific stakeholder groups and a public consultation event. The second stage of stakeholder engagement is intended to inform the public on the draft preferred options and seek any feedback the City may wish to consider in finalizing the Dike Master Plan to implementation.

For Phase 3, the parties consulted to date include the following.

- City of Richmond Transportation;
- City of Richmond Parks, Planning, and Sustainability;
- City of New Westminster; and
- Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD)
    - Included Inspector of Dikes, Flood Safety, and Water Authorizations staff

Meetings were held following options development.

The City requested a meeting with the Department of Fisheries and Oceans (DFO) who declined, stating that their input would be provided during later stages in the established review and approvals process.

Additional stakeholder consultation following Council review for Phase 3 is planned to include the following parties, which will be confirmed with the City following review:

- Port Metro Vancouver,
- Lafarge and Armtec,
- Ministry of Transportation and Infrastructure (MOTI),
- Crown Paper,
- Deas Dock (BC Ferries),
- Canfisco (13140 Rice Mill Road),
- Finn Slough Heritage and Wetland Society, and
- General public

3.6 Options Evaluation and Selection

General Recommendations

The options described in Section 3.4 have been assessed considering the feedback from the stakeholder meetings and the following:

- dike design criteria;
- impacts to habitat;
- cost implications;
- robustness of flood protection;
- impacts to existing properties and operations; and
- ability to accommodate further long-term upgrading.

The recommended options are based on a vision of Richmond progressively improving its level of flood protection ahead of the pace of development and rising sea level. Recommended dike design features include the following for Phase 3.

High and Wide Earth Fill – Favour earth fill dike construction where possible since it is more robust, flexible, and expandable than other types of structures. Build to 4.7 m crest elevation (higher upstream), expandable to 5.5 m to accommodate additional sea level rise. Build the 4.7 m crest elevation with a crest width of 10 m to make it expandable to 5.5 m crest elevation without the need for further road reconstruction or land acquisition.

Separate Roads and Utilities – Utilities pose an unnecessary risk to the dikes. Along with roads, they also increase the complexity and cost of dike maintenance and expansion. The City should seek to separate roads with utilities away from the dike structure, preferably on the land-side the dike, and put the road elevation at dike crest height to be compatible with raised land use behind the dike and road.

Raised Development – Raise the land on the land-side of the dike to facilitate existing and future raised land use. This supports a vision of a waterfront community that has adjacent development above and looking down over the dike instead of behind it. It also reduces the amount of land acquisition required to support dike raising by eliminating the land-side slope.

Land Acquisition for Full Future Needs - Acquire enough land or rights-of-way at first reasonable opportunity to facilitate full width of the future 5.5 m crest height. Land acquisition and rights-of-way may be a condition of redevelopment, or land could be purchased specifically for planned dike construction. For industrial sites, access for inspection, maintenance and future raising is required. For other sites, public use of the dike is also needed. Where land acquisition opportunities can not keep pace with dike requirements, interim narrower dike options may be considered.

Habitat Balance – Dike widening is typically recommended to be on the land-side of the existing dike, as opposed to projecting further toward the river. This is due to a preference to preserve or enhance river riparian habitat. However, there are some cases where inland channel habitat may be impacted or where moving the dike towards the river may be the best option to reduce large impacts to roads. Where habitat and drainage channels would be impacted by dike upgrading, their hydraulic function and habitat value is recommended to be compensated by other means. This may include storm sewers, channels relocated inland, and separate habitat enhancement projects.

Recommended Options

The various high-level dike upgrading strategies and potential dike upgrading options have been distilled to two main recommended options for long-term dike planning, as described below.

- **Separated dike and road** (Option 1):
    - Use in locations where there is a road associated with the dike.
    - Separate the dike and roadway such that there is an over-wide dike and separate travel areas for vehicles and cyclists/pedestrians.
    - Raise the dike crest and road surface to the design dike crest elevation and extend the footprint of fill towards the land-side.
    - Install bank protection works on the river side to match existing.

- **Riverbank dike** (Option 2):
    - Use in locations where there is no road associated with the dike.
    - Raise the dike crest to the design elevation and extend the footprint of fill towards the land-side.
    - Install bank protection works on the river side to match existing.

In general, the two above options are recommended because they are the most robust of the options considered. They produce a wide dike crest at a stable geometry that is set back from the river. The dike portion of the overall crest would be 10 m wide to accommodate future dike raising without having to modify the road. The "separated dike and road" option is recommended in areas where there is currently a road associated with the dike because it is the most robust of the options considered as it produces an earth fill embankment (dike and road) that is approximately 22 m wide at the crest. This is a significant increase above the standard dike crest width of 4 m and is expected to reduce the likelihood of failure across a variety of processes.

Additionally, separating the dike and road provides several community benefits including improved pedestrian, cyclist, and vehicle safety, and the opportunity for a linear park / multi-use path. Other interim options are recommended in areas which are constrained and do not allow for the separated dike and road option.

In addition to the two options listed above, another recommendation for flood protection in all areas of Phase 3 is to target land raising of the areas behind the dike. This is shown as Option 3: Superdike. It should be considered for all reaches.

Interim Options

The two recommended options will require land acquisition and phased implementation as existing development and current land use limit the existing dike corridor and some existing industries need access to the river for operations. To address this phased implementation, additional interim options are recommended, as described below.

- **Road Dike** (Option 4):
    - Use at sites not scheduled for short-term redevelopment.
    - Continue to have the dike in the road where existing development encroaches on the corridor.
    - Raise the road surface to the design dike crest elevation and extend the footprint of fill towards the land-side.
    - Install bank protection works on the river side to match existing.
- **Setback Sheetpile Wall** (Option 5):
    - Use at sites not scheduled for short-term redevelopment where site constraints such as rail lines, barge access and site grading for specialized equipment do not allow for construction of a standard dike.
    - Raise the dike to the design dike crest elevation using sheetpile walls to minimize the encroachment of fill on the property.
    - Use site specific flood response plans to address flood hazards on the site.

- **Riverside Sheetpile Wall** (Option 6):
  - Use at sites not scheduled for short-term redevelopment where site constraints such as rail lines, barge access and site grading for specialized equipment do not allow for construction of a standard dike.
  - Raise the dike to the design dike crest elevation using sheetpile walls to minimize the encroachment of fill on the property.

Summary of Recommended Options by Reach

Table 3-9 presents a summary of the recommended options for each reach as well as the recommended interim options to address site specific concerns. For all reaches, Option 3: Superdike, raising the land for approximately 200 m inland of the dike, is recommended for related flood protection and seismic stability reasons. Because Option 3 is a global recommendation for Phase 3 Dike Master Plan, it has not been included in Table 3-9. The recommended options are shown in Appendix A.

Table 3-9: Recommended Dike Upgrading Options (Phase 3)

Reach # and Name	Recommended Options
1 – Gilmore West	• Option 1: Separated dike and road • Option 2: Riverbank dike (park area)
2 – Crown Packaging	• Option 2: Riverbank dike *Site specific interim options:* • Option 6: Riverside sheetpile wall • Combined with site grading and Option 2
3 – Gilmore East	• Option 1: Separated dike and road • Option 2: Riverbank dike (park area) *Site specific interim options:* • Option 4: Road dike (Finn Slough)
4 – Shellmont West	• Option 1: Separated dike and road
5 – Shellmont Deas Dock	• Option 2: Riverbank dike *Site specific interim options:* • Option 5: Setback sheetpile wall • Combined with site grading and Option 2 • Combined with site specific flood response
6 – Highway 99	• Option 2: Riverbank dike Note: the link to the potential mid-island secondary dike is not shown or addressed because it is dependent on changes to the George Massey Tunnel
7 – Fraser Lands – 13140 Rice Mill Road	• Option 2: Riverbank dike *Site specific interim options:* • Option 5: Setback sheetpile wall • Combined with site grading and Option 2
8 – Fraser Lands Fraser Wharves	• Option 2: Riverbank dike

Reach # and Name	Recommended Options
9 – Fraser Lands Riverport Way	• Option 2: Riverbank dike
10 – Fraser Lands Port Metro Vancouver	• Option 2: Riverbank dike
11 – Fraser Lands Lafarge	• Option 2: Riverbank dike
12 – East Richmond	• Option 1: Separated dike and road • Option 2: Riverbank dike *Site specific interim options:* • Option 4: Road dike
13– Hamilton	• Option 1: Separated dike and road *Site specific interim options:* • Option 4: Road dike
14 – Boundary	• Option 1: Separated dike and road • Site specific option to include a secondary dike to tie into the higher elevations of the Hwy 91 interchange *Site specific interim options:* • Option 4: Road dike (tie into New Westminster's dike system at South Dyke Road)

Drainage Impact Assessment

The internal drainage system of Lulu Island provides irrigation service as well as drainage service. The system of channels allows water from intakes on the Fraser River to flow into Lulu Island and distribute through the drainage conveyance system to provide irrigation water to the farmlands. This use of the drainage conveyance system relies on the storage capacity within the channels to provide adequate water to the farmlands.

There are two large, agricultural drainage channels adjacent to Dyke Road that would potentially be impacted by the proposed increase in road and dike footprint. These include the area adjacent to Finn Slough and the area near London Heritage Farm. The option expected to be both the simplest to implement and the least cost is to replace the existing channels that would be impacted by the dike and road upgrades along Dyke Road with pipes. The replacement pipes would be located within the cross-section of the road and outside of the dike cross-section.

The approach of filling the existing drainage channel and replacing it with a pipe is limited by the size of the pipe that can fit within the road cross-section and the invert elevations of the existing internal agricultural drainage infrastructure (culverts, drainage channels and drain tiles). Multiple connections and or inlets to the pipe may be required to replace existing drainage and irrigation functions for the adjacent agricultural fields. The new pipes would drain to the existing north-south channels that convey runoff to the pump stations.

No detailed drainage assessment has been completed for this study and further work would be needed to assess if replacing the existing drainage channels with pipes is feasible and to size and design the pipes. If feasible, drainage from both Dyke Road and the interior lots adjacent to the road would be directly connected to the new drainage pipes. If the required capacity or depth cannot be provided in a pipe, then replacement open channels would have to be located adjacent to the toe of the upgraded road section.

Habitat Impact Assessment

In total, the estimated impact for the selected Phase 3 options is 19,300 m^2 of high-quality Fraser River intertidal habitat, 27,500 m^2 high quality Fraser River riparian habitat, 14,200 m^2 drainage channel aquatic habitat, and 48,500 m^2 drainage channel riparian habitat.

These areas reflect an estimate of impact area based on FREMP habitat mapping from 2007, and orthoimagery interpretation. Not all Fraser River riparian and intertidal habitat was quantified. The desktop review only quantified high-quality riparian and intertidal habitat types on the Fraser River side of the existing dike. The remaining habitat area, while not calculated here, would also be required in calculations for determining offsetting requirements. A detailed aquatic effects assessment is required to calculate the actual area of impact to fish habitat and to determine potential offsetting requirements.

The impact area presented above represents a significant area of impact that will require major offsetting effort. Estimated reach-by-reach impact areas are presented below.

Table 3-10: Reach-by-Reach Summary of Habitat Impacts

Reach # and Name	High-Quality Fraser River Intertidal (m^2)	High Quality Fraser River Riparian (m^2)	Drainage Channel Aquatic (m^2)	Drainage Channel Riparian (m^2)
1 – Gilmore West	9,900	-	4,400	21,000
2 – Crown Packaging	600	-	-	-
3 – Gilmore East	6,700	2,400	3,100	14,200
4 – Shellmont West	-	200	1,200	4,400
5 – Shellmont Deas Dock	1,000	-	< 100	< 100
6 – Highway 99	-	200	-	-
7 – Fraser Lands – 13140 Rice Mill Road	-	-	-	-
8 – Fraser Lands Fraser Wharves	200	100	-	-
9 – Fraser Lands Riverport Way	100	100	-	-
10 – Fraser Lands Port Metro Vancouver	700	17,000	1,300	900
11 – Fraser Lands Lafarge	-	900	-	-
12 – East Richmond	-	2,500	3,200	5,500
13/14– Hamilton/Boundary	100	4,200	1,100	2,400

Geotechnical Considerations for Recommended Options

The proposed dike improvements were assessed with consideration for the BC Seismic Design Guidelines for Dikes.

Thurber Engineering Ltd. (Thurber) assessed three sample cross-sections to estimate the potential deformation resulting from seismic events. The cross-sections were based on the recommended cross-section at what was judged to be the most susceptible areas for deformation. Soil conditions were determined by cone penetration tests. Seismic performance was assessed on the basis of existing foundation conditions, (i.e. no additional ground improvement/densification) to determine the need for ground improvement or alternative approaches. The analysis included seismic events representing 100, 475 and 2,475-year return period events. Seismic performance was assessed using two methods: 1-D (i.e. flat ground) liquefaction assessment to estimate reconsolidation settlements, and 2-D numerical deformation assessment to estimate dynamic deformations. The methods are complimentary, and the results are interpreted together.

The preliminary geotechnical report is attached in Appendix C.

The key results of the geotechnical analysis are summarized below.

