City of Richmond

Report to Committee

To:	Public Works and Transportation Committee	**Date:**	February 21, 2019
From:	John Irving, P.Eng. MPA Director, Engineering	**File:**	10-6060-01/2019-Vol 01
Re:	**Dike Master Plan - Phases 3 and 5 Report**		

Staff Recommendation

That the "Dike Master Plan - Phase 3 Final Report" and "Dike Master Plan - Phase 5 Final Report" as attached in the staff report titled "Dike Master Plan – Phases 3 and 5 Report," dated February 21, 2019 from the Director, Engineering, be endorsed for the purposes of capital project and development planning.

John Irving, P.Eng. MPA
Director, Engineering
(604-276-4140)

Att. 2

REPORT CONCURRENCE		
ROUTED TO:	**CONCURRENCE**	**CONCURRENCE OF GENERAL MANAGER**
Real Estate Services	☑	
Parks Services	☑	
Roads & Construction	☑	
Sewerage & Drainage	☑	
Development Applications	☑	
Policy Planning	☑	
Transportation	☑	
REVIEWED BY STAFF REPORT / AGENDA REVIEW SUBCOMMITTEE	**INITIALS:** CJ	**APPROVED BY CAO**

Staff Report

Origin

By the year 2100, climate change scientists estimate that sea levels will rise approximately 1.0 metres and the City will subside by 0.2 metres. To maintain Richmond's high level of flood protection, the City will need to increase the height of the perimeter dikes by 1.2 metres over the next 25 to 75 years.

The City of Richmond's 2008-2031 Flood Protection Management Strategy identifies the need to "prepare and implement a comprehensive dike improvement program."

On October 24, 2016, Council endorsed the City's submission to the National Disaster Mitigation Program requesting funding for Dike Master Plan Phase 3. The project was approved and is 100% funded through the grant to a maximum of $250,000.

On December 11, 2017, Council approved $200,000 through the 2018 Capital Budget to prepare Dike Master Plan Phase 5. Subsequently, it was approved to be 100% funded by the Province of British Columbia through the 2017 Flood Risk Assessment, Flood Mapping & Flood Mitigation Planning Program.

The Dike Master Plan Phases 3 and 5 Draft Report was presented at the regular Council meeting on December 19, 2018, where Council resolved:

> *"That the public and key external stakeholders be consulted as identified in the staff report titled "Dike Master Plan – Phase 3 and 5" from the Director, Engineering, dated November 30, 2018."*

Staff completed public and key stakeholder consultation for Dike Master Plan Phases 3 and 5 and the results of that consultation are the focus of this report.

Dike Master Plan Phase 4 is undergoing further analysis on environmental compensation requirements and is scheduled to be brought forward later in the year.

Analysis

The City of Richmond is approximately 1.0 metres above mean sea level and protected by 49 kilometres of dike on Lulu Island, 1.1 kilometres of dike on Sea Island and 3.5 kilometres of flood protection structural works on Mitchell Island. The 2008-2031 Flood Protection Management Strategy identifies the perimeter dike as the primary system to protect the City from flooding due to climate change induced sea level rise.

Climate change scientists estimate that sea levels will rise approximately 1.0 metres by the year 2100 and 0.2 metres of land subsidence is forecasted during the same time period. With a combined 1.2 metres of relative sea level rise, the target dike elevation by year 2100 is 4.7 metres geodetic for the majority of the City. To address sea level rise beyond 2100, all new dikes will be designed to have a further height increase of 0.8 metres.

Current forecasts indicate that dike raising will need to be completed in the next 25 to 75 years. Dike improvements are ongoing through the Council approved Capital Program and development partnerships.

The Dike Master Plans are intended to be a comprehensive guide to:

- Upgrade the City of Richmond's perimeter dike;
- Protect Richmond from both storm surges and Fraser River freshet events;
- Adapt to sea level rise and land subsidence;
- Be seismically resilient;
- Integrate the Ecological Network Management Strategy vision and goals;
- Follow the five strategic directions of the City's 2009 Waterfront Strategy (Working Together, Amenities and Legacy, Thriving Eco-Systems and Community, Economic Vitality, Responding to Climate Change and Natural Hazards); and
- Prioritize dike improvement phasing to efficiently use resources.

The current phases of the Dike Master Plan are shown in Figure 1. Dike Master Plan Phases 1 and 2 have been adopted by Council while preparation of Dike Master Plan Phase 4 is underway. Stakeholder consultation for Dike Master Plan Phases 3 and 5 is complete and is the focus of this report.

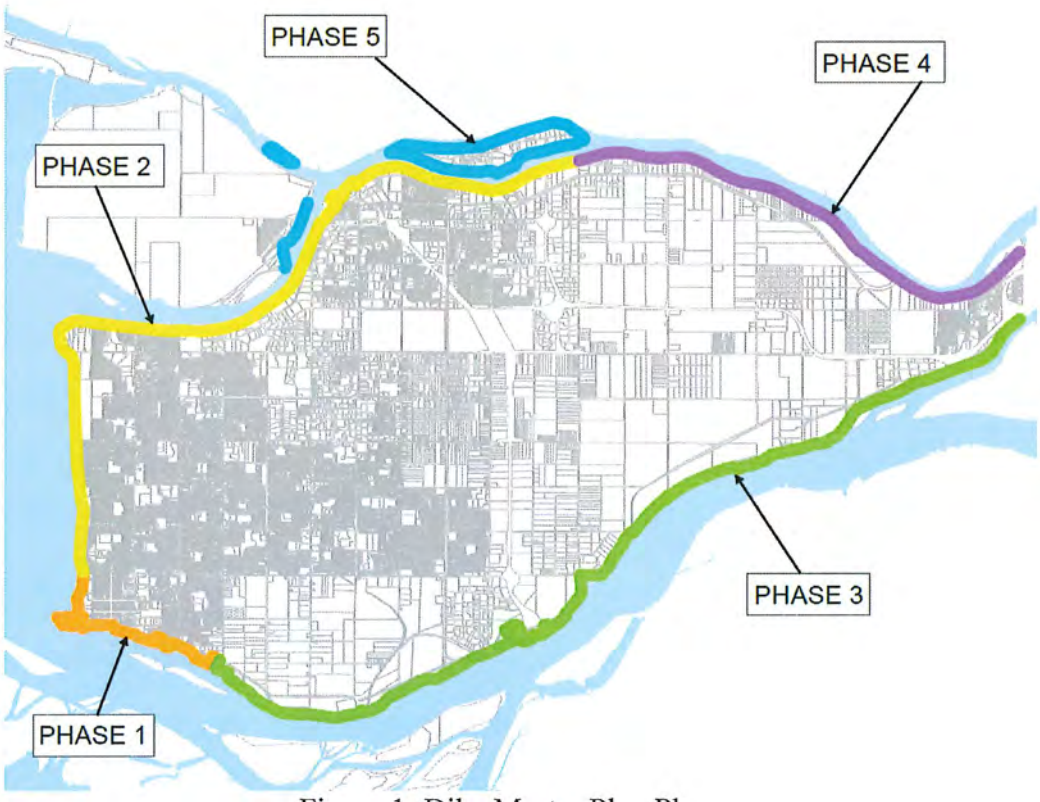


Figure 1: Dike Master Plan Phases

The study area for Dike Master Plan Phase 3 includes the south dike of Lulu Island between No. 2 Road and Boundary Road while the study area of Dike Master Plan Phase 5 includes Sea Island from the Sea Island Connector Bridge to the south end of 3800 Cessna Drive, Mitchell Island, and Richmond Island.

Dike Master Plan Phases 3 and 5 are appended as Attachments 1 and 2.

In order to meet grant funding conditions, the final report for Dike Master Plan Phase 3 is due to the Province of British Columbia and Public Safety Canada no later than March 31, 2019. Similarly, the final report for Dike Master Plan Phase 5 is due to the Province of British Columbia through the Union of BC Municipalities (UBCM) on March 31, 2019 to meet grant funding conditions.

Public Feedback

In January 2019, Dike Master Plan Phases 3 and 5 were presented to the public through two open houses, the Smart Cities Ideas Fair, and the City's "LetsTalkRichmond.ca" public engagement site. The public sessions attracted around 75 attendees while 518 people visited the "LetsTalkRichmond.ca" web page.

Based on feedback, the public indicated:

- support for the proactive approach to dike master planning and dike raising;
- support for the actions being taken with regards to community safety;
- support for ongoing sea level monitoring;
- support for environmental considerations in the Dike Master Plan;
- support for coordination with development to create superdikes;
- support for policy guiding flood construction levels and building standards for flood protection;
- concern regarding the removal of shrubs, trees, logs, and habitat along the dike;
- concern regarding the uncertainty in sea level rise forecasting and support for building dikes higher and in a shorter timeframe that anticipates accelerated sea level rise;
- that they appreciated the thoroughness of the report, the phasing methodology, and the clear concepts within the Plan;
- that the dike trail network is an important amenity with suggestions relating to paved walkways, distance markers, additional lighting, benches, and establishing a continuous perimeter trail; and

- that they would like more information regarding the amount of capital assigned to dike improvements and the timing of dike upgrades.

During the public open houses, staff received questions relating to costs of the proposed works and the public was advised that the City has three funding sources to implement the Dike Master Plan: the Drainage and Diking Utility, senior government grant funding, and development partnerships.

A detailed summary of the open house and website feedback is provided in the attached reports.

Key External Stakeholder Feedback

Key external stakeholders engaged included:

- BC Ferries
- Canadian Fishing Company
- City of New Westminster
- Crown Packaging
- Fisheries and Oceans Canada
- Environment Canada
- Lafarge Canada Inc.
- Ministry of Forests, Lands and Natural Resource Operations and Rural Development
- Ministry of Transportation and Infrastructure
- Mitchell Island Businesses
- Port of Vancouver
- Provincial Inspector of Dikes
- Sea Island Commercial Interests
- Sea Island Community Association
- TransLink
- Urban Development Institute
- Vancouver Airport Authority

Stakeholders that returned comments were generally supportive of the findings in Dike Master Plan Phases 3 and 5.

BC Ferries provided presentations and details on their current development works at the Deas Dock site. The proposed dike design aligns with the Dike Master Plan as an interim option; the ultimate goal being to raise the entire site to create a superdike as redevelopment occurs.

The Ministry of Forests, Lands and Natural Resource Operations and Rural Development continues to refer to the 2014 Seismic Design Guidelines for Dikes – 2nd Edition as the primary resource for seismic design. The Inspector of Dikes is open to flexibility for dike design in specific scenarios but is looking for consistency in seismic standards. Studies are currently being performed for the Province which may affect seismic designs when completed.

The Port of Vancouver indicated general support for the City's goal to have continuous, high-quality flood protection for the entire Lulu Island. The Port of Vancouver is currently in the early

stages of developing their long-term plans for land use and development of their sites. They are interested in working collaboratively with the City during design of dike upgrades to ensure that flood protection is coordinated with their operations.

TransLink does not require further engagement at this time unless the proposed dike improvements impact trucking operations, changes the Major Road Network, or affects bus stops. TransLink should be contacted during the planning phase of projects if these impacts are expected to occur.

Urban Development Institute have no comments on the Plans at this time. They have requested a general presentation on the Dike Master Plans when they have been endorsed by Council.

Vancouver Airport Authority and the City of Richmond agreed to continue discussions to establish a formal agreement of dike ownership on Sea Island. The Airport Authority is currently upgrading their perimeter dike to 4.7 metres and intends to complete a Dike Master Plan to inform their flood protection work.

In addition to the key external stakeholders already consulted, Staff will be planning Dike Master Plan Phases 3 and 5 presentations to the Advisory Committee on the Environment and the Agricultural Advisory Committee.

Recommendations

Following public and key stakeholder consultation, comments received have been reviewed and are incorporated in the finalized report. Recommendations of Dike Master Plan Phases 3 and 5 are summarized as follows:

Lulu Island - south dike between No. 2 Road and Boundary Road

- Raise the dike crest to allow for 1.0 metres of sea level rise and 0.2 metres of subsidence by the year 2100. For the dike area from No. 2 Road to west of Nelson Road, the raised dike elevation would be 4.7 metres geodetic. For the dike east of Nelson Road to Boundary Road, the raised dike elevation would increase from 4.7 metres at Nelson Road to 5.0 metres at Boundary Road.
- Reconfigure and reconstruct Dyke Road to be inland rather than on top of the dike to facilitate short-term and long-term dike upgrading. This will allow for City utilities to be relocated inland of the dike.
- Pursue superdikes and individual site strategies dependant on existing rights and agreements, the urgency of works, and the opportunities for redevelopment of each site.
- Construct the south section of a secondary dike near Boundary Road.
- Construct a separate multi-use path along the dike to improve pedestrian and cyclist safety. This would be consistent with the 2010 Richmond Trail Strategy that guides the City in trail development and aligns with the vision for a perimeter trail system.

Mitchell Island

- Raise roadways to a 4.7 metre dike elevation to provide an emergency egress.
- Acquire rights-of-way along river bank properties for a future dike and for further bank protection works.

- Establish redevelopment policies on Mitchell Island that require superdike formation to a 4.7 metre dike elevation.
- Engage low elevation properties to mitigate flood.

Sea Island - from the Sea Island Connector Bridge to 3800 Cessna Drive

- Raise the dike crest to 4.7 metres to allow for 1.0 metres of sea level rise and 0.2 metres of subsidence.
- Establish redevelopment policies on Sea Island that require superdike formation to a 4.7 metre dike elevation.
- As an interim measure prior to redevelopment, raise the dike to 4.7 metres using individual site strategies where low sections of dike occur.

Richmond Island

- Flood protection responsibility will remain with the property owner.
- Inform the property owner on Richmond Island of the scour risk that has been identified in the North Arm of the Fraser River adjacent to Richmond Island.

Next Steps

Dike Master Plan Phases 3 and 5 identifies a medium to long term program for dike improvements on the south dike of Lulu Island, the City of Richmond's section of perimeter dike on Sea Island, Mitchell Island, and Richmond Island over the next 25 to 75 years to stay ahead of climate change induced sea level rise and land subsidence.

As sea level rise is realized, the rate of dike improvement will be adjusted accordingly. Staff will present annual utility funding levels for dike improvement for Council's consideration through the bi-annual Ageing Infrastructure Report. Upgrades will also occur in conjunction with the City's growth, allowing synergies between the City and the development community.

In the short and medium term, there is a significant amount of work that can be carried out in preparation for these upgrades. Should Council endorse this work plan, staff will:

- Encourage the construction of superdikes through development;
- Re-evaluate current and future flood construction levels and development bylaws to reduce flood risk;
- Strategically acquire properties in support of future dike upgrading;
- Monitor sea level rise using water level sensors; and
- Investigate the creation of a habitat banking program to support dike improvement projects based on environmental assessment.

Financial Impact

Capital projects will be brought forward for Council consideration as part of the Council budget process.

Conclusion

Consistent with the City's 2008-2031 Richmond Flood Protection Management Strategy, Dike Master Plan Phases 3 and 5 identifies the City's preferred medium to long term dike improvements for the south dike of Lulu Island from No. 2 Road to Boundary Road, Sea Island from the Sea Island Connector Bridge to the south end of 3800 Cessna Drive, Mitchell Island, and Richmond Island to address climate change induced sea level rise and land subsidence.

Dike Master Plan Phases 3 and 5 generally recommends that the City raise the dike to a minimum 4.7 metre dike elevation while allowing for a further height increase to 5.5 metres in the future, integrate the proposed dike concepts within the study areas, pursue superdikes through development, and engage private property owners to raise the dike within their property.

Public and key stakeholder feedback on Dike Master Plan Phases 3 and 5 will be incorporated into capital dike improvement projects as identified in this plan.