- Proposed dike cross-sections will not meet the performance requirements of the seismic design guidelines, without ground improvement or alternative approaches, based on the results of both assessment methods.
- The liquefaction hazard is considered insignificant for earthquakes up to the 100-year return period event.
- The liquefaction hazard is considered moderate and high for the 475 and 2,475-year return period events respectively. The resulting deformations would be large.
- Liquefaction may result in a flowslide into the river for dike alignments along the river-bank due to lateral spreading, whereas it would result only in vertical deformation for dike alignments significantly set back from the river bank.
- The deformation analysis indicates that dikes may meet the performance requirements of the seismic design guidelines if they are typically set back 50 m to 100 m from the river-bank and have flat slopes or some localized ground improvement.

Options to address seismically induced deformations, and opinions on each, include:

- **Densification** – The typical approach to densification is to install stone columns. To be effective against the liquefaction expected to follow the 2,475-year return period event, densification would have to extend the depth of the liquefaction zone, and for a similar width. In a typical scenario, this can be considered as a 30 m (width) by 30 m (depth) densification located at the river-side toe of the dike. Densification can be very costly (e.g. $9,000 to $18,000 per lineal metre of dike). Alternate experimental techniques are being tested by the City that may offer a more economic solution.
- **Higher Crest** – For the 100-year return period event, additional crest elevation may compensate for deformations caused by settlement. For events that cause liquefaction, added height results in added deformation, so it would be less effective. This is not an effective strategy by itself for return periods above 100-year due to lateral spreading and large vertical deformations.

- **Setback and Slope** – Flatter side slopes on the dike improves seismic stability. However, to prevent large deformations in the 2,475-year return period event, the maximum acceptable slope between the river channel invert and the dike crest would need to be approximately 2%, which would require a significant setback between the dike and river.
- **Wide Crest** ("superdikes") – A very wide dike (e.g. crest width of 100 m to 200 m) could be used to extend the dike beyond the limit of significant lateral spreading due to liquefaction. A portion of the wide crest could be considered sacrificial in the even to major lateral spreading. Raising the land for approximately 200 m inland of the dike is desirable for related flood protection reasons, and may be desired by the City for other reasons such as land use planning. It has already been done as part of multiple family, commercial, and industrial development projects along the waterfront. Buildings within this area must already account for liquefaction in their foundation design.
- **Dike Relocation / Secondary Dikes** – Place the dike inland of the liquefaction lateral spreading zone (similar to set back approach) or place a secondary dike inland of the liquefaction lateral spreading zone. The wider option above would essentially include a secondary dike. Relocating the primary dike inland would be a form of retreat and would leave existing property and buildings exposed outside of the dike.
- **Post-earthquake Dike Repair** – Dike reach specific plans could be developed for post-earthquake dike repairs. These would need to consider the feasibility of dike repair construction following a major earthquake. In general, it is likely not feasible to quickly repair a dike that has failed due to a flowslide induced by liquefaction lateral spreading, especially if the breach results flooding from regular high tides. However, it may be feasible to prepare dike repair plans for dikes where a flowslide is not anticipated.

Additionally, the City may wish to use alternative seismic performance criteria, such as the criteria discussed in section **Error! Reference source not found.** which aims to develop a consistent level of performance between seismic scenarios and flood level scenarios (i.e. an overall 0.2% annual exceedance probability of failure across all hazards).

Recommendations to manage the seismic risk include:

- Consider the proposed alternative seismic performance criteria provided in Section **Error! Reference source not found.**. Review the criteria if/when the Province issues updated guidelines for seismic performance of dikes.
- Fill land for approximately 200 m inland of the dike to dike crest elevation. Buildings in this zone should be built above the dike crest elevation and have densified foundations capable of withstanding liquefaction. The required distance requires some additional evaluation and may be addressed in the pending updated to the Flood Protection Management Strategy.
- Continue to investigate practical densification options and consider earthquake induced dike deformations in emergency response and recovery planning.

3.7 Cost Opinions

Cost opinions for the recommended option in each reach are provided to help the City consider the financial implications for planning and comparing options. A breakdown is provided to help understand the proportional cost for recommendations such as separating and raising the road.

Costs are based on unit rate cost estimates and tender results for similar works. The most relevant rates are from the City's Gilbert Road dike project. The City provided a summary of the cost estimate prepared by WSP for this project.

Rates from recent tenders for diking on the Lower Fraser River and other locations within the Lower Mainland were used to check the reasonableness of the rates and estimate other features such as sheet piles or large diameter drain pipes.

The costs were broken down by reach so that unit rates could be applied to similar typical cross-sections. They were also broken down into the main features that coincide with options that the City may wish to consider further. These features are described below.

- **Dike Raising** – this is the core element required to provide flood protection. It includes a 10 m crest width at 4.7 m elevation that can be raised while still achieving a 4 m crest width for future raising to 5.5 m. This includes site preparation, fill, and erosion protection.
- **Road Structure and Utilities** – this includes stripping, subgrade preparation, pavement structure, drainage and utilities. Where the existing road is atop the dike, most of this cost would be incurred regardless of where it gets relocated.
- **Road Raising to Dike Crest** – this includes the additional fill required to raise the road to the dike crest elevation.
- **Other** – features such as landscaping, habitat improvements, multi-use paths, driveway ramps and other amenities typically have a combined impact of less that 10%, so are lumped together for conciseness.
- **Contingency** – A 40% contingency is provided because the costs are based on concept plans only.
- **Interim Measures** – some industrial sites may not redevelop within the time frame that dike improvements are planned for. The City can either proceed with the improvements with accompanying disruptions to the existing land use, or proceed with interim measures that provide a reasonable level of protection until the recommended high level of protection can be achieved during redevelopment. These costs are listed separately because they may or may not be needed depending on the timing of redevelopment.

Table 3-11 presents a summary of all reaches with cost breakdowns for the items described above. Costs for each reach are also provided in the Reach Summary Sheets in Section **Error! Reference source not found.**. Table 3-13 presents a summary of the potential interim measures.

Table 3-11: Summary of Construction Costs ($ in Millions)

Item	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11	Reach 12	Reach 13/14	Total
Dike Raising	$12.5 Million	$1.6 Million	$7.9 Million	$4.5 Million	$7.2 Million	$1.1 Million	$2.3 Million	$4.5 Million	$4.5 Million	$15.8 Million	$6.8 Million	$8.1 Million	$7.7 Million	$84.3 Million
Road Structure & Utilities	$16.8 Million		$4.9 Million	$3.9 Million		$.7 Million						$3.9 Million	$6.6 Million	$36.7 Million
Raise Road to Dike Height	$4.4 Million		$6.6 Million	$5.3 Million								$5.3 Million	$9. Million	$30.6 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.4 Million		$0.3 Million	$0.4 Million	$0.3 Million	$0.1 Million		$0.8 Million	$0.1 Million	$0.2 Million	$0.4 Million	$0.4 Million	$1.2 Million	$4.5 Million
Other*	$3.8 Million	$1.0 Million	$2.9 Million	$1.2 Million	$6.8 Million	$.1 Million	$1.5 Million	$2.9 Million	$2.9 Million	$10.2 Million	$4.4 Million	$3.5 Million	$.5 Million	$41.5 Million
Contingency (40%)	**$15.1 Million**	**$1. Million**	**$9. Million**	**$6.1 Million**	**$5.7 Million**	**$.8 Million**	**$1.5 Million**	**$3.3 Million**	**$3. Million**	**$10.5 Million**	**$4.6 Million**	**$8.5 Million**	**$10. Million**	**$79. Million**
Total	**$53.0 Million**	**$3.6 Million**	**$31.5 Million**	**$21.3 Million**	**$20. Million**	**$2.7 Million**	**$5.2 Million**	**$11.5 Million**	**$10.5 Million**	**$36.6 Million**	**$16.1 Million**	**$29.7 Million**	**$35. Million**	**$276.6 Million**

Table 3-12: Summary of Costs for Interim Measures ($ in Millions)

Item	Reach 2	Reach 3	Reach 5	Reach 7	Reach 12	Reach 13/14	Total
Dike Raising	$1.6 Million	$9.5 Million	$2.9 Million	$0.9 Million	$9.7 Million	$9.2 Million	$33.7 Million
Road Structure & Utilities		$6.8 Million			$7. Million	$6.6 Million	$20.5 Million
Raise Road to Dike Height		$9.3 Million			$9.5 Million	$9. Million	$27.8 Million
Driveways, Ramps or Road Intersection Reconstruction		$0.3 Million	$0.3 Million		$0.4 Million	$1.2 Million	$2.1 Million
Other*	$1.5 Million	$0.5 Million	$6.8 Million	$2.1 Million	$0.5 Million	$0.5 Million	$12. Million
Contingency (40%)	**$1.2 Million**	**$10.5 Million**	**$4. Million**	**$1.2 Million**	**$10.9 Million**	**$10.6 Million**	**$38.4 Million**
Total	**$4.3 Million**	**$36.9 Million**	**$13.9 Million**	**$4.2 Million**	**$38.1 Million**	**$37.1 Million**	**$134.5 Million**

PWT - 92

Costs that are not included are noted below.

- Land acquisition is not included. Ideally, land will be acquired during redevelopment. Similarly, there may be opportunities to have dike improvements tied to adjacent development.
- Densification is not included. The recommendation is to fill 200 m back from the dike face as a preferred strategy to deal with liquefaction. If the road and land behind the dike is not raised, then densification is recommended. Current techniques such as stone columns would cost approximately $9,000 to $18,000 per metre of dike.
- Off-site habitat projects (that may be needed beyond the habitat enhancement provided along the dike corridor) are not included. Such cost could be roughly 5% of the construction cost. It is understood that a separate Dike Master Plan may be prepared to address habitat compensation by identifying and developing medium to large habitat compensation concepts.
- Raising the land behind the dike is not included. This is proposed to be a condition of development behind the dike, with the cost and benefit attributed to the property owner.
- Professional fees (engineering, surveying, environmental, archeological, etc.) are not included. Such costs could be in the range of 10% to 15% of the construction cost.

4. Implementation Strategy

The implementation strategy has three parts:

- Pre-design measures;
- Construction sequencing for a typical reach; and
- Prioritization of reaches for construction.

4.1 Pre-design Measures

Before construction can be implemented, the following steps are recommended:

- Use the Dike Master Plan as a planning tool with City land use planning to acquire land during redevelopment, and to rezone land with conditions for land raising inland of the dike.
- Acquire land prior to construction.
- Seek habitat compensation projects to bank credits in preparation for drainage channel and associated riparian area impacts. A separate master plan for habitat compensation could be prepared to identify and develop medium to large habitat enhancement concepts to serve as compensation for multiple reaches.
- Assess required drainage system modifications (e.g. filling drainage channels and constructing a piped drainage system) in additional detail.
- Design with consideration for construction sequencing noted below.
- Advance public space and multi-use path design concepts further.
- Consider the need for an appropriate building setback from the land-side toe of any future flood protection works in view of the current BC setback guideline of 7.5 m. This should consider the planned dike upgrade to 4.7 m CGVD28, as well as future buildout to 5.5 m CGVD28. This may require consultation with the Inspector of Dikes.

4.2 Construction Sequence

The construction sequence for a typical reach is provided below. A typical reach currently has a road atop the dike, and utilities within the dike.

1. Secure land.
2. Coordinate third party utility relocations. This is mainly hydro on poles, Fortis gas infrastructure, and CN and local rail lines.
3. Install storm sewer (diameter to be confirmed at detailed design) in proximity to existing channel.
4. Fill over storm sewer to underside of road structure. The fill placement may be followed by a settlement period depending on geotechnical recommendations. If so, this fill may include a preload depth in excess of the road fill.
5. Install new utilities (typically water and hydro, with some sewer).
6. Construct new road with parking where access outside the dike will be impacted.
7. Divert traffic to new road.
8. Remove existing road and utilities. Do not abandon utilities within dike.

9. Fill dike to crest elevation. Excavation of sub-grade may be required to remove unsuitable materials.
10. Complete armouring, trail, and landscaping.

Larger projects will result in less temporary road diversion works. As an alternate, the entire road could be reconstructed first, in phases, before the dike is built later. This would work with the new road being raised to dike crest elevation.

4.3 Prioritization

Priority for construction will depend on which section is the lowest and therefore most urgent to raise, opportunities such as site development or road improvement plans, level of preparedness for issues such as land acquisition and habitat offsets, and adjacent residents' receptiveness to a higher dike. A preliminary priority list is provided below. Opportunities may shift the order, and the reaches may be broken down into smaller or larger projects.

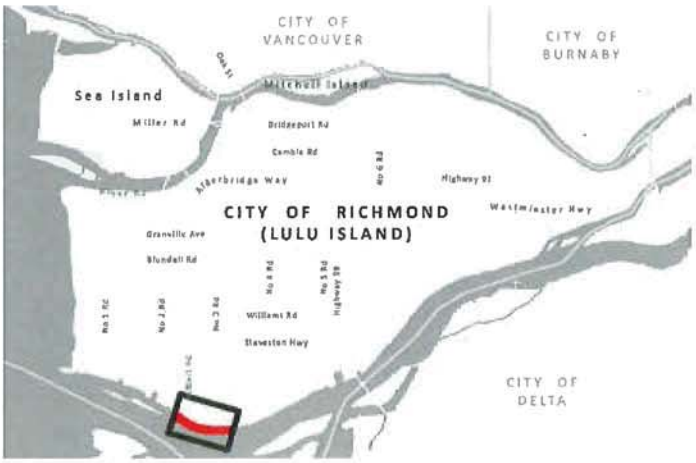
Table 4-1: Priority by Reach

Priority	Reach # and Name	Extent / Length	Major Features
1	1 – Gilmore West	No. 2 Road to Crown Packaging (2.7 km)	• Designed and tendered.
2	2 – Crown Packaging	66+500 to 66+150 (350m)	• Low section. Interim measures planned.
3	7 – Fraser Lands – 13140 Rich Mill Road	Rice Mill Road to Fraser Wharves (500 m)	• Low section. Interim measures likely.
4	3 – Gilmore East	Crown Packaging to Shell Road (1.75 km)	• Relatively straightforward
5	6 – Highway 99	Rice Mill Road (250 m)	• Await MOTI opportunity.
6	8 – Fraser Lands Fraser Wharves	Fraser Wharves to Steveston Hwy (1 km)	• Seek redevelopment opportunities with Port Metro Vancouver (PMV)
7	4 – Shellmont West	Shell Road to No. 5 Road (1 km)	• Seek redevelopment opportunities for land acquisition and to resolve access issues.
8	5 – Shellmont Deas Dock	No. 5 Road to Rice Mill Road (1 km) (1.6 km of dike)	• Seek redevelopment opportunities with BC Ferries.
9	11 – Fraser Lands Lafarge	Nelson Road to Dyke Road (1.5 km)	• Seek redevelopment opportunities with Lafarge, else install interim measures.
10	12 – East Richmond	Dyke Road to Fraserwood Way (1.8 km)	• Seek redevelopment opportunities for land acquisition and to resolve access issues.
11	13/14 – Hamilton/Boundary	Fraserwood Way to Boundary Road (1.7 km)	• Seek redevelopment opportunities for land acquisition and to resolve access issues.
12	10 – Fraser Lands Port Metro Vancouver	Williams Road to Nelson Road (3.5 km)	• Most Land is high. Coordinate with PMV
13	9 – Fraser Lands Riverport Way	Steveston Hwy to Williams Road (1 km)	• This is newer and higher section.
14	Boundary Secondary Dike	Dike Road to Hwy 91	• This is a back up to New Westminster dikes

5. Reach Summary Sheets

The following section contains 2-page, reach-by-reach summary sheets that summarize the existing conditions, design considerations and potential constraints for each reach of Phase 3. The second sheet will summarize the features of the master plan through each reach including typical cross-sections, plan features, costs and priority for upgrade. The second sheet will be completed after stakeholder consultation and option selection.

Reach 1: Gilmore West





Existing Conditions

This reach of the dike is characterized as a dike in the roadway (Dyke Road). There is riparian habitat on the water side of the dike along with a public trail and park amenities. The land side of the dike is predominantly farmland with a drainage channel adjacent to the road. There are utilities (a watermain) within the land side toe of the road between chainage 69+000 to No 3 Road at chainage 67+100.

The final approximately 550 m of dike is along the river through the Dyke Trail Dog Park. This section of dike does not include a road, it is a multi-use trail.

The master plan must balance road, habitat interests, trail and park amenities, while still providing room to expand and minimizing utility risks.

Unique Features

- London Heritage Farm, a historical site featuring a 19th-century farmhouse and barn, is located on the landside of the dike at approximate chainage 68+400. Dike upgrades need to protect this area without impacting the existing structures
- No 3 Road Waterfront Park and Fishing Pier, a public amenity on the water side of the dike, at chainage 67+150
- South Dyke Trail on the dike crest from No. 2 Road to Crown Packaging (then detours inland)
- Lulu Island Waste Water Treatment Plant is located approximately 200 m inland of the dike at chainage 67+950
- Dike upgrade project between Gilbert Road and No 3 Road under construction 2018 (approximate chainage 68+000 to 67+000)
- FREMP habitat compensation site at the base of Gilbert Road
- Gilbert Road South pump station
- No. 3 Road South pump station

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Infrastructure in the dike

Dyke Road

Dike cross-section at the pump station will have to be expanded and modified.

Future pump station upgrades need to consider the planned dike upgrades to allow enough room for pumping infrastructure

Social

No. 2 Road Pier / London's Landing
Gilbert Beach
London Heritage Farm historical site
Dyke Trail Dog Park
South Dyke Trail
No. 3 Road Waterfront Park/Pier
Wayfinding and public information signs
Traffic and road safety

Environmental

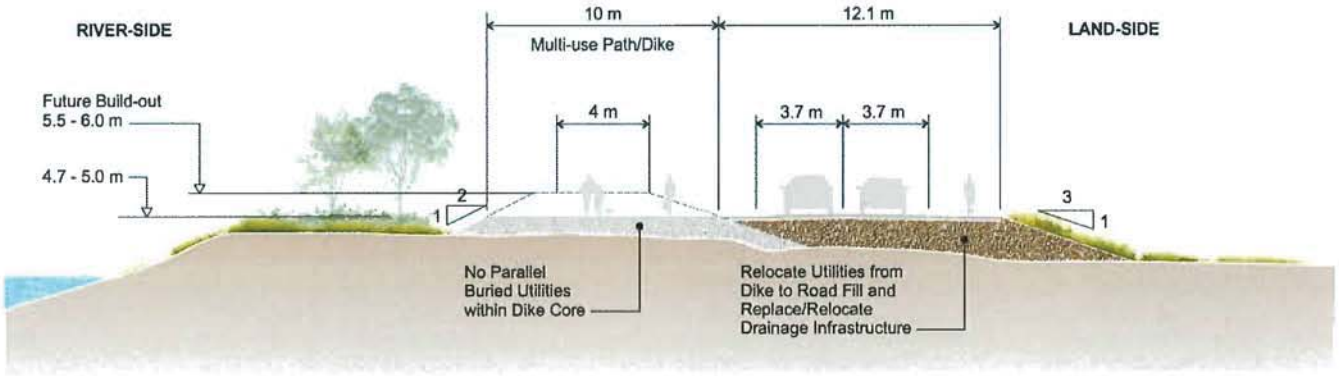
Land side is bordered by a drainage channel that is fish bearing with amphibian habitat.

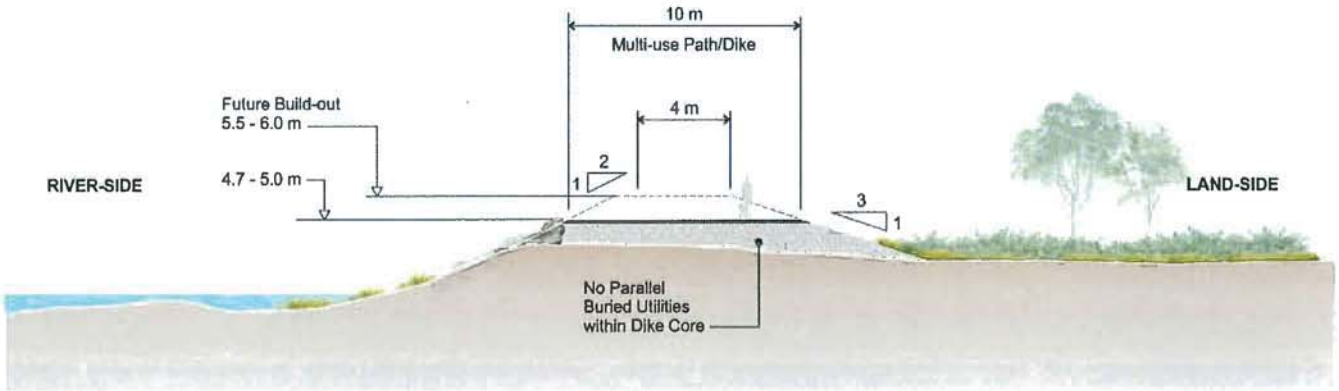
Moderate quality deciduous woodland, tall shrub woodland, and meadow present on inland bank of the drainage channel.

Fraser River side habitat includes:

- high quality marsh and mudflat habitat,
- low quality habitat armoured bank, and
- a narrow strip of marsh habitat.

Reach 1: Gilmore West - Recommended Improvements





Reach 1: Gilmore West - Recommended Improvements

Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Dike side slopes: 2H:1V on waterside (with erosion protection) and 3H:1V on landside

Structure will be over-wide with the adjacent Dyke Road, and to accommodate future dike raising to 5.5 m

Industrial and Infrastructure

Relocate parallel infrastructure in the dike corridor to landside, outside of the dike footprint

Infrastructure crossing the dike will be designed with seepage control

Separate the dike from the road

Dyke Road to be relocated to the land side of the dike, and the dike crest will be a dedicated dike/multi-use path

Relocate and reduce the landside drainage channel, while maintaining internal drainage

Social

Align with 2009 Waterfront Strategy

Traffic and road safety – separate Dyke Road from the multi-use path and include allowances for barricades and road shoulders

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

Environmental

Building the dike to the landside, where possible, to minimize impact to Fraser River aquatic and riparian habitat

The proposed footprint would impact an estimated 9,900 m² of high-quality Fraser River intertidal habitat, 4,400 m² of drainage channel aquatic habitat, and 21,100 m² drainage channel riparian habitat*

Relocating the drainage channel further inland and including appropriate plantings to the land side

*NOTE: This is an estimate based on 2007 FREMP mapping and 2017 orthoimagery interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

This section is first priority due to relative preparedness to proceed. The works are already designed and tendered. The road is planned to remain atop the dike, but utilities are being removed. Road relocation can be reconsidered at a future date as a low priority.

Construction Cost

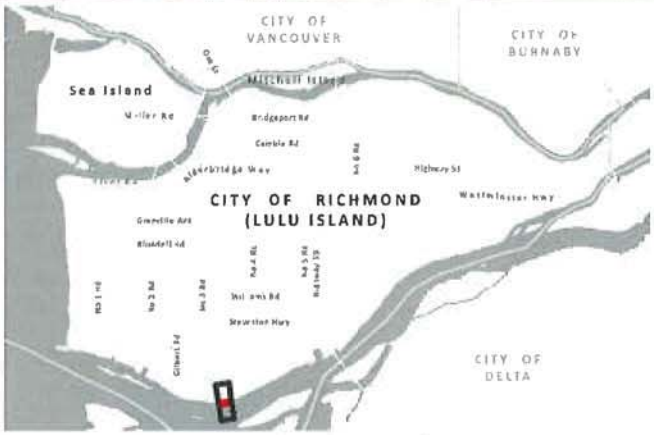
Costs below are for 2700 m of dike similar to cross-sections above.

Item	Cost per metre	Cost
Dike Raising	$5,400	$12.5 Million
Road Structure and Utilities	$7,300	$16.8 Million
Raise Road to Dike Height	$1,900	$4.4 Million
Driveways, Ramps or Road Intersection Reconstruction		$.4 Million
Other*		$3.8 Million
Contingency (40%)		**$15.1 Million**
Total		**$53 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 2: Gilmore Crown Packaging





Existing Conditions

This reach of the dike is characterized as a dike through an active works yard with barge facilities. The land side of the dike consists of paved areas with offices, warehouses and loading facilities. A warehouse structure sits at the landside toe of the dike and there is a barge loading/unloading facility on the river side of the dike.

Site grading needs to accommodate specialized vehicle traffic on the site (*i.e.,* forklifts, semi-trucks, rail cars).

The master plan must balance existing operations and access to barge facilities with improved City maintenance access, while still providing room to expand and minimizing utility risks.

Unique Features

- Active works yard and barge facility
- Restricted City maintenance access with dike crest elevation below 3.5 m
- Rail and road access issues limit options to go around the site
- Property is leased to Crown Packaging with 18 years left on the lease
- Crown Packaging operates a large cardboard production plant on the site (60 to 65 m from top of bank)
- Rail line is located on the property (below the dike crest elevation) with rail access from the east
- Sub-leased shore area to a shipping/receiving company that uses sea-cans, large forklifts, semi-trucks and rail cars as part of their operations

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Marine operations and access to the Fraser River

Forklift, rail and semi-truck access to warehouses

Site grading constraints for vehicle traffic

Social

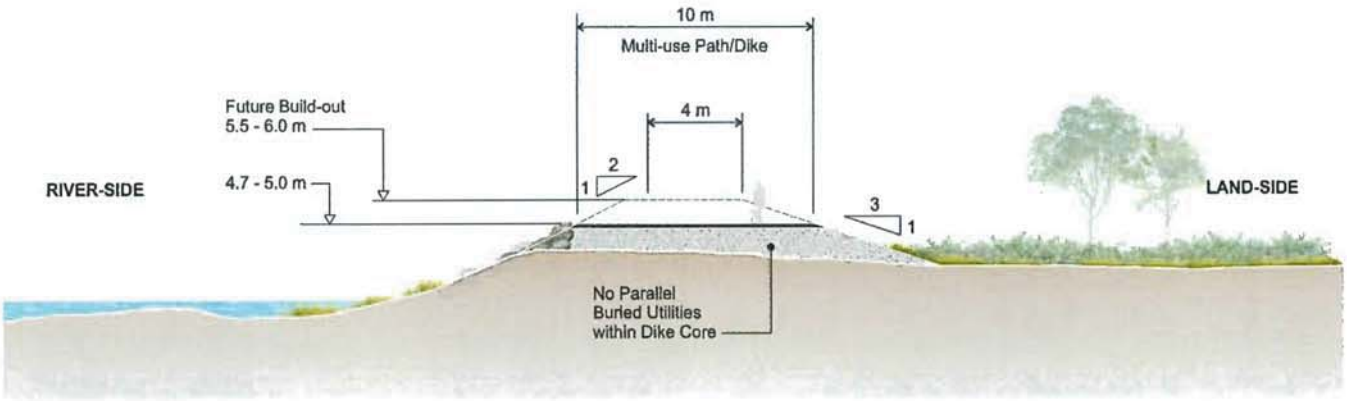
Environmental

Land-side is a paved parking lot.