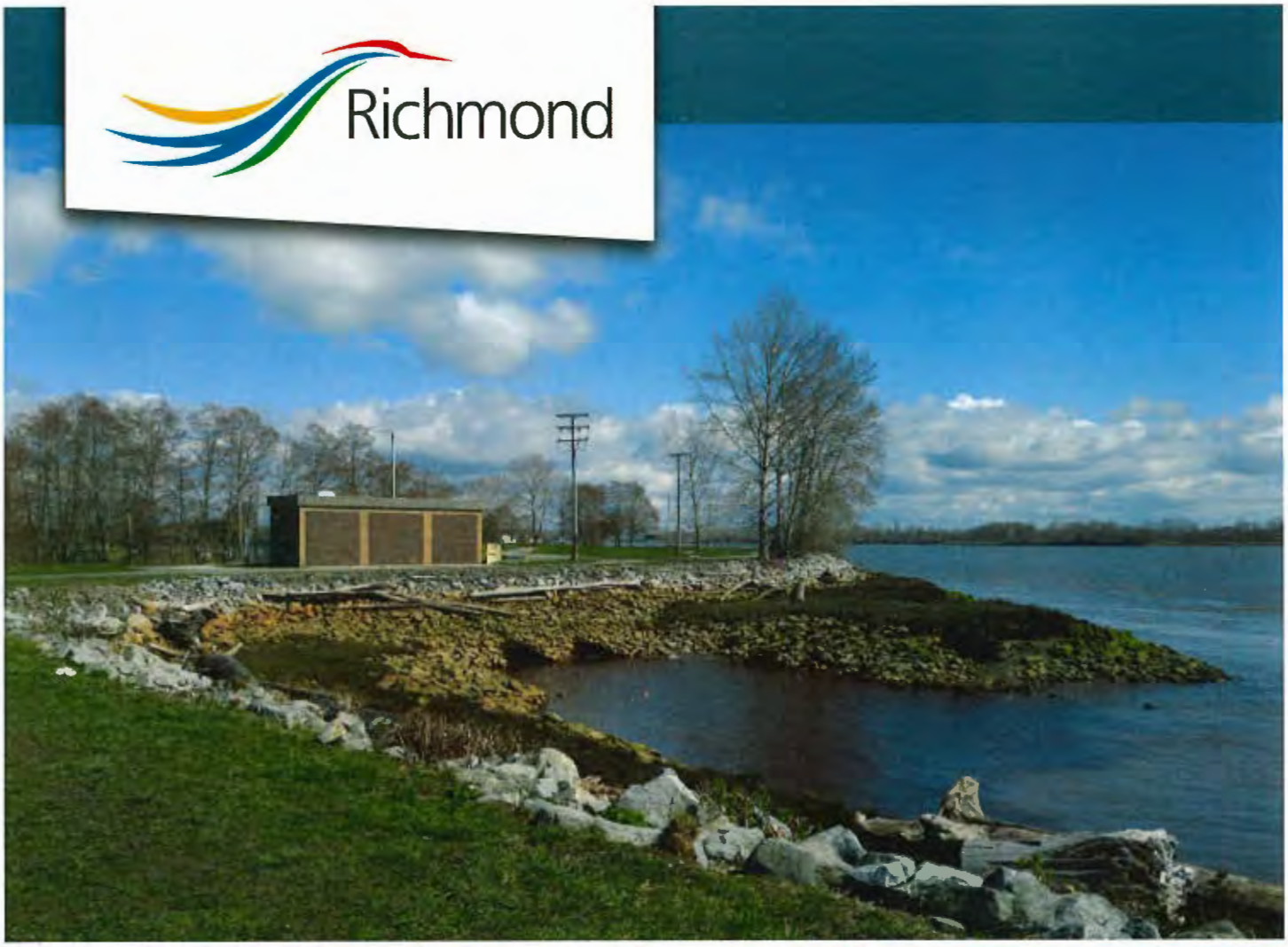
Eric Sparolin, P.Eng.
Acting Manager, Engineering Planning
(604-247-4915)

Christopher Chan, EIT
Acting Project Manager, Engineering Planning
(604-204-8516)

ES: am

Att. 1: Dike Master Plan Phase 3 Final Report 2019
2: Dike Master Plan Phase 5 Final Report 2019

Richmond



Final Report

Richmond Dike Master Plan - Phase 3

February 2019
KWL File No. 0651.110-300

Submitted by:

KERR WOOD LEIDAL
consulting engineers

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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 within Richmond, plus a 5th phase for Sea Island, Mitchell Island and Richmond Island. The goal is to raise the dikes to 4.7 m CGVD28 to allow for 1 m of sea level rise plus 0.2 m of land subsidence, while allowing for further future upgrading. The long-term vision is to provide the City with a world-class level of flood protection to keep pace with the rapidly growing community within the dikes.

This Phase 3 Dike Master Plan 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.

- 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 5.0 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 dike upgrading. This will require the road to be reconfigured and reconstructed, with some additional 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.
- 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.

For all Dike Master Plan phases, the City should continue to investigate alternative ways to achieve seismic performance objectives, including soil densification research, custom design criteria, and filling a wide swath of land inside the dike.

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. The City is currently working on an updated 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;
- Patrick Lilley, M.Sc., R.P.Bio., BC-CESCL – Senior 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;
- Pratima Milaire, P.Eng., PMP - Project Engineer, Engineering Planning; and
- Chris Chan, B.A.Sc., E.I.T. – 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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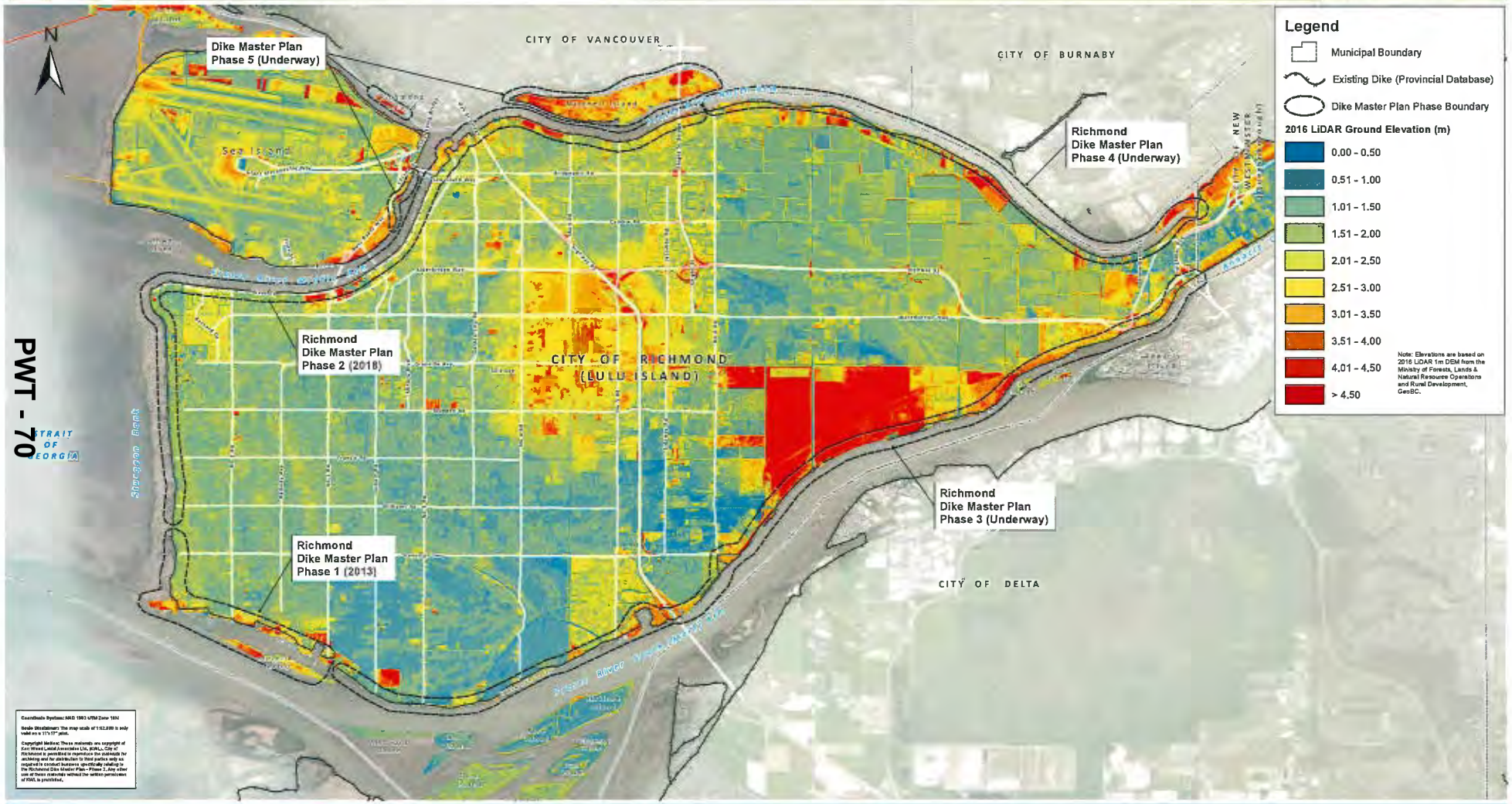
City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



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Dike Master Plan Phases

Figure 1-1

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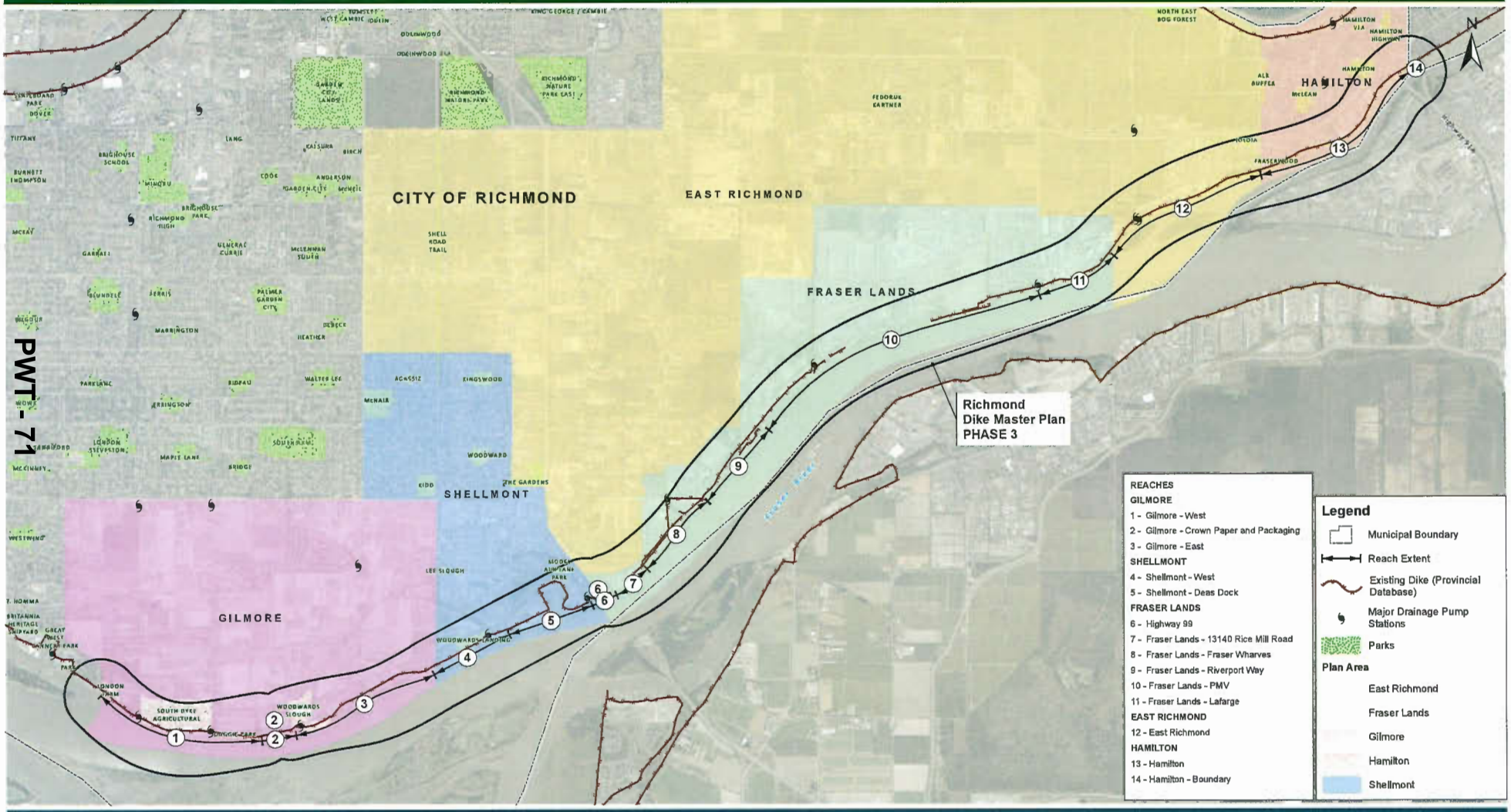
City of Richmond

Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



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Dike Master Plan Phase 3 Reaches

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). Similarly, 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 # & 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 2019 (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 (13911 Garden City Road)	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 • 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

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 BC Ferries Fleet Maintenance Unit (12800 Rice Mill Road)	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
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

Reach # & Name	Extent / Length	Existing Dike Alignment	Major Features
7 – Fraser Lands – Canadian Fishing Company (13140 Rice 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
10 – Fraser Lands Port of 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

Reach # & Name	Extent / Length	Existing Dike Alignment	Major Features
11 – Fraser Lands Lafarge (7611 No 9 Road)	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 (1.7 km)	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 • 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

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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 also 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 existing fish habitat compensation projects 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 13 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; meaning they are considered of special concern, or Red-Listed; meaning they are 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	Richmond ESA types present	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	Shoreline	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	Intertidal Shoreline				
2 Gilmore - Crown Packaging (13911 Garden City Road)	Land Side	• Paved parking lot	Private property	n/a	Unvegetated	Shoreline	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	Intertidal Shoreline				
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	Freshwater wetland Shoreline	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	Intertidal Freshwater wetland Shoreline				
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	Shoreline Freshwater wetland	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	Intertidal Shoreline Freshwater wetland				
5 Shellmont - Deas Dock BC Ferries Fleet Maintenance Unit (12800 Rice Mill Road)	Land Side	• Mostly paved, some low quality herbaceous habitat present	n/a	Low quality habitat and absence of watercourses along full length	Meadow Unvegetated	Shoreline	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	Intertidal Shoreline				
6 Highway 99	Land Side	• Low quality gravel parking lots	n/a	Low quality habitat along full length	Deciduous tree woodland	Shoreline	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	Intertidal Shoreline				

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Reach #	Location	Environmental setting (organized by inland side and shoreline side of existing dike)	Construction Constraints	Construction Opportunities	FREMP Habitat Types	Richmond ESA types present	Known Species at Risk Occurrence Near Dyke Alignment	Potential Raptor Nesting Trees	Potential Migratory Bird Nesting Habitat	Existing Habitat Compensation Sites Present
7 Fraser Lands – Canadian Fishing Company (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	Shoreline	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	Intertidal Shoreline				
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	Shoreline	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	Intertidal Shoreline				
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	Shoreline	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	Intertidal Shoreline				
10 Fraser Lands – Port of Vancouver	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	Shoreline Upland forest	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	Intertidal Shoreline				
11 Fraser Lands – Lafarge Canada Inc. (7611 No 9 Road)	Land Side	• Low quality habitat paved lots and buildings	Private property	Low quality habitat, absence of watercourses	None (Paved)	Shoreline	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	Intertidal Shoreline				
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	Shoreline Upland forest	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	Intertidal Shoreline				
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	Upland Forest	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	Intertidal Upland Forest				