Fraser River-side habitat includes:

- low quality habitat armoured bank, and
- small area of high quality riparian deciduous treed woodland habitat

Reach 2: Gilmore Crown Packaging - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Dike side slopes: 2H:1V on waterside (with erosion protection) and 3H:1V on landside

Structure will be over-wide to accommodate future dike raising to 5.5 m

This site will include a phased plan to increase flood protection to a minimum of 3.9 m in the near-term with long-term flood mitigation to include construction of a standard dike to 4.7 m design elevation at the end of the current lease (2036)

Industrial and Infrastructure

Short term phasing (to 2036):

- construct a standard dike (where possible) on the west side of the property
- construct a steel sheetpile wall to 3.9 m elevation to accommodate the narrow area
- construct a narrow (approx. 2 m wide), paved access ramp with 12% grade to allow for barge access by forklifts

Long term (2036)

- Raise dike and full site to 4.7 m with redevelopment

Social

Align with 2009 Waterfront Strategy

Maintain and improve multi-use path around the site

Environmental

Building the dike to the landside, where possible, to minimize impact to Fraser River aquatic and riparian habitat

The proposed footprint would impact an estimated 600 m² of high-quality Fraser River intertidal habitat *

*NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 2: Gilmore Crown Packaging - Recommended Improvements

Priority

Interim improvements to 3.9 m are high priority due to low elevation of this section of dike.

Full raising to 4.7 m is planned for 2036.

Construction Cost

Costs below are for 350 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$1.6 Million
Other*	$2,900	$1 Million
Contingency (40%)		**$1 Million**
Total		**$3.6 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

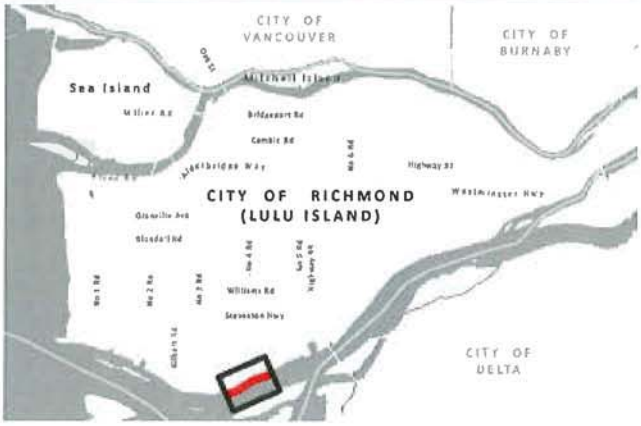
Interim

Item	Cost per metre	Cost
Dike Material	$1,800	$.6 Million
Other*	$4,240	$1.5 Million
Contingency (40%)		**$.8 Million**
Total		**$3 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 3: Gilmore East





Existing Conditions

The first approximately 500 m of this reach is characterized as a dike only section through a City park from Crown Packaging by Woodwards Slough pump station to Dyke Road.

The second portion of this reach of the dike is characterized as a dike in the roadway (Dyke Road). There is riparian habitat on the water side of the dike along with the historical community of Finn Slough. The land side of the dike is predominantly farmland with a drainage channel adjacent to the road.

There are utilities (a watermain) within the land side toe of the road from No. 4 Road (approximate chainage 65+300) onwards.

The master plan must balance drainage and community needs, road, habitat interests, and trail and park amenities, while still providing room to expand and minimizing utility risks.

Unique Features

- Woodwards Slough pump station
- South Dyke Trail runs along the dike crest to No. 5 Road
- Finn Slough heritage community sits on the river side of the dike. The community consists of homes on piles, floating homes, boats, docks and storage sheds with access by a pedestrian-only, wooden draw-bridge
- Drainage channel adjacent to the existing road/dike
- Homes and farm structures (barns etc.) on the land side near the toe of the existing dike/road

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Infrastructure in the dike

Dyke Road

Dike cross-section at the pump station will have to be expanded and modified

Future pump station upgrades need to consider the planned dike upgrades to allow enough room for pumping infrastructure

Social

South Dyke Trail
Traffic and road safety
Finn Slough heritage values

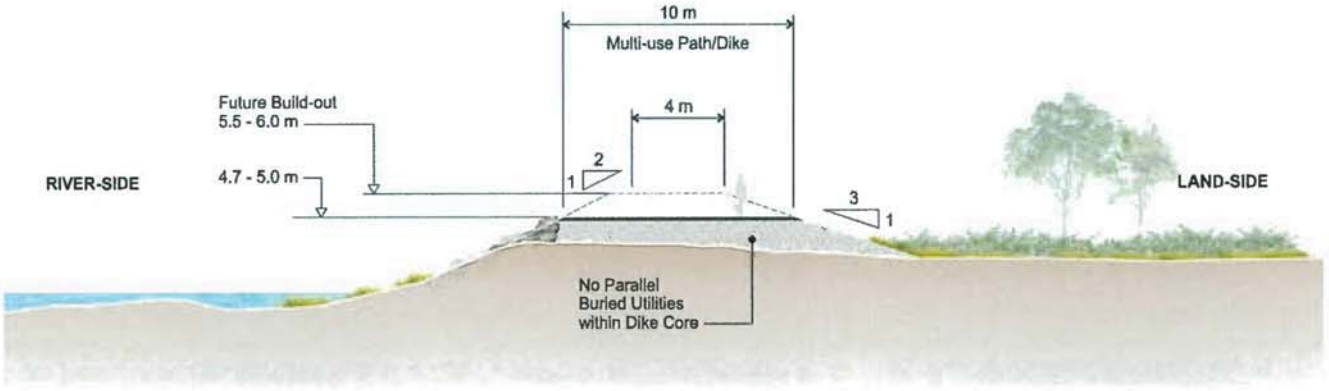
Environmental

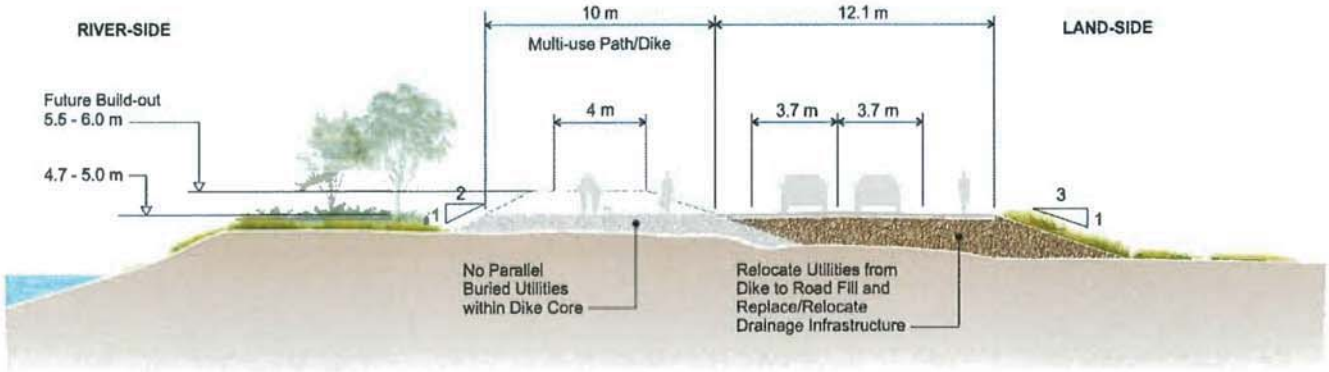
Land-side is bordered by a drainage channel that is potential amphibian breeding habitat. Fish species presence not recorded.

Fraser River-side habitat includes:

- low quality landscaped grasses and walking trails setback from armoured slopes
- high quality marsh habitat on the banks of Finn Slough, and
- high quality riparian habitat on the south side of Finn Slough (tall shrubby woodland)

Reach 3: Gilmore East - Recommended Improvements





Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Dike side slopes: 2H:1V on waterside (with erosion protection) and 3H:1V on landside

Structure will be over-wide to accommodate future dike raising to 5.5m

Industrial and Infrastructure

Separate the dike from the road

Dyke Road to be relocated to the land side of the dike, and the dike crest will be a dedicated dike/multi-use path

Relocate parallel infrastructure in the dike corridor to landside, outside of the dike footprint

Infrastructure crossing the dike will be designed with seepage control

Relocate and reduce the landside drainage channel, while maintaining internal drainage

Short term phasing:

Combine Dyke Road with the dike to minimize the footprint of the proposed master plan

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

Finn Slough habitat and heritage features preserved

Environmental

Building the dike to the landside, where possible, to minimize impact to Fraser River aquatic and riparian habitat

The proposed footprint would impact and estimated 2,400 m² of high-quality Fraser River riparian habitat, 6,700 m² of high-quality Fraser River intertidal habitat, 3,100 m² of drainage channel aquatic habitat, and 14,200 m² drainage channel riparian habitat*

Relocating the drainage channel further inland and including appropriate plantings to the land side

*NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 3: Gilmore East - Recommended Improvements

Priority

High priority due to relative preparedness to proceed. There are driveway coordination details, and there would be some benefit to waiting for adjacent redevelopment. However, redevelopment is likely too far off and the dike and road can be raised without impacting structures. The Finn Slough and housing can remain, although access will change.

Construction Cost

Costs below are for 1750 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$7.9 Million
Road Structure and Utilities	$3,900	$4.9Million
Raise Road to Dike Height	$5,300	$6.6 Million
Driveways, Ramps or Road Intersection Reconstruction		$.3 Million
Other*	$1,150	$2.9 Million
Contingency (40%)		**$9 Million**
Total		**$31.5 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Interim

Item	Cost per metre	Cost
Dike Raising	$5,400	$9.5 Million
Road Structure and Utilities	$3,900	$6.8 Million
Raise Road to Dike Height	$5,300	$9.3 Million
Driveways, Ramps or Road Intersection Reconstruction		$.3 Million
Other*	$300	$.5 Million
Contingency (40%)		**$10.5 Million**
Total		**$36.9 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 4: Shellmont West





Existing Conditions

This reach of the dike is characterized as a dike in the roadway (Dyke Road). The land side of the dike is predominantly light industrial for the first and last approximately 300 m of the reach. These sites do not have river access as part of their operations; however, they do require semi-trailer access to the sites from Dyke Road.

The middle portion of the reach on the landside of the dike is characterized as a park or greenspace called: Woodward's Landing Campground.

There are utilities (a watermain and a stormdrain) within the land side toe of the road. There is also a small surface drainage channel along the Woodward's Landing Campground property.

The master plan must balance road, trail and park amenities, and habitat interests, while still providing room to expand and minimizing utility risks.

Unique Features

- Horseshoe Slough pump station
- South Dyke Trail runs along the dike crest to No. 5 Road and provides connection to Horseshoe Slough Trail
- Log boom mooring dolphins in the Fraser River from Shell Road to No 5 Road
- First and last 300 m (approx.) of the reach is light industrial with no river operations, but building access required for semi-trailers
- Middle 300 m (approx.) of the reach is Woodward's Landing Campground on the landside of Dyke Road

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Infrastructure in the dike
Dyke Road
Dike cross-section at the pump station will have to be expanded and modified
Future pump station upgrades need to consider the planned dike upgrades to allow enough room for pumping infrastructure

Social

South Dyke Trail (provides connection to inland trail system)
Woodward's Landing Park
Wayfinding and public information signs
Traffic and road safety

Environmental

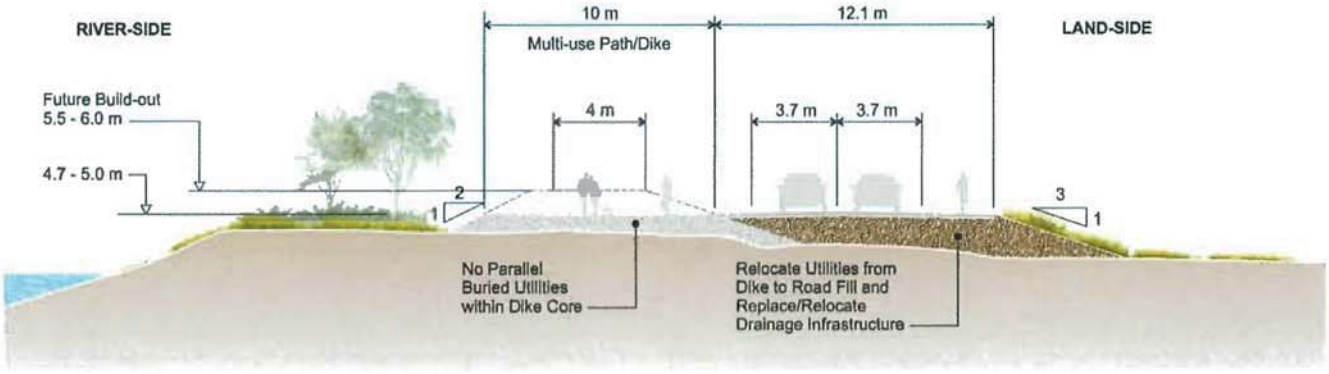
Land-side habitat includes:

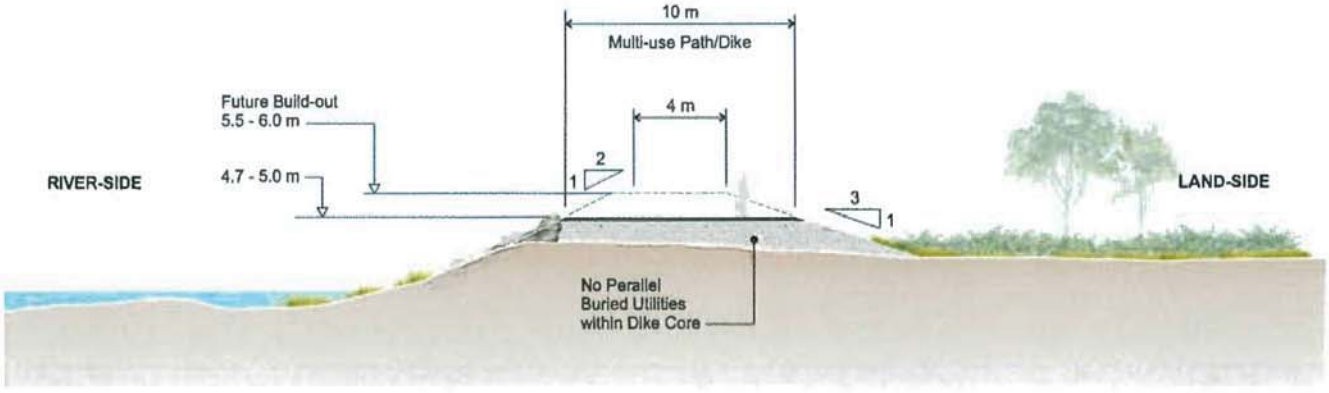
- low quality habitat (walking path and lawn) at east and west end of reach
- drainage channel adjacent to middle of reach (Threespine stickleback, amphibian habitat)

Fraser River-side habitat includes:

- low quality paved or gravel surfaces setback from armoured slopes
- very west end of reach is set back from Fraser River
- high quality marsh habitat in Fraser River in east half of reach

Reach 4: Shellmont West - Recommended Improvements





Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Dike side slopes: 2H:1V on waterside (with erosion protection) and 3H:1V on landside

Structure will be over-wide with the adjacent Dyke Road and to accommodate future dike raising to 5.5m

Industrial and Infrastructure

Relocate parallel infrastructure in the dike corridor to landside, outside of the dike footprint

Infrastructure crossing the dike will be designed with seepage control

Relocate and reduce the landside drainage channel, while maintaining internal drainage

Dike cross-section at the pump station will have to be expanded and modified

Future pump station upgrades need to consider the planned dike upgrades to allow enough room for pumping infrastructure

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

Environmental

Building the dike to the landside, where possible, to minimize impact to aquatic and riparian habitat

The proposed footprint would impact an estimated 200 m² of high-quality Fraser River riparian habitat, 1,200 m² of drainage channel aquatic habitat, and 4,400 m² drainage channel riparian habitat*

Relocating the drainage channel further inland and including appropriate plantings to the land side

* NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 4: Shellmont West - Recommended Improvements

Priority

High priority due to relative preparedness to proceed. There are driveway coordination details, and there would be some benefit to waiting for adjacent redevelopment. However, redevelopment is likely too far off and the dike and road can be raised without impacting structures.

Construction Cost

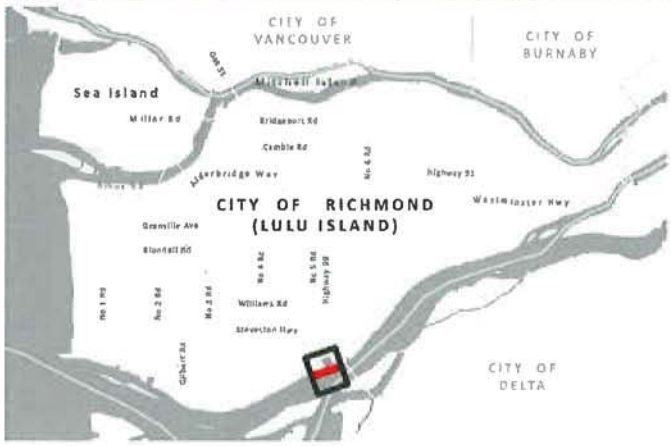
Costs below are for 1000 m of dike similar to cross-sections above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$4.5 Million
Road Structure and Utilities	$3,900	$3.9 Million
Raise Road to Dike Height	$5,300	$5.3 Million
Driveways, Ramps or Road Intersection Reconstruction		$1.2 Million
Other*	$1,150	$.4 Million
Contingency (40%)		**$6.1 Million**
Total		**$21.3 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 5: Shellmont Deas Dock





Existing Conditions

This reach of the dike is characterized as a dike through an active port facility. The land side of the dike consists of paved areas with offices, warehouses and loading facilities.

Current stakeholders include: Mainland Sand and Gravel (No. 5 Rd Depot) and BC Ferries Richmond (Deas Pacific Marine).

The master plan must balance existing operations and access to the river with improved City maintenance access, while still providing room to expand and minimizing utility risks.

Redevelopment offers the opportunity to raise the site (super-dikes) and improve access.

Unique Features

- Port facilities under redevelopment
- Active marine work yard and shipyard facilities with restricted maintenance access
- Rail and road access issues limit options to go around the site
- Active redevelopment activities
- FREMP habitat compensation site (plantings) in the Deas Dock area

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Marine operations and access to the Fraser River

Forklift, rail and semi-truck access to warehouses

Site grading constraints for vehicle traffic

No defined dike structure in Mainland Sand and Gravel depot with the active movement of material and loading of barges

Social

Connect to existing and planned trails and public amenities

Wayfinding and public information signs

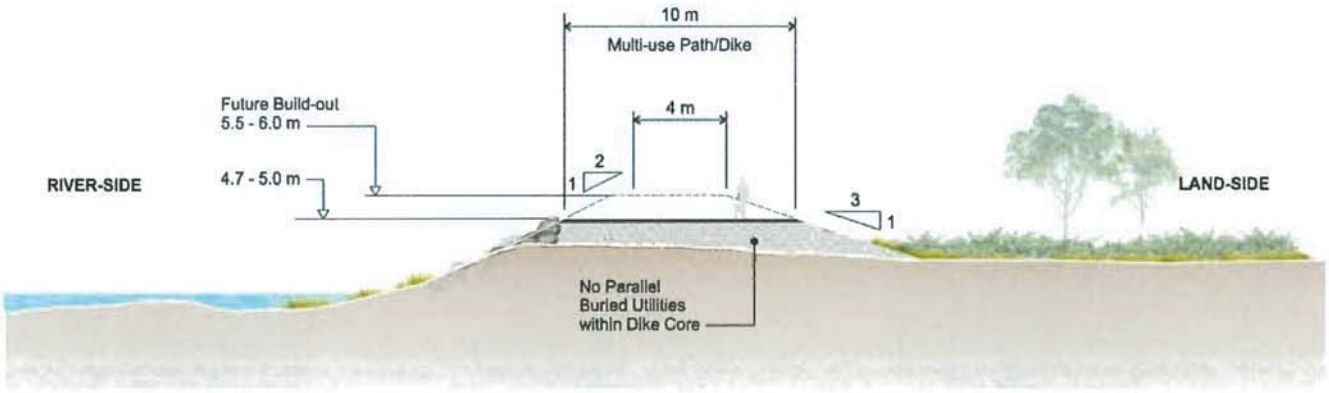
Environmental

Land-side is mostly paved with some low-quality herbaceous habitat present

Fraser River-side habitat includes:

- high quality marsh habitat where the dike is setback approx. 100 m in west half of reach
- high quality mudflats and marsh habitat bordering dike in the east third of reach

Reach 5: Shellmont Deas Dock - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

This site will include an interim measure for non-standard cross-section (setback sheetpile wall) to accommodate space constraints and operations until site can be raised to final elevation

Industrial and Infrastructure

Short term phasing:

- construct a standard dike (where possible); and
- construct a steel sheetpile wall to 4.7 m elevation to accommodate the narrow area
- potential for building a structure around the site and allow the stakeholder to address the flood hazards with site-specific response plans

Social

Align with 2009 Waterfront Strategy

Maintain and improve multi-use path around the site

This path will divert around the Deas Dock

Environmental

The proposed footprint would impact an estimated 1,000 m² of high-quality Fraser River intertidal habitat, less than 100 m² of drainage channel aquatic habitat, and less than 100 m² drainage channel riparian habitat*

* NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 5: Shellmont Deas Dock - Recommended Improvements

Priority

Medium priority. Timing will depend on coordination with BC Ferries and the potential raising of the dike and site along with redevelopment of Deas Dock. If improvements don't proceed in a reasonable timeframe, interim measures such as raising the road around the site, may need to proceed before site redevelopment.

Construction Cost

Costs below are for 1600 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$7.2 Million
Driveways, Ramps or Road Intersection Reconstruction		$.3 Million
Other*	$2,900	$4.6 Million
Contingency (40%)		**$4.8 Million**
Total		**$17 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

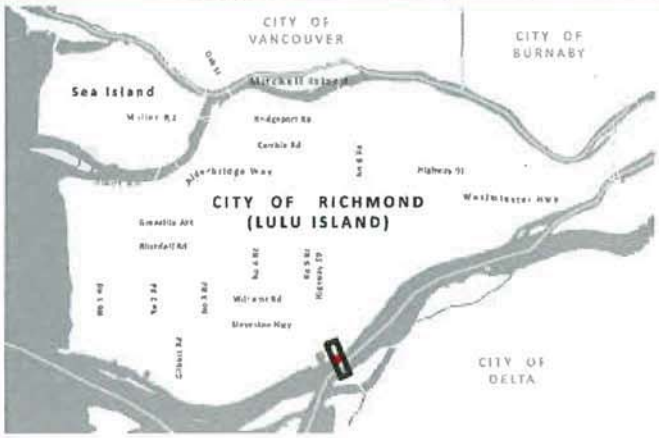
Interim

Item	Cost per metre	Cost
Dike Raising	$1,800	$2.9 Million
Driveways, Ramps or Road Intersection Reconstruction		$.3 Million
Other*	$4,240	$6.8 Million
Contingency (40%)		**$4 Million**
Total		**$13.9 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 6: Highway 99





Existing Conditions

This reach of the dike is characterized as a dike and a dike in a road (Rice Mill Road). The land side of the dike consists of gravel parking lots and infrastructure for the George Massey Tunnel.

The master plan must balance the unique risks of having a tunnel through the dike with habitat interests, trail and park amenities, while still providing room to expand.

Unique Features

- Flood protection needs to integrate with the George Massey Tunnel
- Unique risks associated with having a tunnel under the dike
- Peace Arch (Hwy 99) pump station

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Dike cross-section at the pump station will have to be expanded and modified

Future pump station upgrades need to consider the planned dike upgrades to allow enough room for pumping infrastructure

Social

Connect to existing and planned trails and public amenities

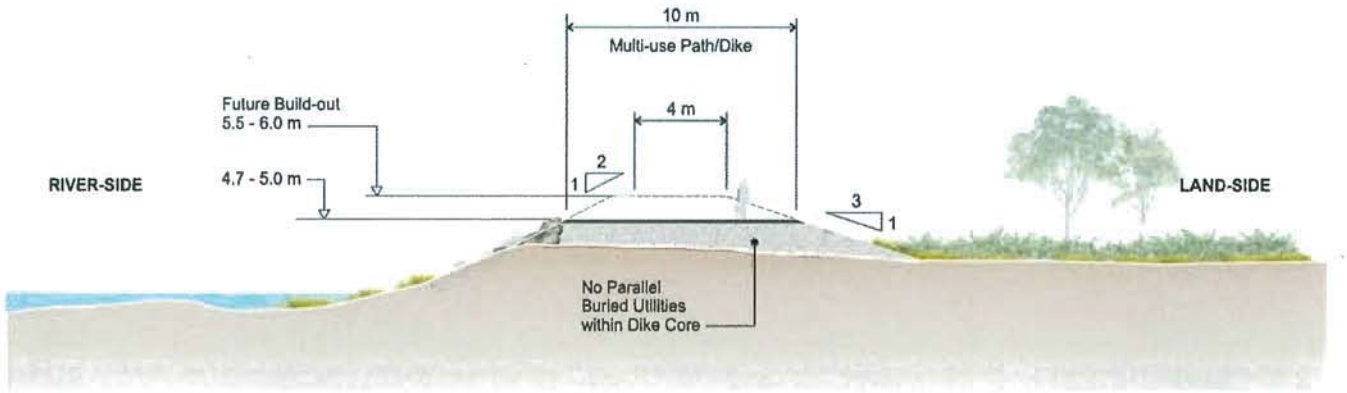
Wayfinding and public information signs

Environmental

Land-side is mostly low-quality gravel parking lots

Fraser River-side habitat includes high quality deciduous tree riparian woodland (at the west end)

Reach 6: Highway 99 - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Design to respond to Massey tunnel replacement. Previous plans included sealing off the tunnel and constructing a bridge

Industrial and Infrastructure

Relocate parallel infrastructure in the dike corridor to landside, outside of the dike footprint

Infrastructure crossing the dike will be designed with seepage control

Relocate and reduce the landside drainage channel, while maintaining internal drainage

Dike cross-section at the pump station will have to be expanded and modified

Future pump station upgrades need to consider the planned dike upgrades to allow enough room for pumping infrastructure

If a bridge is selected to replace the tunnel, seal off the tunnel

If a tunnel is selected, the approach should rise to 4.7m with berms leading up to it as a barrier to tunnel collapse and flooding

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

Environmental

The proposed footprint would impact an estimated 200 m² of high-quality Fraser River riparian habitat*

* NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 6: Highway 99 - Recommended Improvements

Priority

Medium priority. Timing will depend on coordination with BC Ministry of Transportation and Infrastructure.