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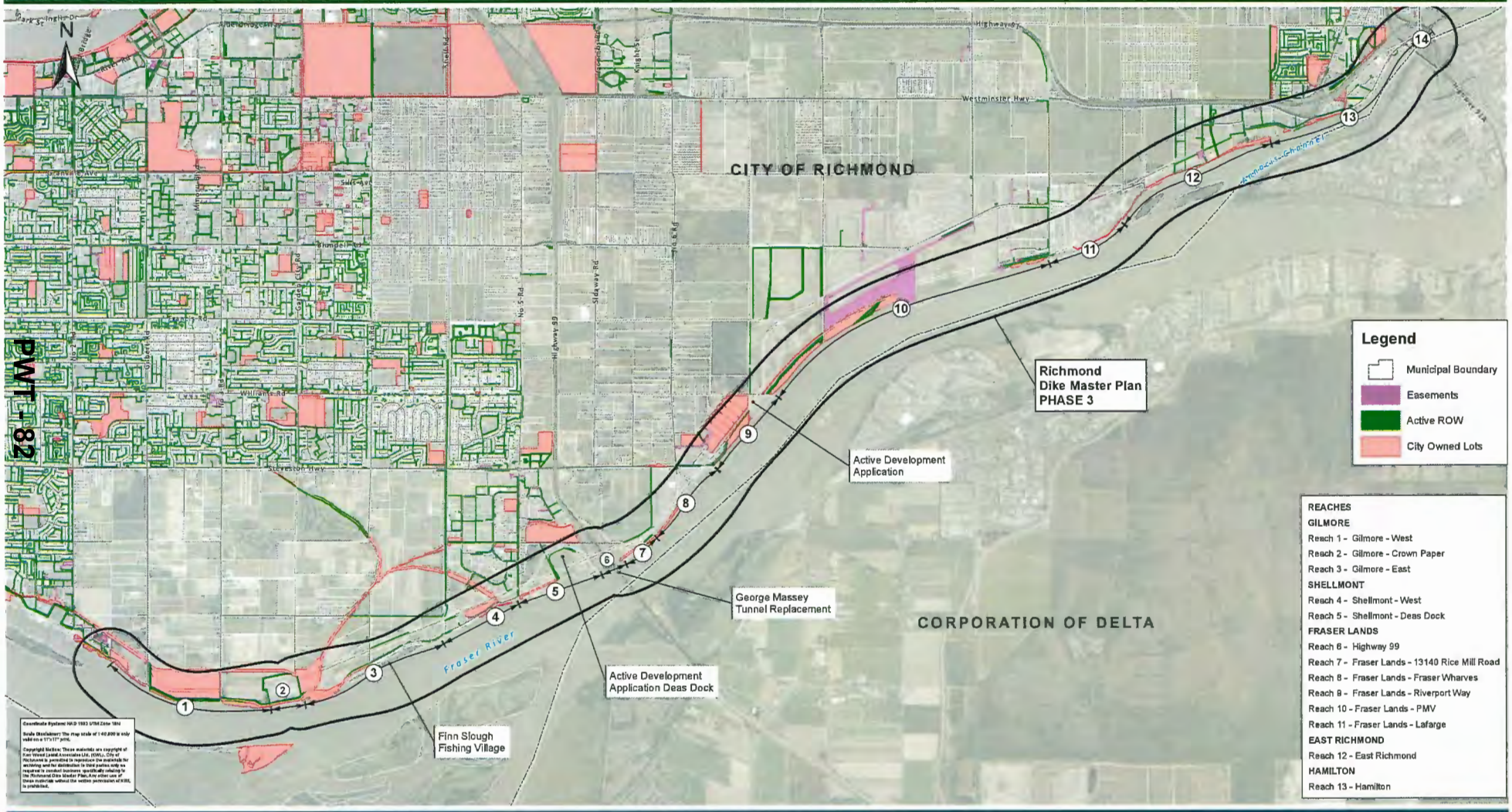
City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL
consulting engineers



Legend

- Municipal Boundary
- Easements
- Active ROW
- City Owned Lots

REACHES

GILMORE
Reach 1 - Gilmore - West
Reach 2 - Gilmore - Crown Paper
Reach 3 - Gilmore - East

SHELLMONT
Reach 4 - Shellmont - West
Reach 5 - Shellmont - Deas Dock

FRASER LANDS
Reach 6 - Highway 99
Reach 7 - Fraser Lands - 13140 Rice Mill Road
Reach 8 - Fraser Lands - Fraser Wharves
Reach 9 - Fraser Lands - Riverport Way
Reach 10 - Fraser Lands - PMV
Reach 11 - Fraser Lands - Lafarge

EAST RICHMOND
Reach 12 - East Richmond

HAMILTON
Reach 13 - Hamilton

Coordinate System: NAD 1983 UTM Zone 10N
Scale Disclaimer: The map scale of 1:40,000 is only valid on a 17"x11" print.
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Project No. 651-110
Date February 2019
Scale 1:40,000

500 250 0 500 m

Existing Land Tenure

Figure 2-1

3. Options Assessment

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

- design considerations and design criteria;
- upgrading strategies;
- upgrading options and concepts;
- summary of external stakeholder consultation; and
- recommended options for implementation.

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. For the river dikes, including those in Phase 3, this is determined as the site-specific maximum of spring freshet flood and a coastal winter flood (combination of tide/storm surge with Fraser River winter flow). 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). The dike design should consider the need for regular and emergency maintenance.
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. The specifics of post-earthquake protection requirements are dependent on the seismic performance criteria currently under review as part of the Richmond Flood Protection Management Strategy update.
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	• 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 land use planning and development control tools to raise private properties to the dike elevation to create a wider raised 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 (2012) includes an Ecological Network Management Strategy (ENMS) that identifies ecologically important areas in the City's Ecological Network (EN). These areas include Environmentally Sensitive Areas (ESAs), 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 (City of Richmond 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 Regulation* of the *Riparian Areas Protection Act* (formerly the *Fish 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: (City of Richmond 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 with the effectiveness and time lag between impacts and offsetting. Often, the offset area is equal to an area greater than that of the impacted area.

Where possible, impacts to existing habitat compensation sites should be avoided. Where impacts to these sites are not avoidable, habitat offsetting will likely be required, and requirements will be determined through discussions with Fisheries and Oceans Canada (DFO).

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 Phase 3 Dike Master Plan. These criteria were developed and reviewed in collaboration with City staff.

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	Seismic performance criteria currently under review as part of the pending Richmond Flood Protection Management Strategy update and further consultation with the Province	
River-side Slope, Setback and Vegetation	2H:1V bank slope with riprap revetment Vegetation in/near the dike should adhere to provincial guidelines	>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
Road Design Width[a]	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

a. *Based on City of Richmond Engineering Design Specifications for* Roadworks (2008) and City staff input. https://www.richmond.ca/__shared/assets/Roadworks20127.pdf

Dike Crest Elevation

At this time, the Province has not established an official 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 (MFLNRO, 2014).

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

- 500-year return period coastal water level with 1 m of sea level rise (no wind/wave effects) with winter Fraser River flood flow; 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 wind/wave effects and 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. Adequate information on wind/wave effects is not available at this time and is a consideration in the pending Richmond Flood Protection Management Strategy update. However, it is generally assumed that the dike reaches within Phase 3 are not significantly impacted by wind/wave effects. This assumption should be confirmed during detailed design. 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 (with historic winter Fraser River flow)	Fraser River freshet		
Level of Performance	500-year return period (0.2% annual exceedance probability)			
Climate Change Allowance	1 m sea level rise	1 m sea level rise and 20% freshet flow increase		
Design Flood Level (m, CGD28)[a]	3.8		4.2	4.6
Wind/Wave Effects Allowance	None			
Freeboard (m)	0.6			
Land Subsidence Allowance (m)	0.2			
Minimum Dike Crest Elevation (m, CGVD28)[b]	4.7[c]		5.0	5.4

Notes:

a) From (BC MFLNRO, 2014).

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

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

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

Seismic Performance

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. In January 2019[1], the Province released a status update for the two components of the review and clarifications on the existing guidelines:

- Dike Consequence Classification (anticipated to be completed in 2019); and
- Seismic Assessment and Geotechnical Investigation of Lower Mainland Dikes (anticipated to be completed in 2021).

The seismic performance criteria for dikes in Richmond are currently under review as part of the pending update to the Richmond Flood Protection Management Strategy, with consideration of potential alternative performance approaches. As a result, City-specific seismic performance criteria have not been established as a part of Dike Master Plan Phase 3, with the expectation that this will be further developed and discussed as part of the Flood Protection Management Strategy and in discussion with the Province.

Vegetation

Vegetation on and adjacent to the dike should adhere to provincial guidelines[2]. These guidelines limit vegetation on the dike crest, side slopes, and landside toe predominantly to trimmed grass, with specific situations where other vegetation may be allowed (overwide dikes, natural levees, setback dikes). The guidelines include consideration for variations that may be considered for sensitive habitat:

> "Where environmental agencies have significant concerns for areas of sensitive habitat (such as historically overgrown works and/or FREMP red-coded areas), variations from these guidelines may be considered to increase protection of habitat where practical and economic, provided public safety is not compromised."

Richmond could consider developing more prescriptive city-wide dike vegetation management guidelines, which would require acceptance by the Province. A City-specific vegetation management plan could investigate opportunities to increase the robustness of dikes while accommodating vegetation beyond trimmed grass (e.g. exploring methods to armour dikes against overtopping erosion while accommodating shrubs and small trees).

3.3 Alternative Upgrading Strategies

Several high-level dike upgrading strategies, summarized in Table 3-5, were considered to inform the development of specific options for the Dike Master Plan.

[1] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/iod_letter_re_seismic_2019.pdf
[2] Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment. http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/env_gd_veg_man.pdf

Table 3-5: 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 3-6 presents a summary of the options for each reach. Appendix B includes landscape concepts prepared by Hapa associated with the cross-section options.

Table 3-6: Dike Upgrading Options

Reach # and Name	Options
1 – Gilmore West	• Option 1: Separated dike and road • Option 2: Riverbank dike • Option 3: Superdike *Site-specific interim options:* • Option 4: Road Dike
2 – Crown Packaging (13911 Garden City Road)	• 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 BC Ferries Fleet Maintenance Unit (12800 Rice Mill Road)	• 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 – Canadian Fishing Company (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 of Vancouver	• Option 2: Riverbank dike • Option 3: Superdike
11 – Fraser Lands Lafarge Canada Inc. (7611 No 9 Road)	• 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.

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 3-7: Space Limitations and Access Issues

Reach / Location / Description	Photo	Options to Address Footprint and Access
Reach 1 London Farm		• Work with Museum and Heritage Services to site the upgrades to preserve character-defining elements of the site
Reach 3 Finn Slough		• Steeper driveway access • Provide parking on land-side • Steeper or longer road ramps up to the new road elevation

Reach / Location / Description	Photo	Options to Address Footprint and Access
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 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 three sites:

- Crown Packaging, 13911 Garden City Road (Reach 2);
- Deas Dock, BC Ferries Fleet Maintenance Unit, 12800 Rice Mill Road (Reach 5); and
- Canadian Fishing Company, 13140 Rice Mill Road, (Reach 7).

For all three 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.

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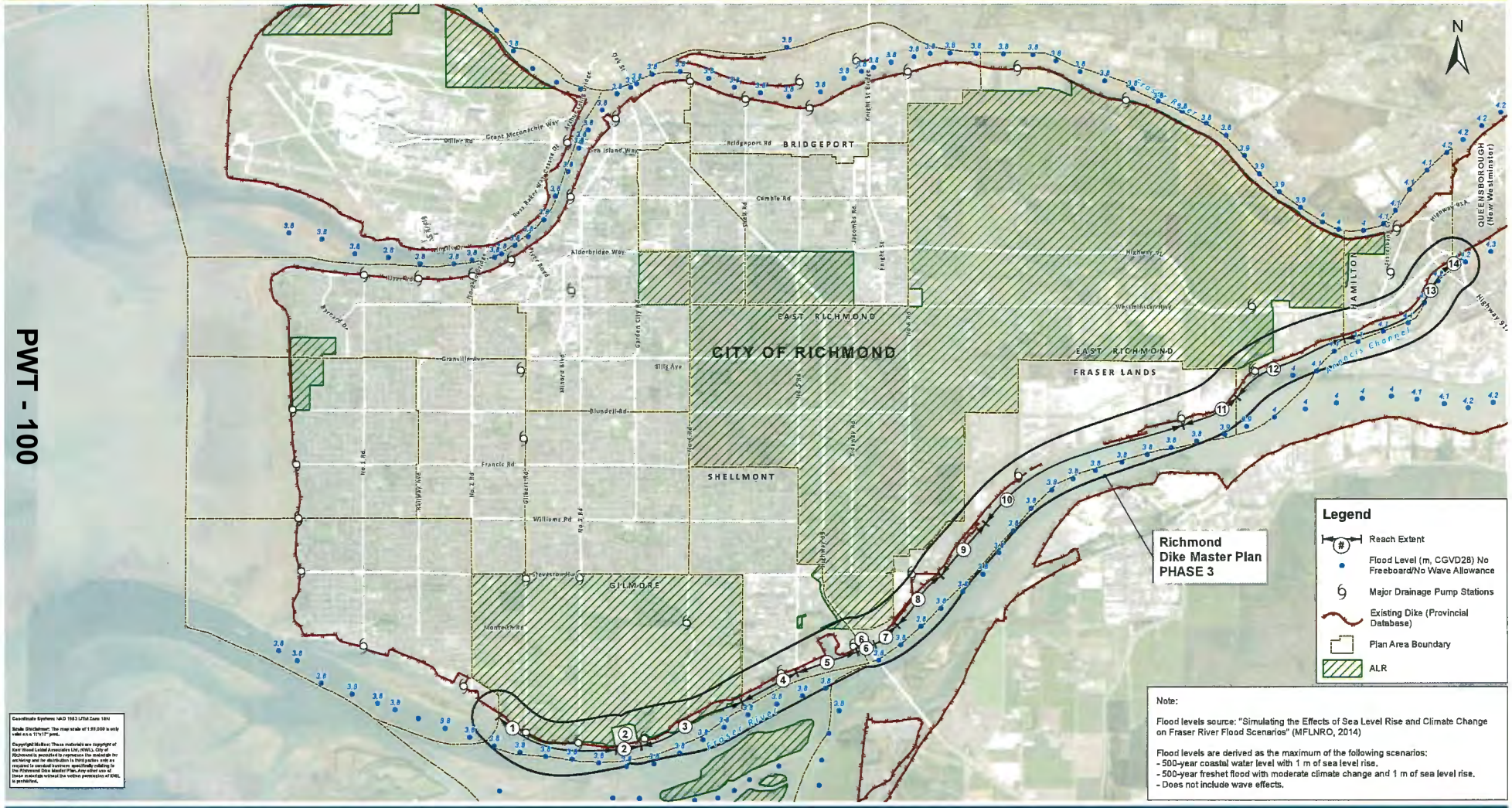
City of Richmond

Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

PWT - 100



Project No. 651-110

Date February 2019

Scale 1:55,000

1,000 500 0 1,000 m

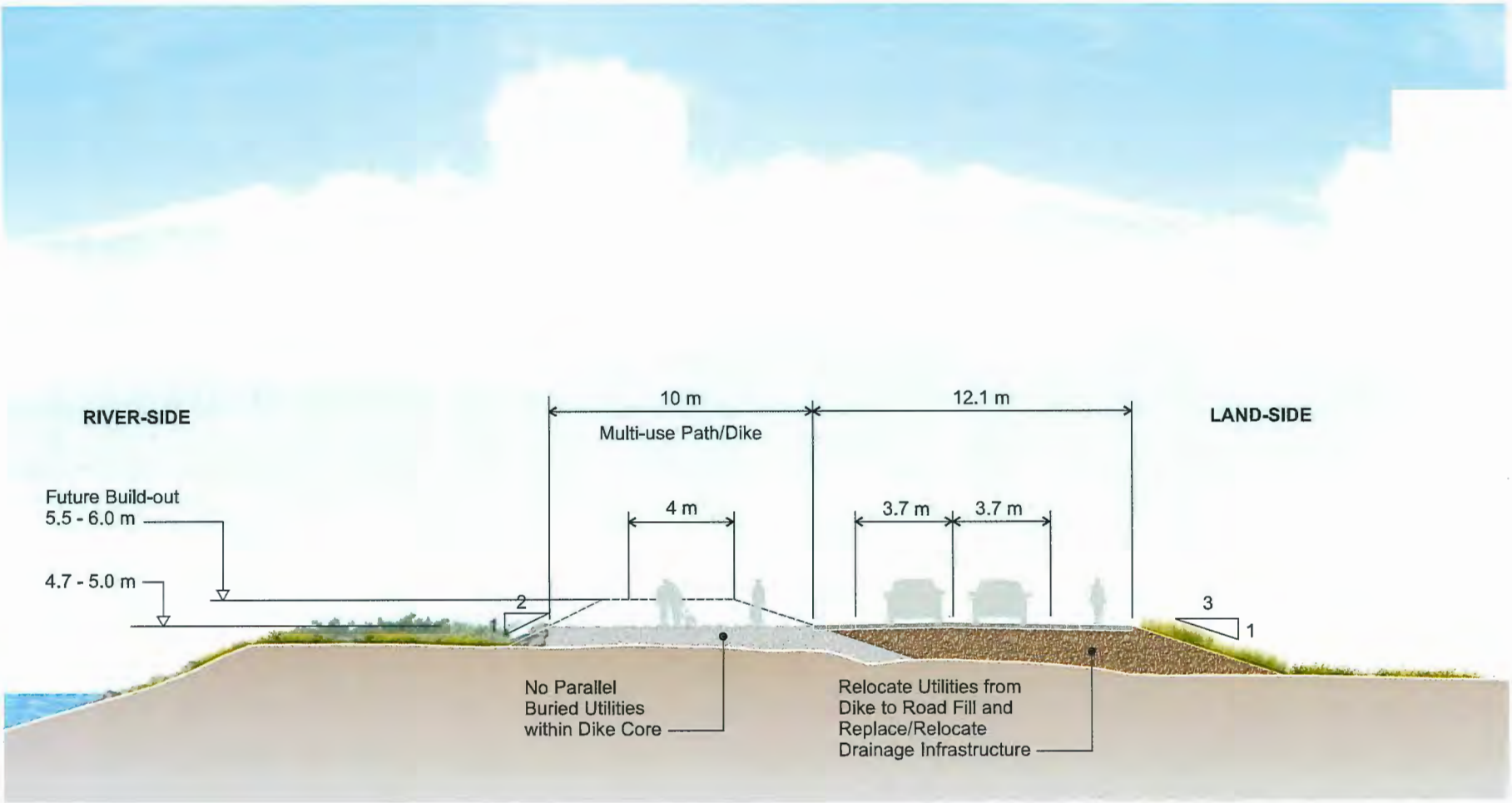
Fraser River Flood Elevations

Figure 3-1

City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL
consulting engineers

PWT - 101



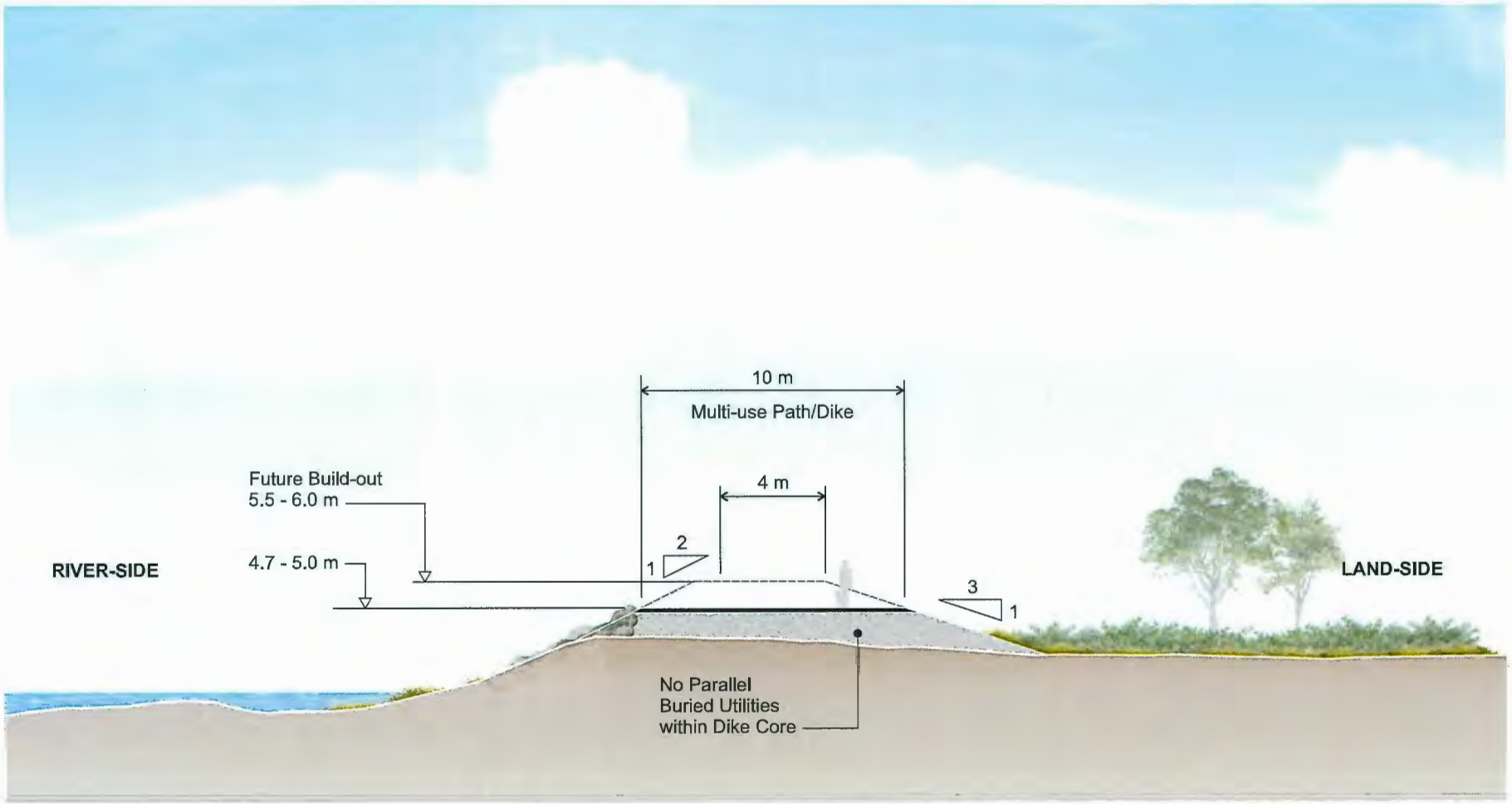
Project No.	651.110
Date	February 2019
Scale	Not to Scale

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

Figure 3-2

City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL
consulting engineers



PWT - 102

Project No.	651.110
Date	February 2019
Scale	Not to Scale

Option 2: Riverbank Dike
Raise Dike Only and Extend Land-side

Figure 3-3

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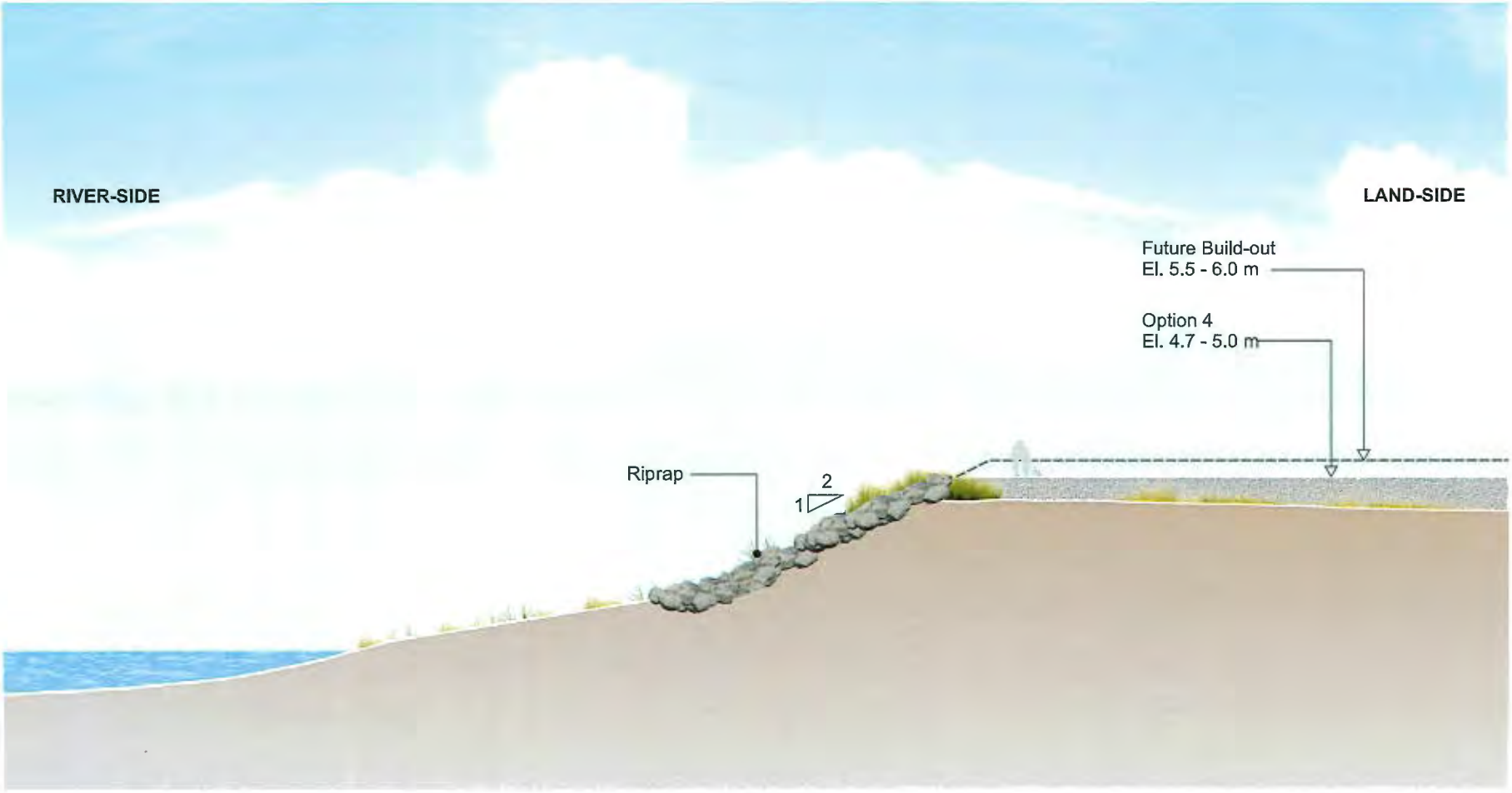
City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL
consulting engineers

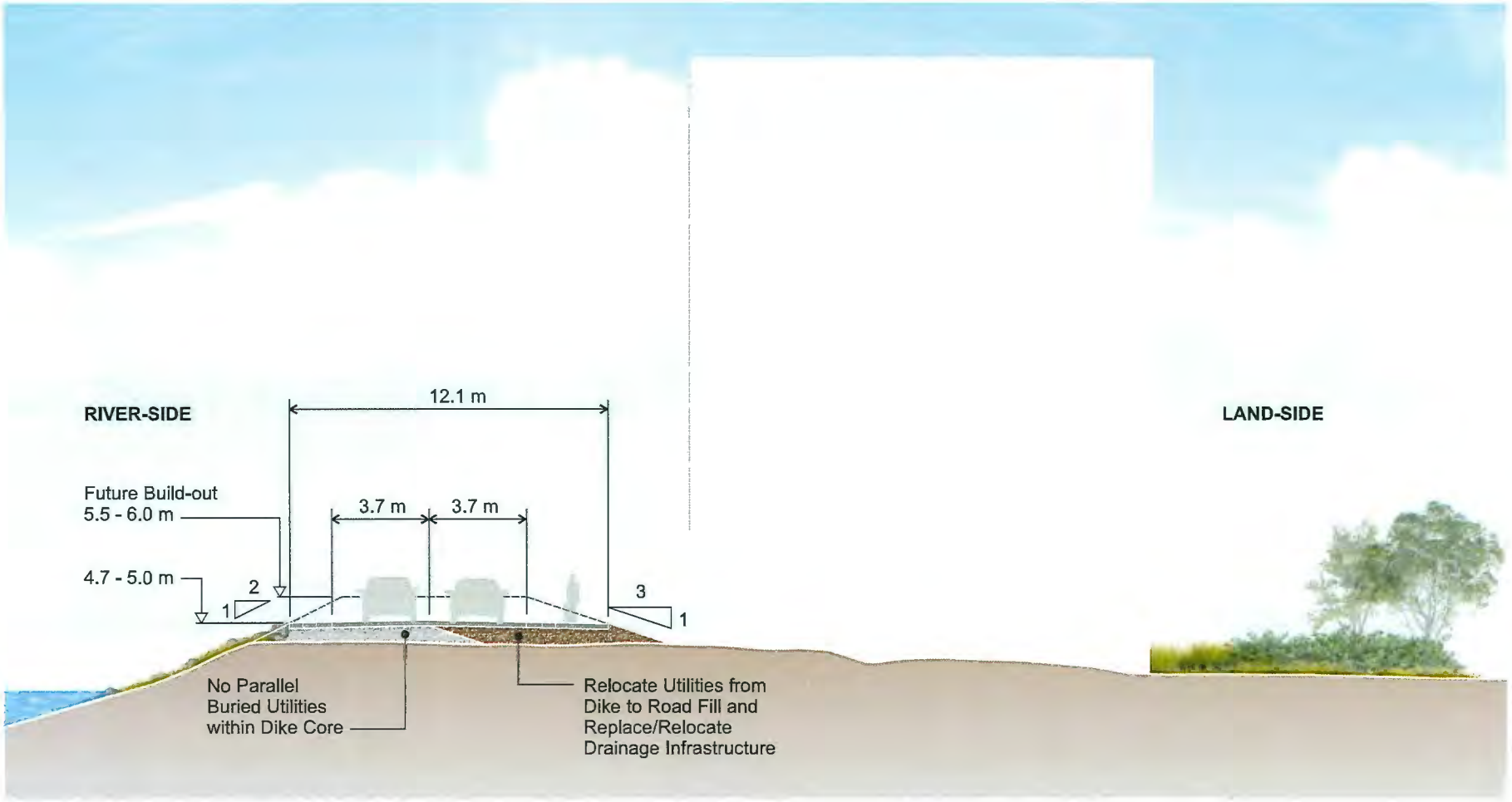


PWT - 103

Project No.	651.110
Date	February 2019
Scale	Not to Scale

Option 3: Superdike
Raise Land Behind Dike

Figure 3-4



Project No.	651.110
Date	February 2019
Scale	Not to Scale

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

Figure 3-5

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City of Richmond
Richmond Dike Master Plan - Phase 3