If improvements don't proceed in a reasonable timeframe, interim measures such as sheetpile walls, may need to proceed before the tunnel replacement.

Construction Cost

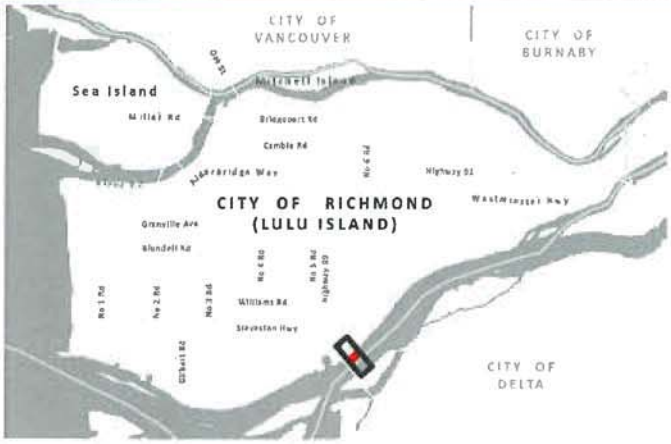
Costs below are for 250 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$1.1 Million
Road Structure and Utilities	$2,600	$.7 Million
Driveways, Ramps or Road Intersection Reconstruction		$.1 Million
Other*	$300	$.1 Million
Contingency (40%)		**$.8 Million**
Total		**$2.7 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 7: Fraser Lands 13140 Rice Mill Road





Existing Conditions

This reach of the dike is characterized as a dike through an active works yard with barge facilities (Canadian Fishing Company). The land side of the dike consists of paved areas with offices, warehouses and loading facilities. Current buildings are located on the dike, with no access for City maintenance crews to inspect or maintain the area.

Rail lines are located north of the property and limit the options for routing a standard dike around the property.

Site grading needs to accommodate specialized vehicle traffic on the site (*i.e.*, forklifts and semi-trucks).

The master plan must balance existing operations and access to barge facilities with improved City maintenance access, while still providing room to expand and minimizing utility risks.

Unique Features

- Active works yard and barge facility
- Restricted City maintenance access with dike crest elevation below 3.5 m
- Rail and road access issues limit options to go around the site
- FREMP habitat compensation site in the area

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Marine operations and access to the Fraser River
Forklift, rail and semi-truck access to warehouses
Site grading constraints for vehicle traffic

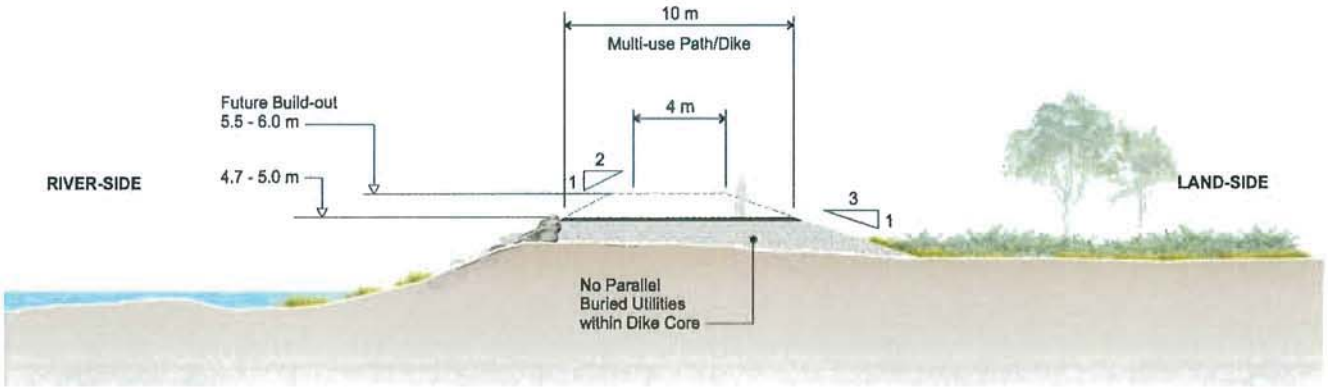
Social

Connect to existing and planned trails and public amenities
Wayfinding and public information signs
Traffic and road safety

Environmental

Land-side has some deciduous trees, but most of the area is paved or has buildings
Fraser River-side habitat is low quality habitat with armoured slope or pier

Reach 7: Fraser Lands 13140 Rice Mill Road - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Dike side slopes: 2H:1V on waterside (with erosion protection) and 3H:1V on landside

Structure will be over-wide to accommodate future dike raising to 5.5 m

This site will include a phased plan to increase flood protection to a minimum of 3.9 m in the near-term with long-term flood mitigation to include construction of a standard dike to 4.7 m design elevation at the end of the current lease

Industrial and Infrastructure

Short term phasing:

- construct a standard dike (where possible); and

Interim

- construct a steel sheetpile wall to 3.9 m elevation to accommodate the narrow area north of the site, between it and the rail ROW
- potential for building a structure around the site and allow the stakeholder to address the flood hazards with site-specific response plans
- Relocate site access to the west in order to install dike across current entrance

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

This path will divert north around this site

Environmental

Building the dike to the landside, where possible, to minimize impact to Fraser River aquatic and riparian habitat

The proposed footprint would not impact fish or aquatic habitat

Reach 7: Fraser Lands 13140 Rice Mill Road - Recommended Improvements

Priority

High priority due to low elevations. This may be limited to interim measures until the full standard dike can be coordinated with future site redevelopment.

Construction Cost

Costs below are for 500 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$2.3 Million
Driveways, Ramps or Road Intersection Reconstruction		$. Million
Other*	$2,900	$1.5 Million
Contingency (40%)		**$1.5 Million**
Total		**$5.2 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Interim

Item	Cost per metre	Cost
Dike Raising	$1,800	$.9 Million
Other*	$4,240	$2.1 Million
Contingency (40%)		**$1.2 Million**
Total		**$4.2 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 8: Fraser Lands Fraser Wharves





Existing Conditions

This reach of the dike is characterized as a dike through an active port facility. The land side of the dike consists of paved areas with offices, warehouses and loading facilities.

The master plan must address existing operations and access to unloading facilities, and balance existing operations and access to the river with improved City maintenance access, while still providing room to expand and minimizing utility risks.

Redevelopment offers the opportunity to raise the site (super-dikes) and improve access, habitat and community amenities.

Unique Features

- Active ship-to-land car unloading facilities
- Active redevelopment activities
- No 6 Road South pump station

Considerations

Flood Protection

- Dike alignment
- Dike crest elevation
- Erosion protection
- Seismic performance
- Static stability and seepage
- River toe stability and setbacks
- Boat waves

Industrial and Infrastructure

- Marine operations and access to the Fraser River
- Site grading constraints for vehicle traffic
- No defined dike structure in Mainland Sand and Gravel depot with the active movement of material and loading of barges
- Dike cross-section at the pump station will have to be expanded and modified
- Future pump station upgrades need to consider the planned dike upgrades to allow enough room for pumping infrastructure

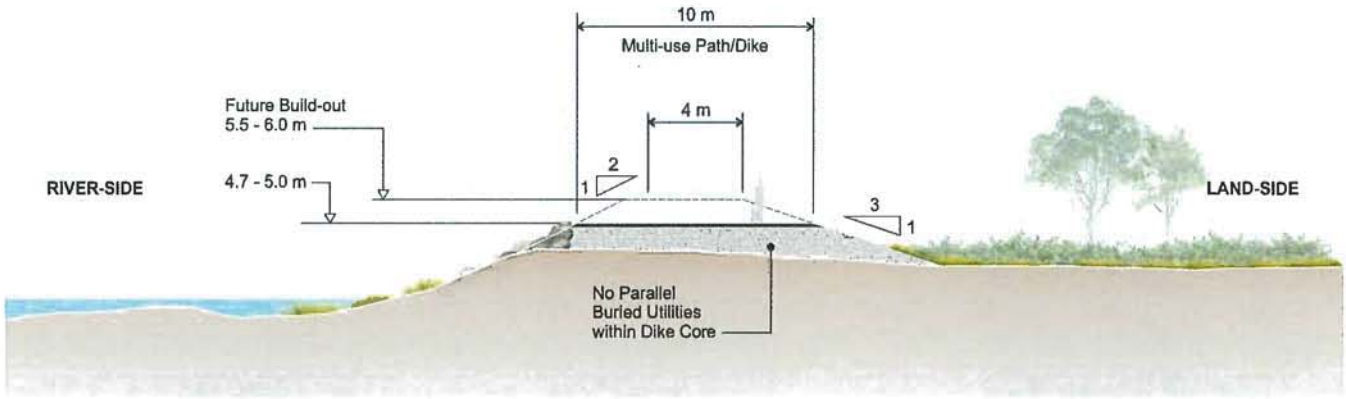
Social

- Connect to existing and planned trails and public amenities
- Wayfinding and public information signs

Environmental

- Land-side is mostly paved with some low-quality shrub habitat between dike and pavement.
- Fraser River-side habitat includes:
  - high quality deciduous treed riparian habitat in east half and small patch in west half
  - armoured slope and pier in middle of reach

Reach 8: Fraser Lands Fraser Wharves - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Industrial and Infrastructure

Coordinate improvements with Port Metro Vancouver

Dike runs through active port operations, so is expected to be gated

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

This path will divert north around this site

Environmental

The proposed footprint would impact an estimated less than 100 m² of high-quality Fraser River riparian habitat, and 200 m² of high-quality Fraser River intertidal habitat*

*NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

Medium priority due to need to coordinate with PMV. Improvements may be achieved through site redevelopment.

Construction Cost

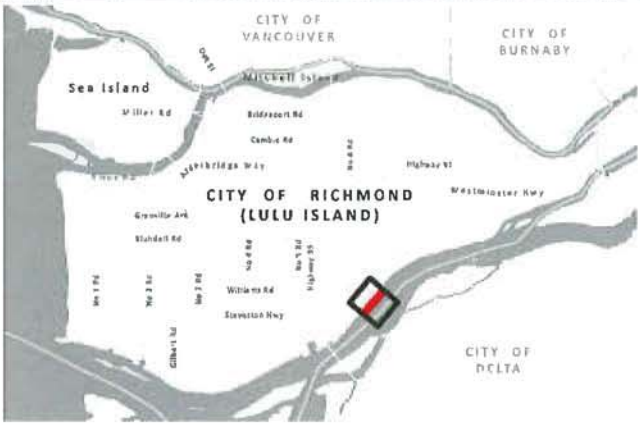
Costs below are for 1000 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$4.5 Million
Driveways, Ramps or Road Intersection Reconstruction		$.8 Million
Other*	$2,900	$2.9 Million
Contingency (40%)		**$3.3 Million**
Total		**$11.5 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 9: Fraser Lands Riverport Way





Existing Conditions

This reach of the dike is characterized as a dike with a pedestrian walkway and path. There is riparian habitat on the water side of the dike along with a public trail and park amenities.

The master plan must balance recent development, habitat interests, trail and park amenities, while still providing room to expand.