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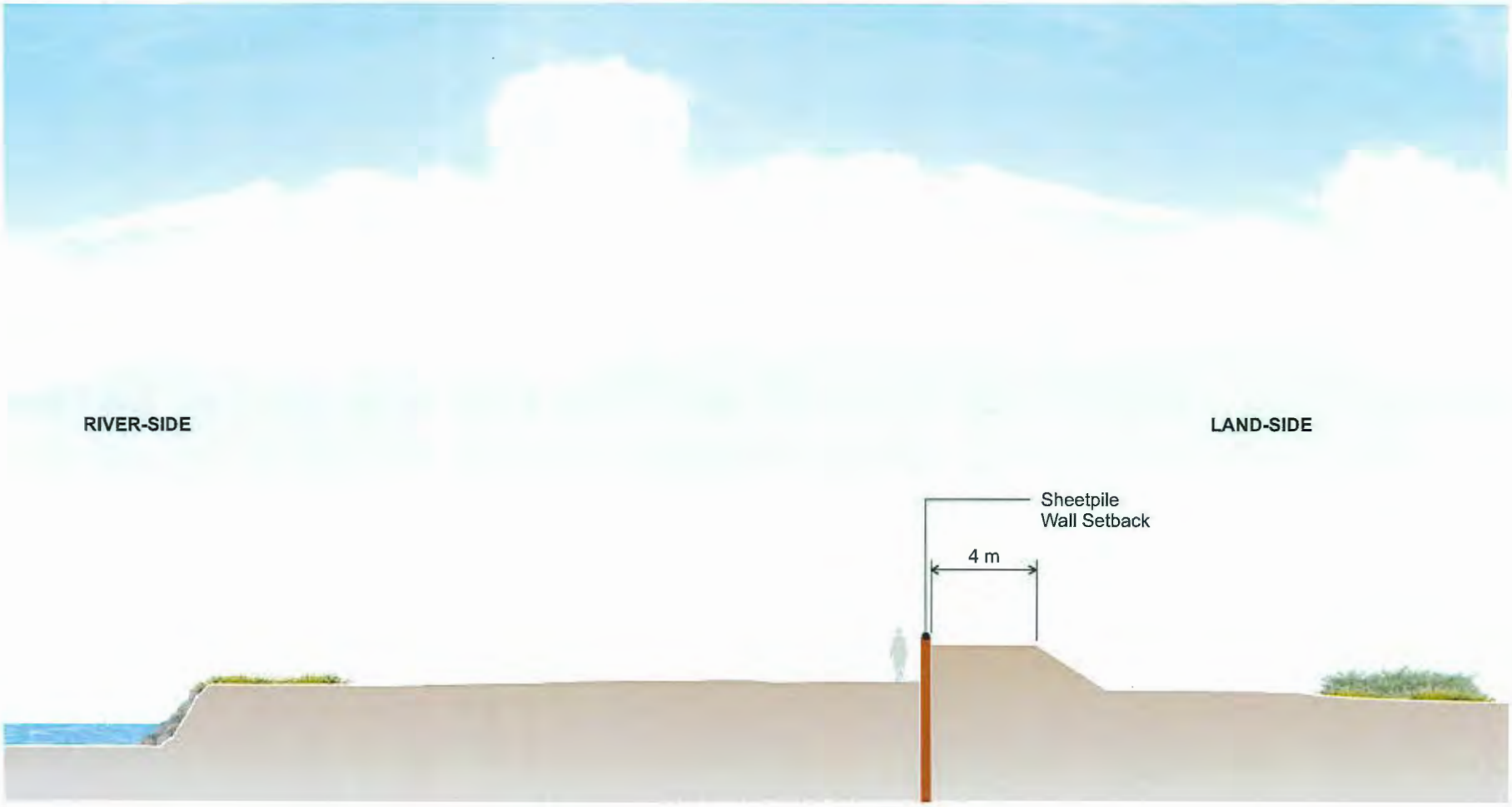

PWT - 105

Project No.	651.110
Date	February 2019
Scale	Not to Scale

Option 5: Setback Sheetpile Wall (Interim Option)

Figure 3-6

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City of Richmond
Richmond Dike Master Plan - Phase 3

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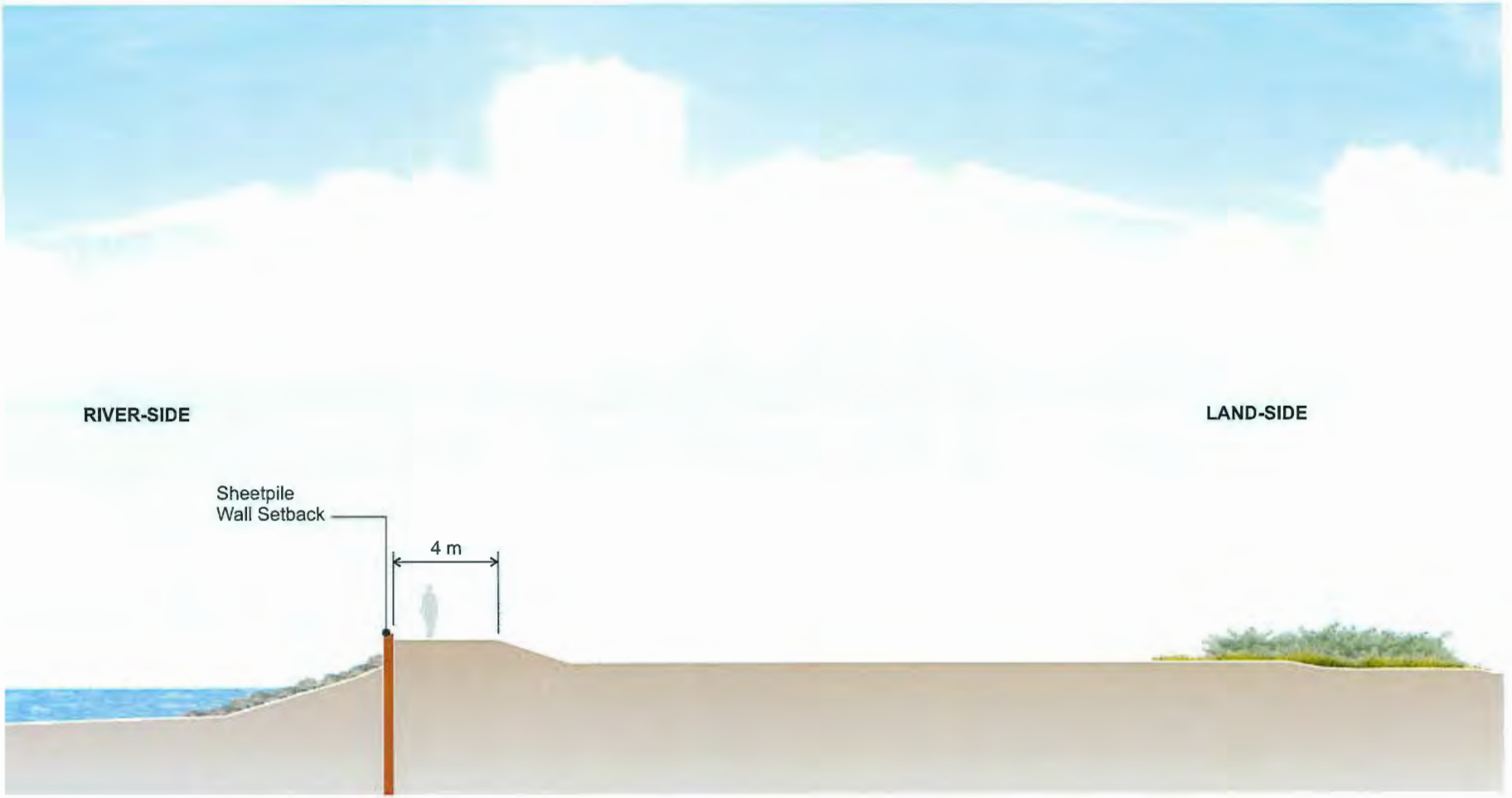


PWT - 106

Project No.	651.110
Date	February 2019
Scale	Not to Scale

Option 6: Riverside Sheetpile Wall (Interim Option)

Figure 3-7

3.5 Stakeholder Engagement

Stakeholder engagement for Phases 3, and 5 of the Dike Master Plan has being completed jointly in two stages. Prior to initial City Council review, initial stakeholder engagement was completed that included meetings with internal City departments and some government agencies (also including Phase 4). This initial stakeholder engagement allowed 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 was completed, which included reaching out for meetings with specific stakeholder groups and several public consultation events. The second stage of stakeholder engagement was 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 and moving towards implementation.

For Phase 3, the City engaged the following parties:

- City of Richmond Internal Stakeholders:
    - Transportation,
    - Development Applications,
    - Policy Planning,
    - Engineering & Public Works,
    - Real Estate,
    - Parks Planning, Design & Construction,
    - Parks Operations;
- City of New Westminster;
- Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD), including Inspector of Dikes, Flood Safety, and Water Authorizations staff;
- Lafarge Canada Inc. (7611 No 9 Road);
- Crown Packaging (13911 Garden City Road);
- Deas Dock BC Ferries Feet Maintenance Unity (12800 Rice Mill Road);
- Canadian Fishing Company (13140 Rice Mill Road);
- Port of Vancouver;
- Fisheries and Oceans Canada (DFO); and
- general public.

The City and KWL met with internal stakeholders, Port of Vancouver, and MFLNRO and hosted public open houses. All other parties contacted requested engagement closer to project planning in areas that may affect their operations. Additional collaboration and discussions should be held during detailed design of dike upgrades. DFO declined to meet with the City, stating that input would be provided during later stages in the established review and approvals process. Additionally, Richmond is within the traditional territory of the Coast Salish people and the City works with Nations on various projects where appropriate. Feedback from external stakeholders is summarized in Table 3-8.

Table 3-8: External Stakeholder Feedback

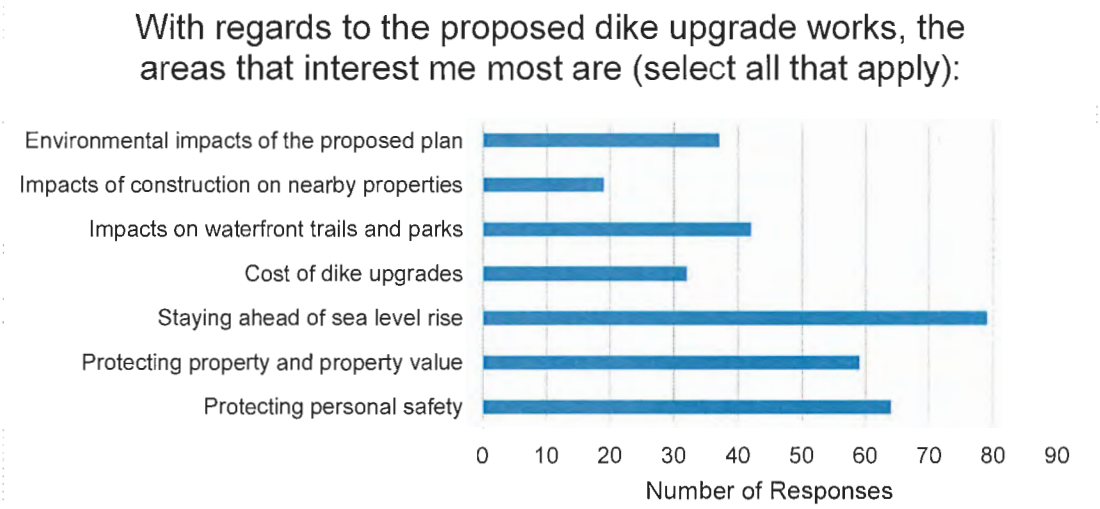
Stakeholder	Summary of Comments
Ministry of Forests, Lands, Natural Resource Operations, and Rural Development Inspector of Dikes	**Inspector Of Dikes (IOD):** Currently there are two projects that may impact the application of the Guidelines for Seismic Design of Dikes: The Dike Consequence Classification (lead by the Province), and the Seismic Assessment and Geotechnical Investigation of Lower Mainland Dikes (lead by the Fraser Basin Council). Until this work is completed, all applicants for Dike Maintenance Act approvals are to continue to follow the 2014 Seismic Design Guidelines for Dikes – 2nd Edition, where the dike is considered a high consequence dike. IOD is generally open to flexibility in specific scenarios but is looking for consistency with seismic standards. It is unlikely that an expedited application process would be considered.
Ministry of Forests, Lands, Natural Resource Operations, and Rural Development Water Authorizations	Noted that the Province provides emergency bulletin to property owners to remove harmful substances in the floodplain in high water/flood scenarios, in order to reduce risk of environmental contamination from flooding. Generally interested in larger scale compensation for impacts of large-scale dike upgrades in Richmond to achieve more meaningful compensation. There is still a need to compensate locally. This could potentially include approval of overall compensation program and plan, but it would still require project by project approvals (approval in principle of the plan already). This method hasn't been developed before and would need to be developed with Richmond.
Port of Vancouver	Generally supports the City's goal to have continuous, high-quality flood protection for the entire Lulu Island. Much of the Port land is high near the area called Richmond Lands. This is not a high-priority for dike raising; however, the Port understands that as areas redevelop, this is the best time to improve the dike and create opportunities for superdikes. The Port is in the early stages of developing their long-term plan for operations and response to sea level rise and climate change. The Port is interested in working collaboratively with the City during design of dike upgrades to ensure that the flood protection works with current and planned operations.
BC Ferries (Deas Dock, Fleet Maintenance Unit)	The BC Ferries Corp. provided a copy of the TetraTech presentation for their proposed dike design. The proposed dike design aligns with the Dike Master Plan optional alignment for a setback sheetpile wall (interim option). The proposed dike design provided is for a dike with portions that have over-steepened side slopes and a 4 m wide crest. This should be considered an interim option, with the ultimate goal the raising of the entire site to create a superdike as redevelopment occurs.

Two public open houses were held for Phase 3 and 5 jointly, including one event at the City Centre Community Centre on January 15, and another event at City Hall on January 23. In addition, City staff participated at a Smart Cities event with the public consultation materials on January 17. A total of 75 people attended the open houses. Draft reports and information poster boards were also available online at LetsTalkRichmond.ca with 518 visits to the site during the consultation window (January 14 to February 2). A survey to seek feedback was provided at open houses and online, and a total of 92 responses were received. Feedback from public consultation is summarized in Table 3-9 and Infographic 3-1.

Table 3-9: Summary of Public Consultation Feedback

Topic	Summary of Comments
Proactive Planning / Flood Protection	Many comments appreciating the proactive approach for dike planning, the robust concepts, and the long-reaching strategies. Several comments relating to expediting the dike raising process in anticipation of accelerated sea level rise. A couple questions received on earthquake effects, the application of a secondary inland diking system, and the role of internal drainage related to flood protection. Over 80% of participants rank perimeter dike upgrading as being either very important or extremely important.
Dike Aesthetics / Recreational Use	Many comments received noting the importance of maintaining pedestrian-friendly, multi-use trails. Suggestions relating to recreational use include paved pathways, distance markers, additional lighting, benches, and establishing a continuous perimeter trail. Two commenters like the opportunity to upgrade infrastructure and trails in the Hamilton area. One comment about improving trails around Crown Packaging.
Development / Property Value	Several commenters like the Plans with respect to protection of properties and future developments. A commenter suggested research into riverside expansion of the dike. One commenter suggested residential construction standards. One commenter does not support superdikes (development on the dike).
Thoroughness/Consultation	Several comments appreciating the thoroughness of the report; the phasing methodology and clear concepts made the Plan easy to understand. One suggestion to further consult utility stakeholders who may cross the dike.
Priority Areas / Safety	Many commenters like that the City is taking action with regards to community safety. Single commenters noted priority areas which include: Phase 3, Steveston, Terra Nova. A single comment on the west dike as a priority location and for barrier islands to be built. A single comment questioning how Britannia will be protected and concern for houses along Dyke Road.
Environment / Habitat	A few comments and questions on the importance of maintaining habitat and the environment. One comment on using free fill material for the dike rather than other forms of disposal. One commenter is concerned about removal of shrubs, trees, logs, and habitat along the dike.
Climate Change / Sea Level Rise	Several questions were received relating to level of protection, climate change, and sea level rise science. A couple of comments suggested that raising the dikes are premature and that sea level rise may not happen.

Topic	Summary of Comments
Cost	Several questions on cost to taxpayers and Provincial/Federal involvement in paying for flood protection upgrades. One question relating to evaluating the cost of managed retreats from certain areas.
General	One comment on providing more information on social media. One question about elevation of areas adjacent to dikes. One commenter requesting additional signage in project areas.



Infographic 3-1: Summary of Pubic Responses

It is expected that there will be opportunity for more engagement with stakeholders during detailed design of dike upgrades.

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 extending the dike footprint further toward, or into, 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, it is recommended that their hydraulic function and habitat value be compensated by other means. This may include storm sewers, channels relocated inland, and separate habitat offsetting 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 3-10: 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) *Site specific interim options:* • Option 4: Road dike (London Farm)
2 – Crown Packaging (13911 Garden City Road)	• 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, BC Ferries Fleet Maintenance Unit (12800 Rice Mill Road)	• 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 – Canadian Fishing Company (13140 Rice Mill Road)	• Option 2: Riverbank dike *Site specific interim options:* • Option 5: Setback sheetpile wall • Combined with site grading and Option 2

Reach # and Name	Recommended Options
8 – Fraser Lands Fraser Wharves	• Option 2: Riverbank dike
9 – Fraser Lands Riverport Way	• Option 2: Riverbank dike
10 – Fraser Lands Port of Vancouver	• Option 2: Riverbank dike
11 – Fraser Lands Lafarge Canada Inc. (7611 No 9 Road)	• 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. In the case of the drainage channel south of London Farm, the change to the dike footprint would be discussed with the Museum and Heritage Services during detailed design to preserve character-defining elements of the site.