Unique Features

- FREMP habitat compensation site in front of the Riverport Way development
- Recent Riverport Way development includes some recently constructed improvements (paved pedestrian pathway) that are challenging to raise
- Redevelopment activities along the eastern portion of the reach

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Pedestrian pathway in front of Riverport Way development is paved and buildings open directly onto the dike

Social

Connect to existing and planned trails and public amenities

Wayfinding and public information signs

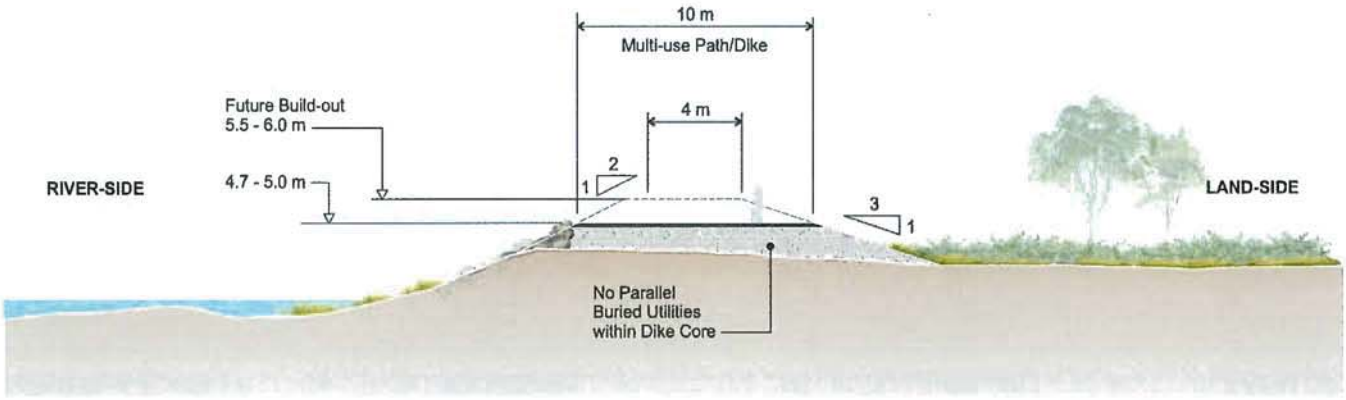
Environmental

Land-side is characterized by lawn or gravel lot with low quality habitat.

Fraser River-side habitat includes:

- high quality deciduous forest riparian habitat in middle of reach
- low quality habitat armoured bank at east and west ends a narrow strip of marsh habitat

Reach 9: Fraser Lands Riverport Way - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Dike side slopes: 2H:1V on waterside (with erosion protection) and 3H:1V on landside

Structure will be over-wide to accommodate future dike raising to 5.5m.

Industrial and Infrastructure

No existing infrastructure within the dike

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

Environmental

Building the dike to the landside, where possible, to minimize impact to aquatic and riparian habitat

The proposed footprint would impact an estimated 100 m² of high-quality Fraser River riparian habitat, and 100 m² of high quality Fraser River intertidal habitat *

* NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

Low priority. This portion of dike is newer and relatively high. Improvements can be deferred until the higher priority sections are addressed.

Construction Cost

Costs below are for 1000 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$4.5 Million
Driveways, Ramps or Road Intersection Reconstruction		$.1 Million
Other*	$2,900	$2.9 Million
Contingency (40%)		**$3 Million**
Total		**$10.5 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 10: Fraser Lands Port Metro Vancouver (PMV)





Existing Conditions

Much of this reach of the dike is characterized as a dike through an active port facility. Some locations within the reach have the dike in the road (Dyke Road) and in some locations, the dike is a trail through area.

The master plan must balance existing operations and access to the river with improved City maintenance access, while still providing room to expand and minimizing utility risks.

Redevelopment offers the opportunity to raise the site (super-dikes) and improve access. Continued development offers opportunities for dike material stockpile areas and some public amenities.

Unique Features

- Port facilities under redevelopment
- Active marine work yard and shipyard facilities with restricted maintenance access
- Active redevelopment activities
- City-owned waterfront between Williams Road and Coast 2000 terminals
- Three (3) FREMP habitat compensation sites: front face of the loading area in the Port, and two (2) intertidal areas near No. 8 Rd
- No. 7 Road South pump station
- Nelson Road South pump station

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Marine operations and access to the Fraser River

Forklift, rail and semi-truck access to warehouses

Site grading constraints for vehicle traffic

No defined dike structure or rights of way in some areas

Social

City owns portion of the waterfront that is used as an unofficial recreation area

Connect to existing and planned trails and public amenities

Wayfinding and public information signs

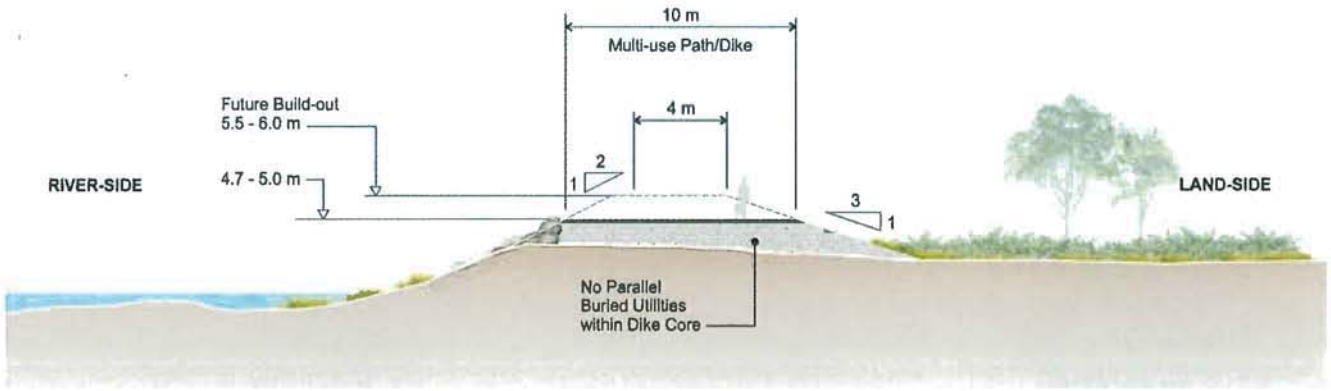
Environmental

Land side has:

- drainage channel at east end (Stickleback, amphibian habitat),
- paved lots at east and west ends, and
- large, seasonally flooded area in middle of reach (Potential for overwintering habitat creation).

Fraser River side habitat includes large areas of high-quality riparian forest, intertidal marsh along full length of reach

Reach 10: Fraser Lands PMV - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Industrial and Infrastructure

Most of the Port Metro Vancouver lands are high and above the proposed dike crest height

Fill remaining low areas above dike elevations during redevelopment

Seek rights of way or agreement for inspection, maintenance, and construction of dikes or erosion protection along section that isn't within the City's jurisdiction

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

This path will divert north up the east bank of the No. 7 Rd. drainage channel and north around the PMV lands

Environmental

The proposed footprint would impact an estimated 17,000 m² of high-quality Fraser River riparian habitat, 700 m² of high quality Fraser River intertidal habitat, 1,300 m² of drainage channel aquatic habitat, and 900 m² drainage channel riparian habitat*

Opportunities for habitat improvements or creation of overwintering habitat in the middle of the reach

*NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

Low priority because most of the land and dikes are high. Coordinated planning with PMV should proceed earlier to develop and plan to deal with future site development, land raising, and responsibility or rights of way over federal portion of waterfront.

Construction Cost

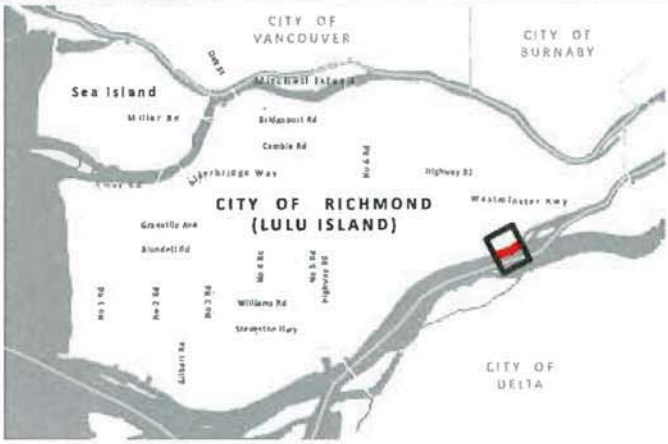
Costs below are for 3500 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$15.8 Million
Driveways, Ramps or Road Intersection Reconstruction		$.2 Million
Other*	$2,900	$10.2 Million
Contingency (40%)		**$10.5 Million**
Total		**$36.6 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 11: Fraser Lands Lafarge



Existing Conditions

Much of this reach of the dike is characterized as a dike through an active port facility.

The master plan must balance existing operations and access to the river with improved City maintenance access, while still providing room to expand and minimizing utility risks.

Unique Features

- Active works yard and barge facilities with restricted maintenance access.
- Restricted access for City maintenance
- Rail and road access issues limit options to go around the site
- Dike upgrades designed 2018

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Marine operations and access to the Fraser River

Forklift, rail and semi-truck access to warehouses

Site grading constraints for vehicle traffic

No defined dike structure in some areas

Social

Connect to existing and planned trails and public amenities

Wayfinding and public information signs

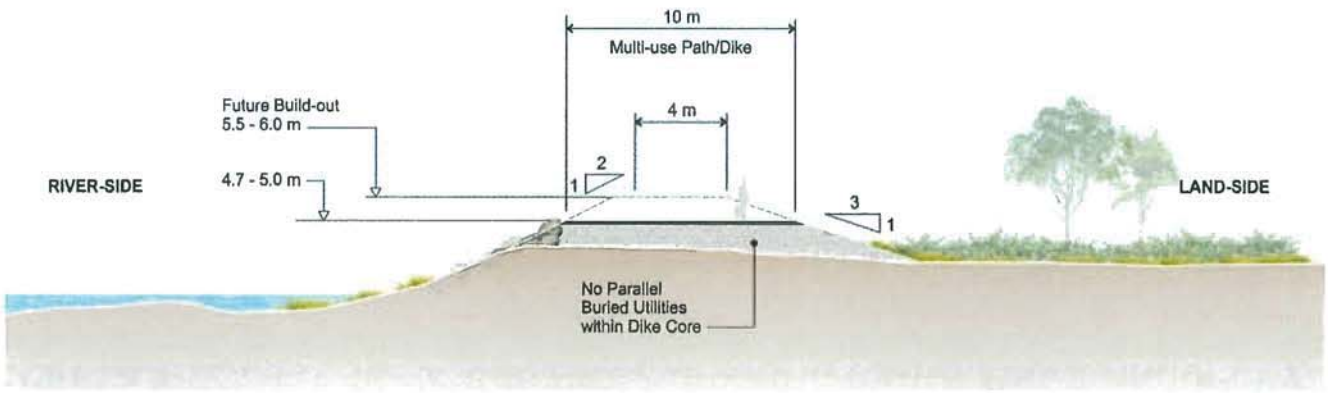
Environmental

Land-side has low quality habitat with paved lots and buildings.

Fraser River-side habitat includes some:

- high quality forested riparian habitat at the east end, and
- low quality habitat armoured bank at the west end

Reach 11: Fraser Lands Lafarge - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment through site, or negotiate a change in alignment that is favourable to the City and adjacent land owner

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Industrial and Infrastructure

Raising the dike in its current location will be very disruptive to Lafarge

Relocation to the water's edge would provide better control over erosion inspection and maintenance

Alternatively, relocation along the north perimeter of their site would limit the conflict of land use to access ramps

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road. Link to parks, trails, public amenities, and wayfinding, per Lululoop concept. This path will run along the north side of the Lafarge lands

Environmental

The proposed footprint would impact an estimated 900 m² of high-quality Fraser River riparian habitat *

Opportunities for habitat improvements or creation of overwintering habitat in the middle of the reach

* NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

Medium to low priority because the land is relatively high. However, raising the land and dike will be challenging with the current operations, so negotiated changes may take time. Seek redevelopment opportunities. Consider interim measures if opportunities not forthcoming.

Construction Cost

Costs below are for 1500 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$6.8 Million
Driveways, Ramps or Road Intersection Reconstruction		$.4 Million
Other*	$2,900	$4.4 Million
Contingency (40%)		**$4.6 Million**
Total		**$16.1 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 12: East Richmond





Existing Conditions

This reach of the dike is characterized as a dike in the roadway (Dyke Road).

There are utilities (a watermain and storm main) within the land side toe of the road as well as local drainage provided by surface channels at the toe of the slope.

The master plan must balance drainage and community needs, road, habitat interests, and trail and park amenities, while still providing room to expand and minimizing utility risks.