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 of drainage channel aquatic habitat, and 48,500 m^2 of 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 estimated area of overlap of proposed dike improvements with the City's ESA's is 2,000 m^2 of Freshwater Wetland ESA, 44,200 m^2 of intertidal ESA, 300 m^2 of Old Field and Shrublands ESA, 188,700 m^2 of Shoreline ESA and 5,700 m^2 of Upland Forest ESA. ESAs often overlap with high quality habitat (i.e. high quality Fraser River intertidal, high quality Fraser River riparian) but they can also include modified habitat (i.e. dikes), low quality habitat (e.g. areas infested with invasive plant species) and developed areas (e.g. buildings and roads) which do not provide habitat value. If ESAs are to be disturbed due to dike upgrades, mitigation and compensation may be required. In order to properly assess the environment values that may be disturbed by dike improvements in ESAs and thus the amount of compensation that is required, detailed site-specific assessments are recommended.

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 3-11: Reach-by-Reach Summary of Potential Habitat Impacts and ESA Overlap

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)	Overlap with ESA Types (m)
1 – Gilmore West	9,900	-	4,400	21,100	Intertidal:7,500 Shoreline: 7,800
2 – Crown Packaging (13911 Garden City Road)	600	-	-	-	Intertidal: 700 Shoreline: 6,300

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)	Overlap with ESA Types (m)
3 – Gilmore East	6,700	2,400	3,100	14,200	Freshwater Wetland: 300 Intertidal: 8,100 Shoreline: 21,000
4 – Shellmont West	-	200	1,200	4,400	Freshwater Wetland: 1,700 Intertidal: 700 Old Fields and Shrublands: 300 Shoreline: 19,300
5 – Shellmont Deas Dock, BC Ferries Fleet Maintenance Unit (12800 Rice Mill Road0	1,100	-	< 100	< 100	Intertidal: 11,200 Shoreline: 18,200
6 – Highway 99	-	200	-	-	Intertidal: 1,500 Shoreline: 6,900
7 – Fraser Lands – Canadian Fishing Company (13140 Rice Mill Road)	-	-	-	-	Intertidal: 1,700 Shoreline:7,900
8 – Fraser Lands Fraser Wharves	200	100	-	-	Intertidal: 300 Shoreline: 10,600
9 – Fraser Lands Riverport Way	100	100	-	-	Intertidal: 1;200 Shoreline: 7,500
10 – Fraser Lands Port of Vancouver	700	17,000	1,300	900	Intertidal: 5,300 Shoreline: 45,100 Upland Forest: 5,500
11 – Fraser Lands Lafarge Canada Inc. (7611 No 9 Road)	-	900	-	-	Intertidal: 300 Shoreline: 11,500
12 – East Richmond	-	2,500	3,200	5,500	Intertidal: 4,800 Shoreline: 25,300 Upland Forest: <100
13/14– Hamilton/Boundary	100	4,200	1,100	2,400	Intertidal: 900 Shoreline: 200 Upland Forest: 100

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 BC Seismic Design Guidelines for Dikes based on numerical deformation analysis, without ground improvement or alternative approaches.
- 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 are provided below.

- **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. several hundred metres) 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. The minimum distance for each fill area should be based on a geotechnical evaluation of the setback required for the superdike to retain its hydraulic integrity under seismic design performance criteria (seismic stability and flowslide). Raising the land 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 in some waterfront areas. Buildings in this zone should be built above the dike crest elevation and have densified foundations capable of withstanding liquefaction.
- **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, as is considered in the pending update to the Flood Protection Management Strategy.

Considerations to manage the seismic risk are provided below.

- Consider alternative seismic performance criteria as considered in the pending Flood Protection Management Strategy. Review the criteria if/when the Province issues updated guidelines for seismic performance of dikes.
- Fill a wide swath of land (several hundred metres) inland of the dike to the design 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 update 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. The cost estimate for the recommended option includes construction from existing condition to recommended option, without considering any potential interim works. Cost estimates for interim works are provided, and it is expected that there would be some cost saving associated with upgrading the interim dike to the long-term option, which are not accounted for. 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 5. Table 3-13 presents a summary of the potential interim measures. Some cost savings may be expected in situations where the interim option is constructed initially and the recommended option is constructed at a later date, as an upgrade to the interim option. The cost opinion does not account for these savings. The cost opinion for the recommended option includes construction from existing condition to recommended option, without considering any potential interim works.

Table 3-12: 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	$9.0 Million		$4.9 Million	$3.9 Million		$0.7 Million						$3.9 Million	$6.6 Million	$28.9 Million
Raise Road to Dike Height	$12.2 Million		$6.6 Million	$5.3 Million								$5.3 Million	$9.0 Million	$38.4 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	$0.1 Million	$1.5 Million	$2.9 Million	$2.9 Million	$10.2 Million	$4.4 Million	$3.5 Million	$0.5 Million	$41.5 Million
Contingency (40%)	**$15.1 Million**	**$1.0 Million**	**$9.0 Million**	**$6.1 Million**	**$5.7 Million**	**$0.8 Million**	**$1.5 Million**	**$3.3 Million**	**$3.0 Million**	**$10.5 Million**	**$4.6 Million**	**$8.5 Million**	**$10.0 Million**	**$79.0 Million**
Total	**$53.0 Million**	**$3.6 Million**	**$31.5 Million**	**$21.3 Million**	**$20.0 Million**	**$2.7 Million**	**$5.2 Million**	**$11.5 Million**	**$10.5 Million**	**$36.6 Million**	**$16.1 Million**	**$29.7 Million**	**$35.0 Million**	**$276.6 Million**

Table 3-13: 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			$7.0 Million	$6.6 Million	$20.5 Million
Raise Road to Dike Height							
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	$12.0 Million
Contingency (40%)	**$1.2 Million**	**$6.8 Million**	**$4.0 Million**	**$1.2 Million**	**$7.1 Million**	**$7.0 Million**	**$27.3 Million**
Total	**$4.3 Million**	**$23.9 Million**	**$13.9 Million**	**$4.2 Million**	**$24.8 Million**	**$24.5 Million**	**$95.6 Million**

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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.
- Seismic performance measures are not included. Raising land inside the dike is likely a preferred strategy to deal with liquefaction. If the road and land behind the dike is not raised, then densification may be appropriate. Current techniques such as stone columns would cost approximately $9,000 to $18,000 per metre of dike.
- Habitat enhancement and 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 (13911 Garden City Road)	66+500 to 66+150 (350m)	• Low section. Interim measures planned.
3	7 – Fraser Lands – Canadian Fishing Company (13140 Rice 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, BC Ferries Fleet Maintenance Unit (12800 Rice Mill Road)	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 Canada Inc. (7611 No 9 Road)	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.

Priority	Reach # and Name	Extent / Length	Major Features
12	10 – Fraser Lands Port of 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 scheduled for construction in 2019 (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

Intertidal and Shoreline ESAs present in the reach

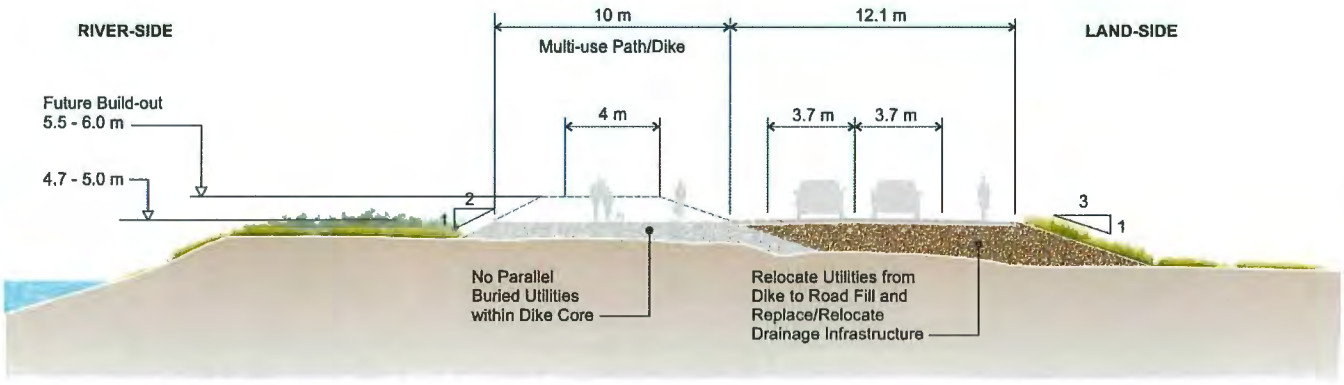
Land side is bordered by a drainage channel that is fish bearing with amphibian habitat.

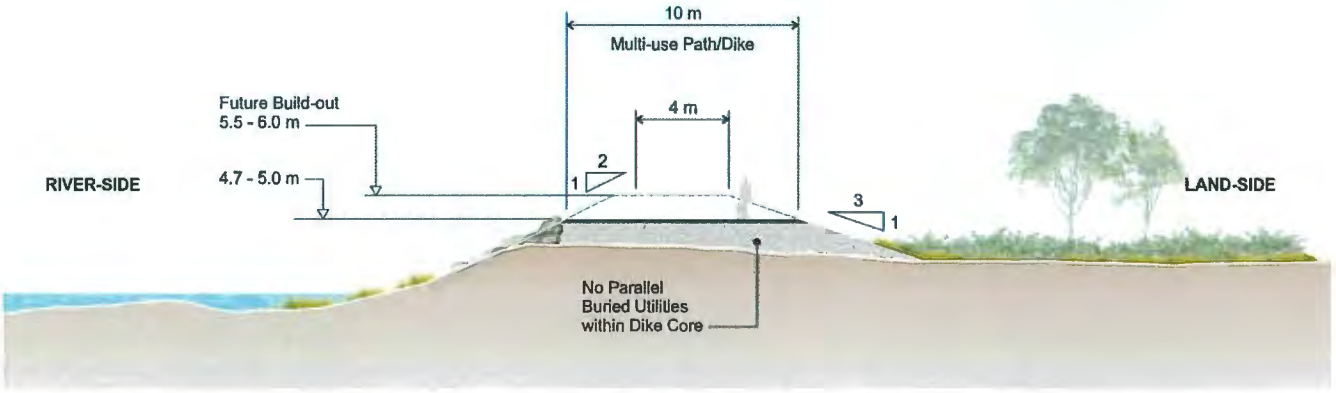
Moderate quality deciduous woodland, tall shrub woodland, and meadow present on inland bank of the drainage channel.

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

Long term

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 perimeter trail concept (Appendix B)

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

Mitigation and compensation for disturbance to ESAs may be required

*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
Dike Raising	$12.5 Million
Road Structure and Utilities	$9.0 Million
Raise Road to Dike Height	$12.2 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.4 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 (13911 Garden City Road)

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

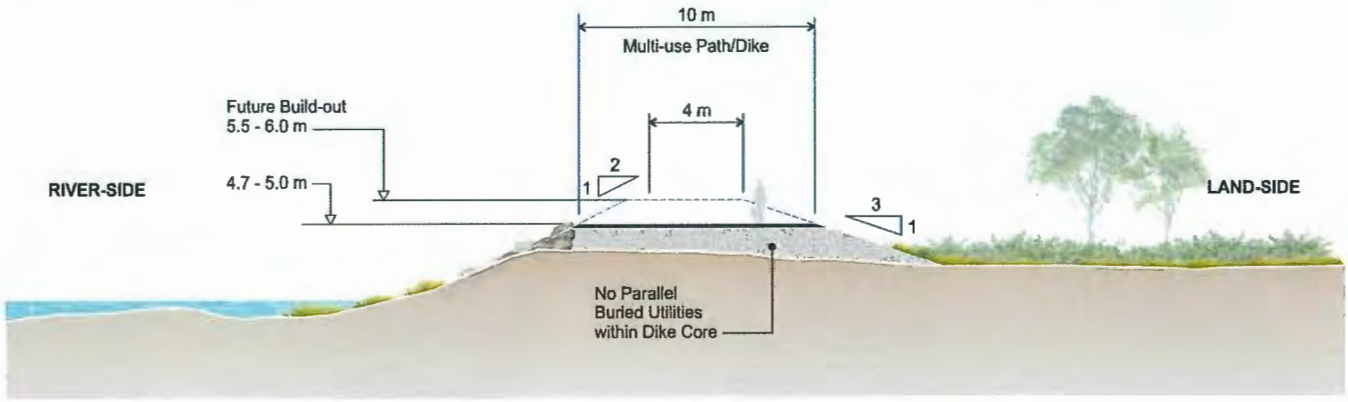
Intertidal and Shoreline ESAs present in the reach

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 (13911 Garden City 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 (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 *

Mitigation and compensation for disturbance to ESAs may be required

*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 (13911 Garden City Road) - 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
Dike Raising	$1.6 Million
Other*	$1.0 Million
Contingency (40%)	**$1.0 Million**
Total	**$3.6 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

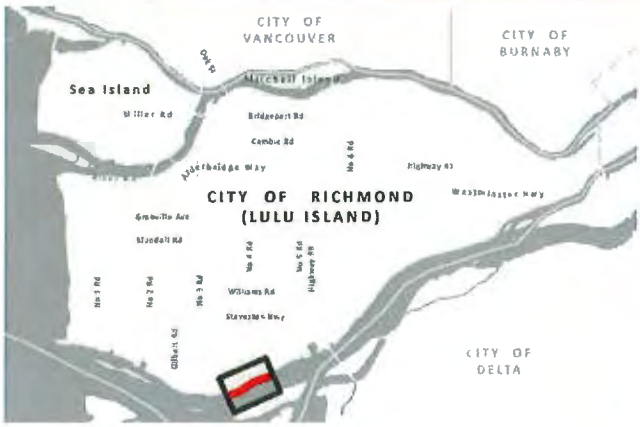
Interim

Item	Cost
Dike Raising	$1.6 Million
Other*	$1.5 Million
Contingency (40%)	**$1.2 Million**
Total	**$4.3 Million**

*Other – Pathways, Utilities, Sheetpile walls

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 Finn Slough residences. 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 residences sits on the river side of the dike. The homes consists of houses 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 residences

Environmental

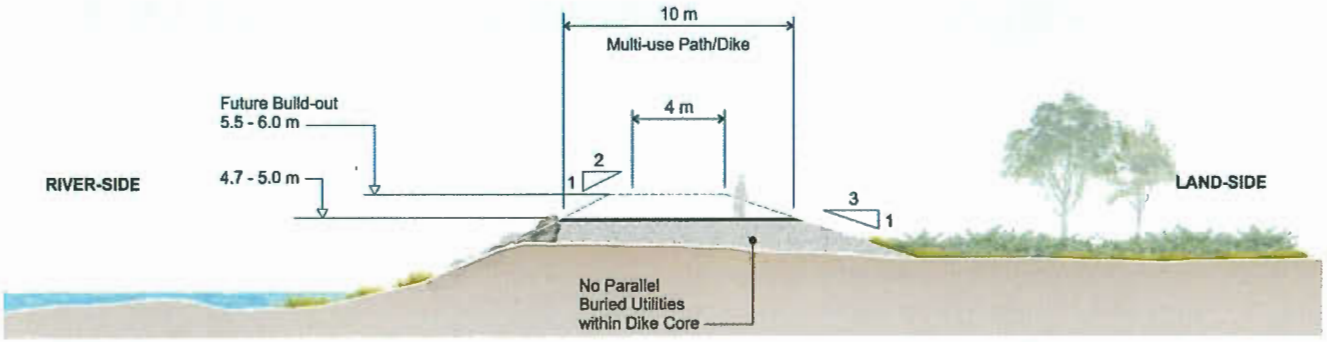
Freshwater Wetland, Intertidal and Shoreline ESAs present in the reach

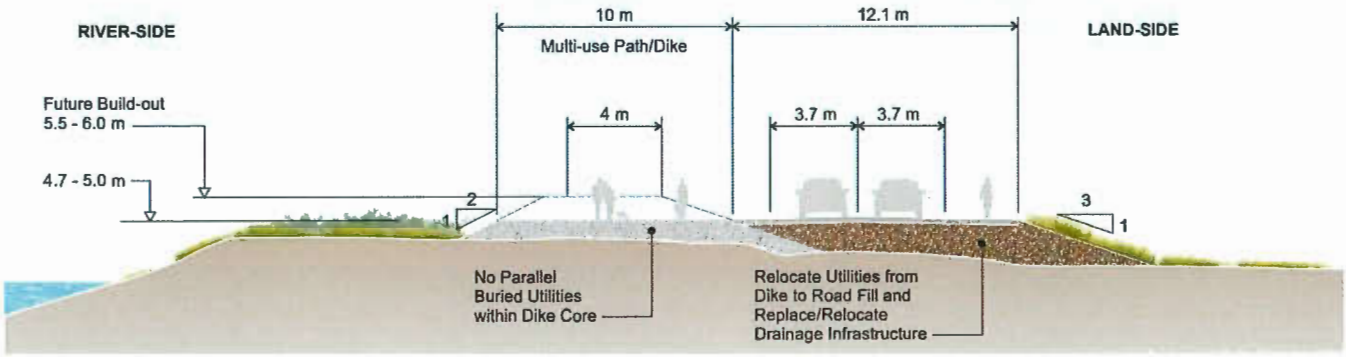
Land-side is bordered by a drainage channel that is potential amphibian breeding habitat. Fish species presence not recorded.

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

Short term phasing:

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

Long term

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

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per perimeter trail concept (Appendix B)

Finn Slough habitat 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

Mitigation and compensation for disturbance to ESAs may be required

*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
Dike Raising	$7.9 Million
Road Structure and Utilities	$4.9Million
Raise Road to Dike Height	$6.6 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.3 Million
Other*	$2.9 Million
Contingency (40%)	**$9.0 Million**
Total	**$31.5 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Interim

Item	Cost
Dike Raising	$9.5 Million
Road Structure and Utilities	$6.8 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.3 Million
Other*	$0.5 Million
Contingency (40%)	**$6.8 Million**
Total	**$23.9 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

Freshwater Wetland, Intertidal, Old Field and Shrubland and Shoreline ESAs present in the reach

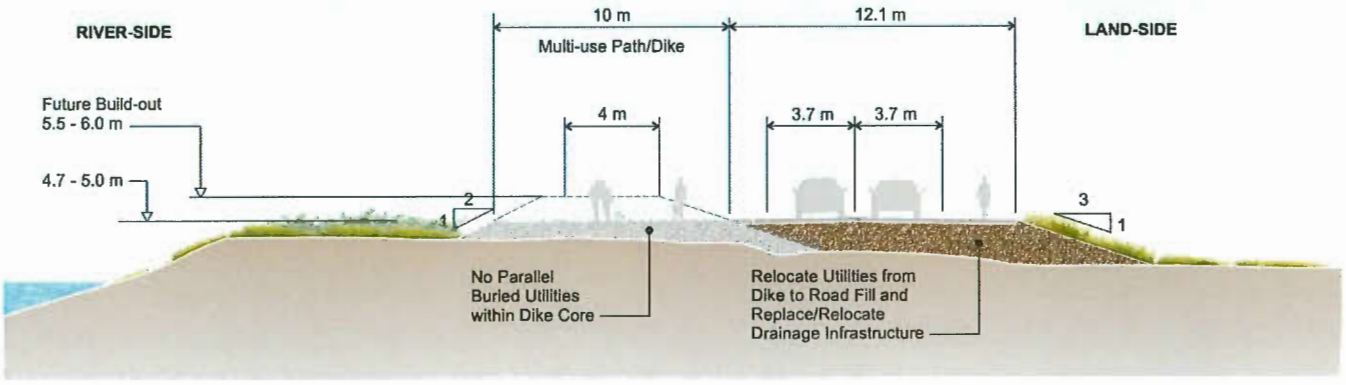
Land-side habitat includes:

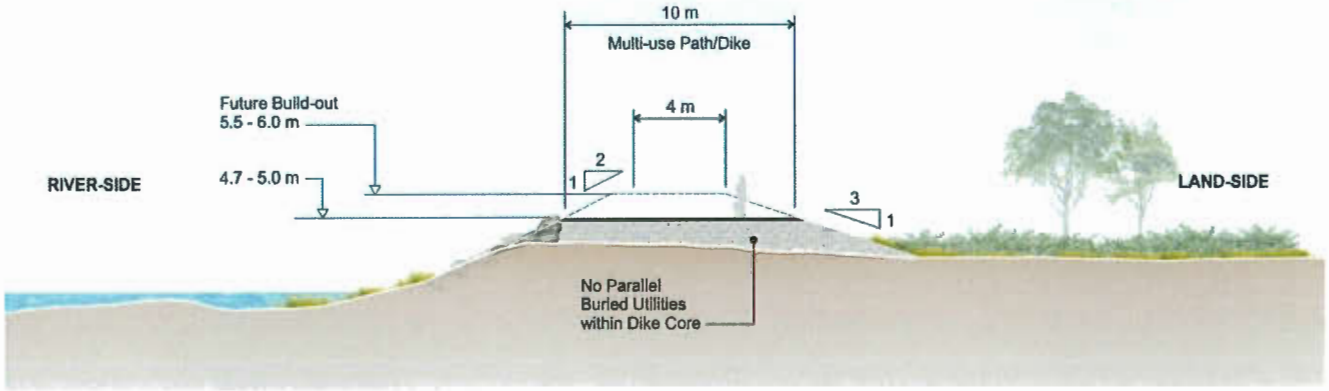
- low quality habitat (walking path and lawn) at east and west end of reach
- drainage channel adjacent to middle of reach (Threespine stickleback, amphibian habitat)

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

Long term

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 perimeter trail concept (Appendix B)

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

Mitigation and compensation for disturbance to ESAs may be required

* 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
Dike Raising	$4.5 Million
Road Structure and Utilities	$3.9 Million
Raise Road to Dike Height	$5.3 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.4 Million
Other*	$1.2 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, BC Ferries Fleet Maintenance Unit (12800 Rice Mill Road)

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

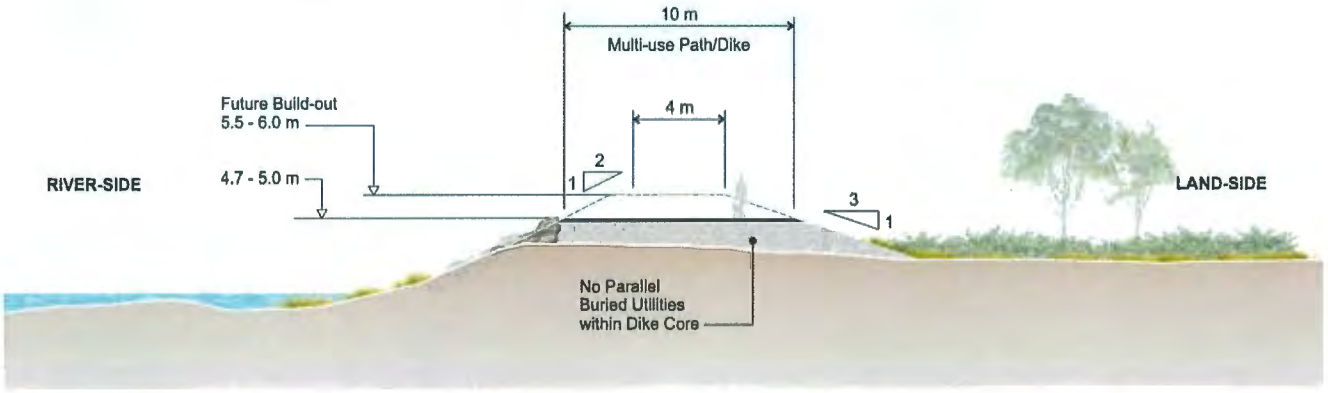
Intertidal and Shoreline ESAs present in the reach

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, BC Ferries Fleet Maintenance Unity (12800 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

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

Long term

- create a superdike and raise the property during redevelopment

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*

Mitigation and compensation for disturbance to ESAs may be required

* 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, BC Ferries Fleet Maintenance Unit (12800 Rice Mill Road) - 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
Dike Raising	$7.2 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.3 Million
Other*	$6.8 Million
Contingency (40%)	**$5.7 Million**
Total	**$20.0 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

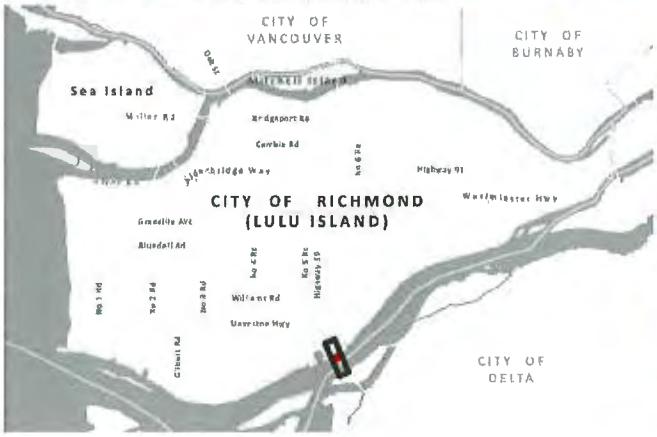
Interim

Item	Cost
Dike Raising	$2.9 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.3 Million
Other*	$6.8 Million
Contingency (40%)	**$4.0 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 (Highway 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

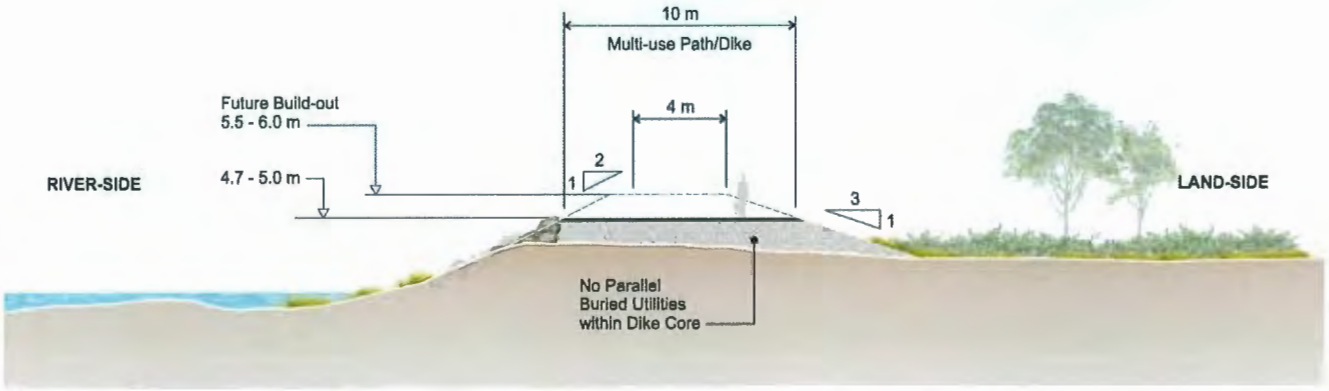
Environmental

Intertidal and Shoreline ESAs present in the reach

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

Long term

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 perimeter trail concept (Appendix B)

Environmental

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

Mitigation and compensation for disturbance to ESAs may be required

* 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

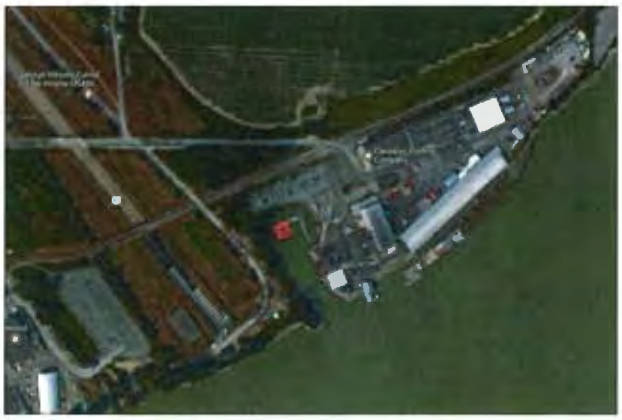
Costs below are for 250 m of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$1.1 Million
Road Structure and Utilities	$2,600	$0.7 Million
Driveways, Ramps or Road Intersection Reconstruction		$0.1 Million
Other*	$300	$0.1 Million
Contingency (40%)		**$0.8 Million**
Total		**$2.7 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 7: Fraser Lands Canadian Fishing Company (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

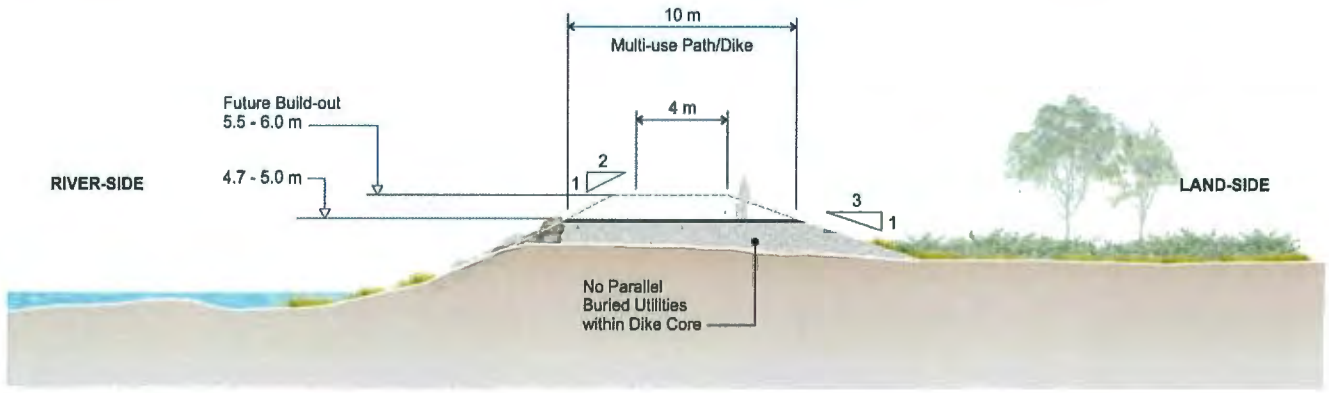
Social

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

Environmental

Intertidal and Shoreline ESAs present in the reach
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 Canadian Fishing Company (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

Long term

- create a superdike and raise the property during redevelopment

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per perimeter trail concept (Appendix B)

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

Mitigation and compensation for disturbance to ESAs may be required

Reach 7: Fraser Lands Canadian Fishing Company (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
Dike Raising	$2.3 Million
Other*	$1.5 Million
Contingency (40%)	**$1.5 Million**
Total	**$5.2 Million**

*Other – Pathways, Utilties, Furnishings & Bollards

Interim

Item	Cost
Dike Raising	$0.9 Million
Other*	$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

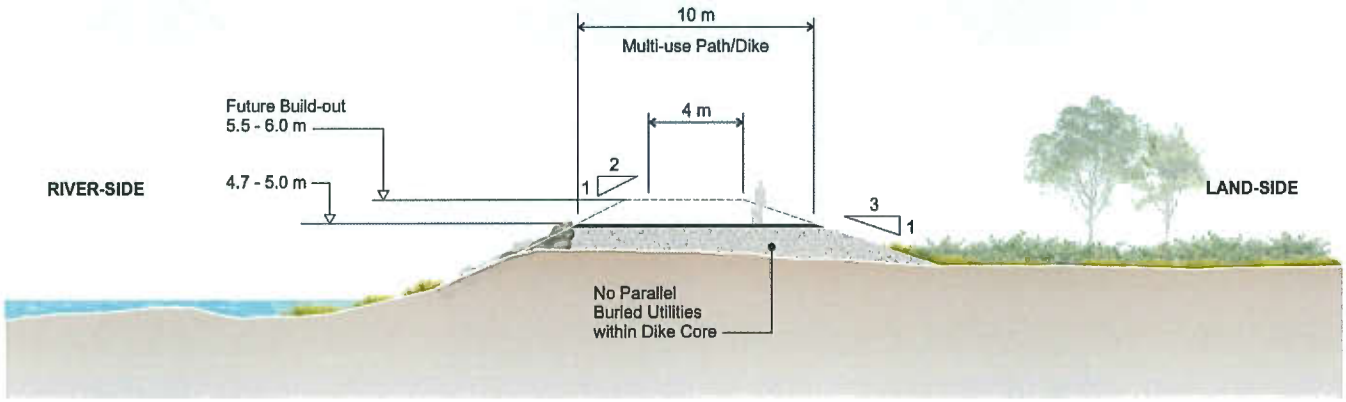
Intertidal and Shoreline ESAs present in the reach

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

Long term

Coordinate improvements with Port Metro Vancouver

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

Raise the property during redevelopment to create a "superdike"

Construct a riverside dike that function with current and planned operations

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per perimeter trail concept (Appendix B)

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*

Mitigation and compensation for disturbance to ESAs may be required

*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

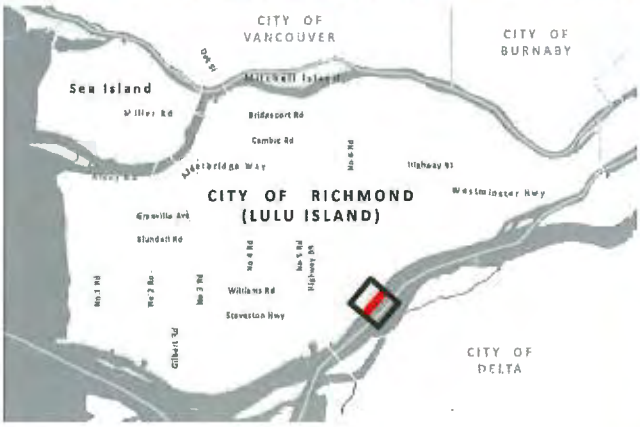
Costs below are for 1000 m of dike similar to cross-section above.