Unique Features

- Ewen Road Irrigation pump station
- Commercial development on the land side
- East Richmond Trail runs along the dike crest adjacent to Dyke Road from No. 9 Road
- Very little room for dike works
- Multiple marinas with access over the dike on the water side
- Shelter Island Marina and Boatyard needs low gradient access across the dike for the Travelifts to haul out or launch boats

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Infrastructure in the dike
Dyke Road
Dike cross-section at the pump station will have to be expanded and modified
Future pump station upgrades need to consider the planned dike upgrades to allow enough room for pumping infrastructure

Social

East Richmond Trail
Connect to existing and planned trails and public amenities
Wayfinding and public information signs
Traffic and road safety

Environmental

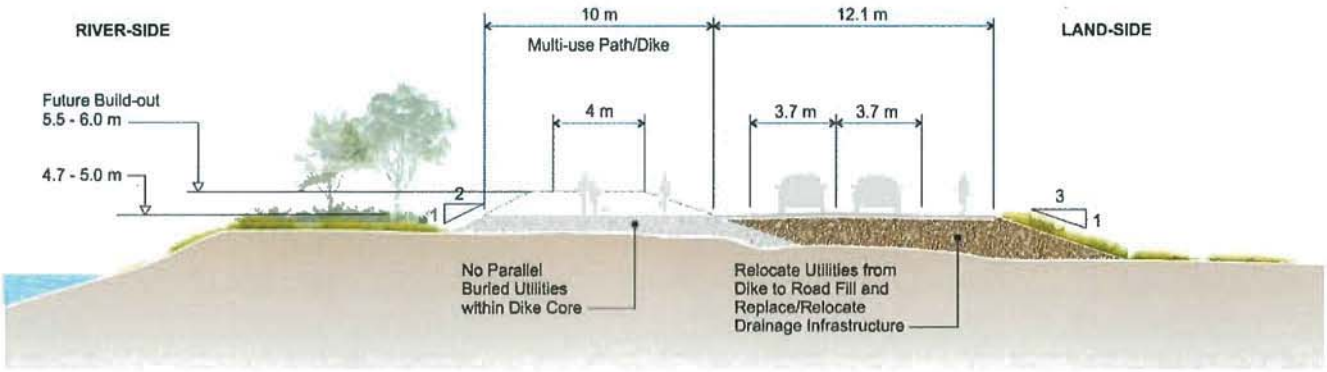
Land-side includes:

- drainage channel adjacent to dike at east and west ends of reach (amphibian habitat)
- low quality habitat paved or maintained lawn in middle of reach

Fraser River-side habitat includes:

- high quality habitat mud flats at middle and east end of reach
- deciduous treed woodland high quality habitat at west end of reach

Reach 12: East Richmond - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Dike side slopes: 2H:1V on waterside (with erosion protection) and 3H:1V on landside

Structure will be over-wide to accommodate future dike raising to 5.5m

Industrial and Infrastructure

Relocate parallel infrastructure in the dike corridor to landside, outside of the dike footprint

Infrastructure crossing the dike will be designed with seepage control

Relocate and reduce the landside drainage channel, while maintaining internal drainage

Combine Dyke Road with the dike to minimize the footprint of the proposed master plan

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

Environmental

Building the dike to the landside, where possible, to minimize impact to aquatic and riparian habitat

The proposed footprint would impact an estimated 2,500 m² of high-quality Fraser River riparian habitat, 3,200 m² of drainage channel aquatic habitat, and 5,500 m² drainage channel riparian habitat*

Relocating the drainage channel further inland and including appropriate plantings to the land side

* NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 12: East Richmond - Recommended Improvements

Priority

Medium to low priority due to the many property access conflicts to be resolved. Raise and acquire land over time along with redevelopment to prepare for dike raising and road relocation and raising.

Construction Cost

Costs below are for 1800 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$8.1 Million
Road Structure & Utilities	$3,900	$3.9 Million
Raise Road to Dike Height	$5,300	$5.3 Million
Driveways, Ramps or Road Intersection Reconstruction		$.4 Million
Other*	$1,150	$3.5 Million
Contingency (40%)		**$8.5 Million**
Total		**$29.7 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

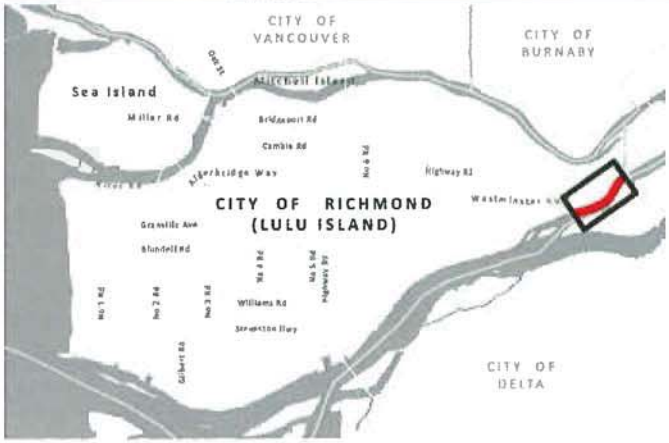
Interim

Item	Cost per metre	Cost
Dike Raising	$5,400	$9.7 Million
Road Structure & Utilities	$3,900	$7 Million
Raise Road to Dike Height	$5,300	$9.5 Million
Driveways, Ramps or Road Intersection Reconstruction		$.4 Million
Other*	$300	$.5 Million
Contingency (40%)		**$10.9 Million**
Total		**$38.1 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 13/14: Hamilton/Boundary



Existing Conditions

This reach of the dike is characterized as a dike in the roadway (Fraserwood Way and Dyke Road) with utilities. The land side of the dike is predominantly commercial developments with marinas, businesses and houses with river access over the dike.

There are utilities (a watermain and storm main) within the land side toe of the road as well as local drainage provided by surface channels at the toe of the slope.

The master plan must balance drainage and community needs, road, marina, habitat interests, and trail and park amenities, while still providing room to expand and minimizing utility risks.

Unique Features

- Dike is set back for the final 500 m before the connection with New Westminster
- Newly developed townhouses on the river, outside of the dike (23740 and 23580 Dyke Road)
- FREMP habitat compensation site plantings in front of Townhome complex at 23740 and 23580 Dyke Road
- Commercial development on land side
- Marinas and float homes with river access over the dike on both the land side and river side
- East Richmond Trail and Fraserwood Trail run along the dike crest on or adjacent to the roadway to Boundary Road
- Highway 91 and City of New Westminster dike interface

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial and Infrastructure

Infrastructure in the dike
Fraserwood Way

Social

East Richmond Trail
Fraserwood Trail
Connect to existing and planned trails and public amenities
Wayfinding and public information signs
Traffic and road safety
Finn Slough heritage values

Environmental

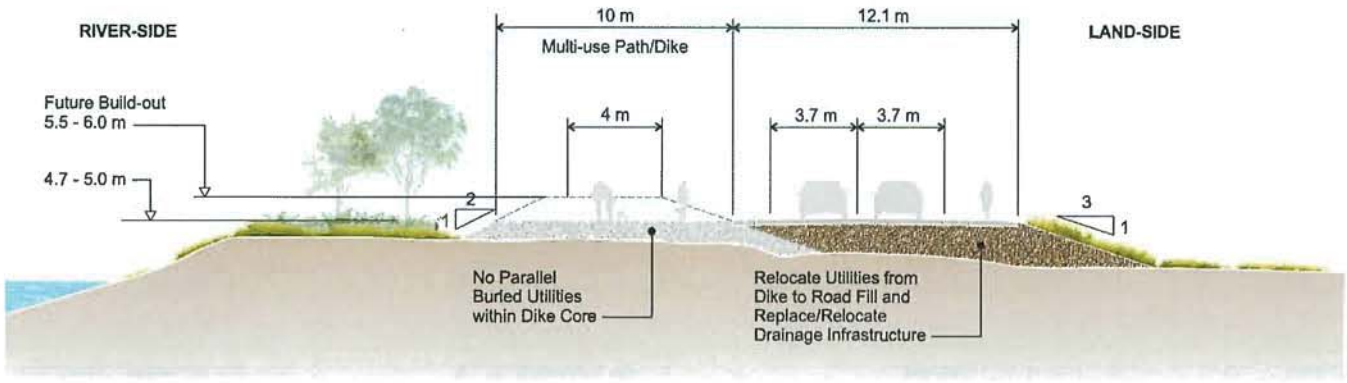
Land-side includes:

- drainage channels at very west end and in middle of reach (amphibian habitat)
- low quality paved or landscaping shrubs at west end of reach habitat
- high quality shrubland habitat at east end of reach

Fraser River-side habitat includes:

- high quality mud flats and marsh at west end of reach
- patches of high quality marsh and riparian deciduous woodland along east end of reach
- small patches of unvegetated low quality habitat along reach

Reach 13/14: Hamilton/Boundary - Recommended Improvements



Master Plan Features

Flood Protection

Maintain existing alignment

Dike crest elevation: 4.7 m, with future buildout to 5.5 m

Dike crest width: 10 m, future buildout to 4 m

Dike side slopes: 2H:1V on waterside (with erosion protection) and 3H:1V on landside

Structure will be over-wide to accommodate future dike raising to 5.5m

Industrial and Infrastructure

Separate the dike from the road

Road to be relocated to the land side of the dike, and the dike crest will be a dedicated dike/multi-use path

Relocate parallel infrastructure in the dike corridor to landside, outside of the dike footprint

Infrastructure crossing the dike will be designed with seepage control

Relocate and reduce the landside drainage channel, while maintaining internal drainage

Short term phasing:

Combine Fraserwood Way and Dyke Road with the dike to minimize the footprint of the proposed master plan

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per Lululoop concept

Environmental

Building the dike to the landside, where possible, to minimize impact to aquatic and riparian habitat

The proposed footprint would impact an estimated 4,200 m² of high quality Fraser River riparian habitat, 100 m² of high quality Fraser River intertidal habitat, 1,100 m² of drainage channel aquatic habitat , and 2,400 m² drainage channel riparian habitat*.

Relocating the drainage channel further inland and including appropriate plantings to the land side

* NOTE: This is an estimate based on air photo interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 13/14: Hamilton/Boundary - Recommended Improvements

Priority

Low priority due to the many property access conflicts to be resolved inside and outside the dike. Raise and acquire land over time along with redevelopment to prepare for dike raising and road relocation and raising.

The proposed secondary dike near Boundary road is a low priority because it provides back-up to the primary defenses. However, it is relatively simple to construct, but requires coordination and agreement with MoTI.

Cost

Costs below are for 1700 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$7.7 Million
Road Structure & Utilities	$3,900	$6.6 Million
Raise Road to Dike Height	$5,300	$9 Million
Driveways, Ramps or Road Intersection Reconstruction		$1.2 Million
Other*	$1,150	$2 Million
Contingency (40%)		**$10.6 Million**
Total		**$37 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Interim

Item	Cost per metre	Cost
Dike Raising	$5,400	$9.2 Million
Road Structure & Utilities	$3,900	$6.6 Million
Raise Road to Dike Height	$5,300	$9 Million
Driveways, Ramps or Road Intersection Reconstruction		$1.2 Million
Other*	$300	$.5 Million
Contingency (40%)		**$10.6 Million**
Total		**$37.1 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

6. Recommendations

It is recommended that the City adopt the Phase 3 Dike Master Plan as documented in this report, including the main features described below.

- Raise the dike crest to allow for 1 m of sea level rise. West of Nelson Road, the raised dike crest would be 4.7 m (CGVD28). East of Nelson Road, the raised dike crest would increase to 5.1 m at Boundary Road. The plan also allows for longer term upgrading to accommodate a further 1 m of sea level rise (i.e. 2 m of sea level rise).
- Widen the dike on the land side rather than into the Fraser River.
- Move Dyke Road inside the dike to facilitate short-term and long-term dike upgrading. This will require the road to be reconfigured and reconstructed, with some additional need for land tenure. Moving the road will allow removal of utilities within the dike.
- Raise the relocated Dyke Road to the dike crest elevation. This will facilitate driveway access over the dike to riverside properties. It will also be compatible with the desire to raise land inside the dike.
- Pursue individual industrial site strategies depending on the existing rights and agreements, the urgency of the works, and opportunities for redevelopment for each site. These include:
    - Crown Packaging – construct interim improvements to 3.5 m to correct low spot. Raise dike and full site to 4.7m during redevelopment expected in 18 years.
    - Deas Dock – seek improvement opportunities with BC Ferries. Raise full site, else raise road behind the site.
    - Canfisco 13140 Rice Mill Road – determine redevelopment opportunities with owner. Plan for interim improvements within limited space including new access from west and sheet pile wall between site and rail ROW.
    - Port Metro Vancouver Lands – Where rights exist, coordinate improvements with adjacent PMV operations. There no rights exist, collaborate with PMV to either acquire rights or develop agreement on responsibility to inspect, maintain, and improve dikes and shoreline protection.
    - Lafarge – Either raise the dike within the current City property that bisects their site, or negotiate land swap to place and build dike improvements at the riverside. Raise entire site with future redevelopment.
- Replace the drainage channel immediately inside the dike with storm sewers and swales. This will improve dike stability, and will provide some of the land needed to relocate Dyke Road.
- Raise land and roads immediately inside the dike (during redevelopment) to improve seismic resilience. This will also improve liveability by allowing residents to looking down over the water, rather than at the backside of a dike.
- Improve pedestrian and cyclist safety by constructing a separate multi-use path along the dike. This would be consistent with the City Parks vision for a perimeter trail system ("Lululoop" perimeter trail network envisioned in Appendix B)
- Construct the south section of a secondary dike near Boundary Road.

It is also recommended that the City prepare a comprehensive implementation plan for dike upgrading that incorporates the elements of the Phase 3 Dike Master Plan, and the elements of the other Dike Master Plans.

To address habitat compensation issues associated with the Dike Master Plans, it is further recommended that the City consider development of a habitat banking program that could provide effective large-scale compensation for the environmental impacts of dike upgrading.

Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

DRAFT

Sarah Lawrie, P.Eng.
Project Engineer

Reviewed by:

DRAFT

Mike V. Currie, M.Eng., P.Eng., FEC
Technical Reviewer

DRAFT

Colin Kristiansen, MBA, P.Eng.
Project Manager

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Revision History

Revision #	Date	Status	Revision	Author
D	November 21, 2018	DRAFT		SJL
C	October 30, 2018	DRAFT	Updated based on City comments on Version 2 and geotechnical input	SJL/ATAL
B	August 7, 2018	DRAFT	Updated based on City comments on Version 1 (pre-consultation)	SJL/ATAL

OQM CERTIFIED