Item	Cost
Dike Raising	$4.5 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.8 Million
Other*	$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

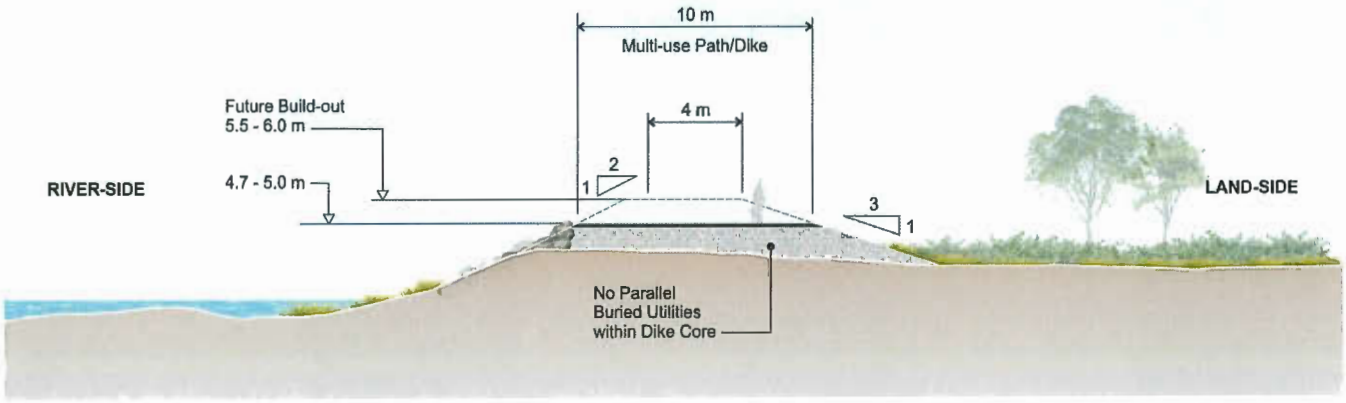
Intertidal and Shoreline ESAs present in the reach

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

Long term

No existing infrastructure within the dike

Construct a riverside dike

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per perimeter trail concept (Appendix B)

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 *

Mitigation and compensation for disturbance to ESAs may be required

* 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
Dike Raising	$4.5 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.1 Million
Other*	$2.9 Million
Contingency (40%)	**$3.0 Million**
Total	**$10.5 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Cost opinions are in 2018 Canadian Dollars.

Reach 10: Fraser Lands Port of Vancouver

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

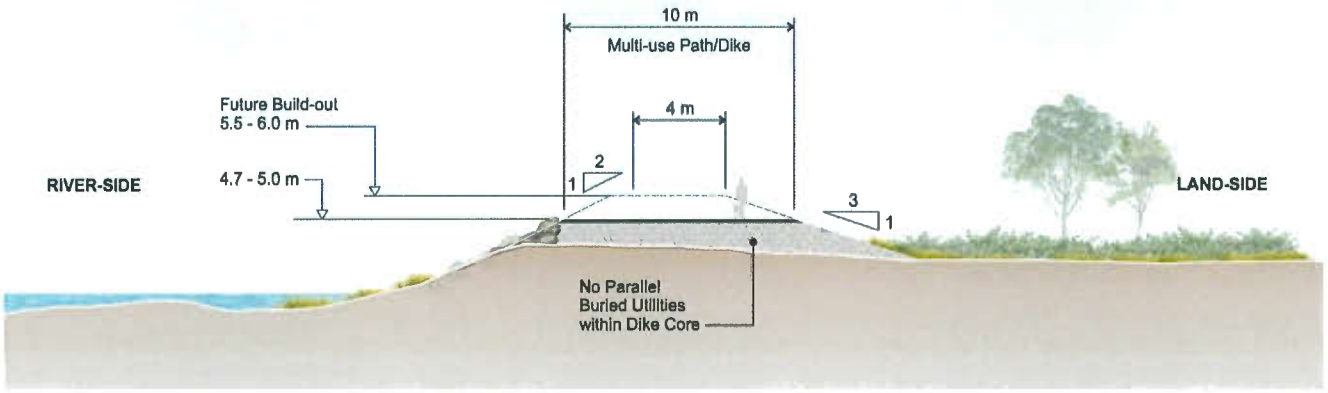
Intertidal, Shoreline, and Upland Forest ESAs present in the reach

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 Port of Vancouver - 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

Long term

Most of the Port of 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 perimeter trail concept (Appendix B)

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

Mitigation and compensation for disturbance to ESAs may be required

*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
Dike Raising	$15.8 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.2 Million
Other*	$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 Canada Inc. (7611 No 9 Road)

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

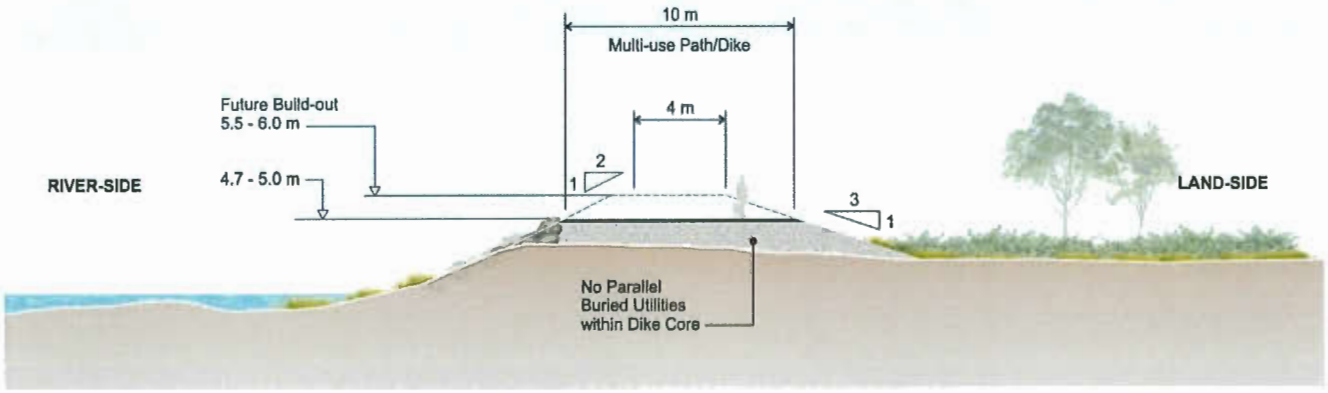
Intertidal and Shoreline ESAs present in the reach

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 Canada Inc. (7611 No 9 Road) - 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

Long term

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 perimeter trail concept (Appendix B). 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

Mitigation and compensation for disturbance to ESAs may be required

* 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
Dike Raising	$6.8 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.4 Million
Other*	$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

Intertidal, Shoreline, and Upland Forest ESAs present in the reach

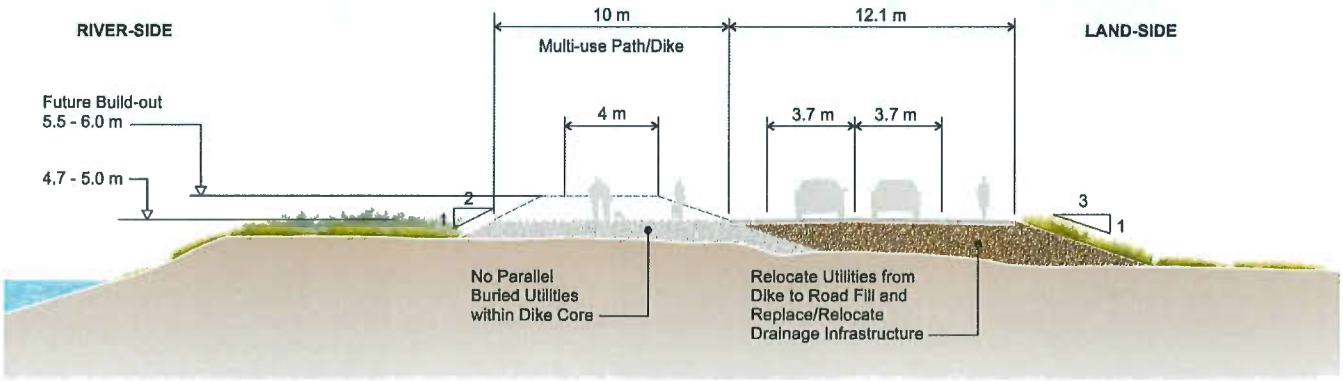
Land-side includes:

- 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

Short term phasing:

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

Long term

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

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per perimeter trail concept (Appendix B)

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

Mitigation and compensation for disturbance to ESAs may be required

* 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
Dike Raising	$8.1 Million
Road Structure & Utilities	$3.9 Million
Raise Road to Dike Height	$5.3 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.4 Million
Other*	$3.5 Million
Contingency (40%)	**$8.5 Million**
Total	**$29.7 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

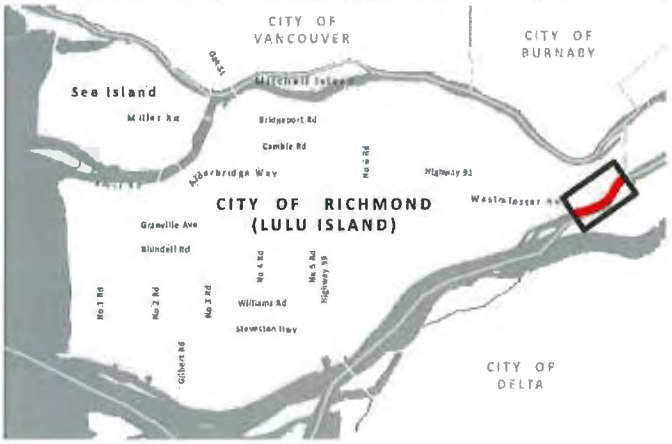
Interim

Item	Cost
Dike Raising	$9.7 Million
Road Structure & Utilities	$7.0 Million
Driveways, Ramps or Road Intersection Reconstruction	$0.4 Million
Other*	$0.5 Million
Contingency (40%)	**$7.1 Million**
Total	**$24.8 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

Intertidal, Shoreline, and Upland Forest ESAs present in the reach

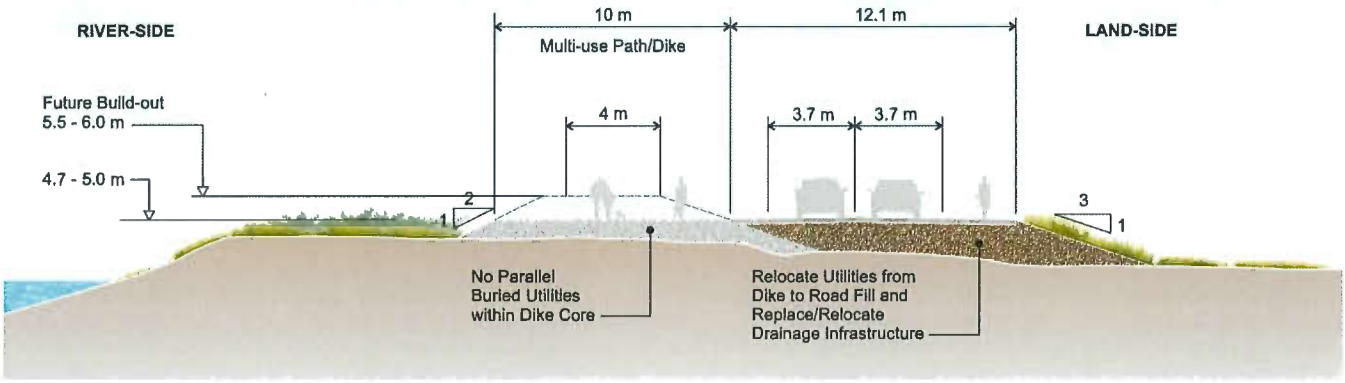
Land-side includes:

- 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

Short term phasing:

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

Long term

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

Social

Align with 2009 Waterfront Strategy

Construct multi-use path separate from road

Link to parks, trails, public amenities, and wayfinding, per perimeter trail concept (Appendix B)

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

Mitigation and compensation for disturbance to ESAs may be required

* 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
Dike Raising	$7.7 Million
Road Structure & Utilities	$6.6 Million
Raise Road to Dike Height	$9.0 Million
Driveways, Ramps or Road Intersection Reconstruction	$1.2 Million
Other*	$0.5 Million
Contingency (40%)	**$10.0 Million**
Total	**$35.0 Million**

*Other – Pathways, Utilities, Furnishings & Bollards

Interim

Item	Cost
Dike Raising	$9.2 Million
Road Structure & Utilities	$6.6 Million
Driveways, Ramps or Road Intersection Reconstruction	$1.2 Million
Other*	$0.5 Million
Contingency (40%)	**$7.0 Million**
Total	**$24.5 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 5.0 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, 13911 Garden City Road – 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, BC Ferries Fleet Maintenance Unit, 12800 Rice Mill Road – seek improvement opportunities with BC Ferries. Raise full site, else raise road behind the site.
    - Canadian Fishing Company, 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 of Vancouver Lands – Where rights exist, coordinate improvements with adjacent Port operations. There no rights exist, collaborate with Port to either acquire rights or develop agreement on responsibility to inspect, maintain, and improve dikes and shoreline protection.
    - Lafarge Canada Inc., 7611 No 9 Road – 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.
- Assess and modify drainage system infrastructure to maintain drainage services for lots before and after land raising.

- 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 (similar to the 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.

For all phases of the Dike Master Plan, the City should continue to research alternative densification strategies for seismic stability, consider alternative seismic performance criteria, and consider a plan to fill a wide swath of land (several hundred metres) inside the dike. The latter two points (seismic criteria and fill inside the dike) are considerations in the pending update to the Flood Protection Management Strategy.

Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

Feb. 21, 2019
S. J. LAWRIE
35409

Sarah Lawrie, P.Eng.
Project Engineer

Reviewed by:

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

Colin Kristiansen, MBA, P.Eng.
Project Manager

Patrick Lilley, M.Sc., R.P.Bio., BC-CESCL
Senior Biologist

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Revision History

Revision #	Date	Status	Revision	Author
0	February 21, 2019	FINAL	Issued to client as final	SJL

References

BC Ministry of Environment (MoE). 2013. Guidelines for Raptor Conservation During Urban and Rural Land Development in British Columbia (2013). Available: http://www.env.gov.bc.ca/wld/documents/bmp/raptor_conservation_guidelines_2013.pdf. Accessed Nov. 8, 2017.

City of Richmond. 2011. Official Community Plan (OCP) – Schedule 1 of Bylaw 9000. 2041 OCP – Moving Towards Sustainability. Richmond, BC. Available: https://www.richmond.ca/__shared/assets/OCP_9000_consolidation34181.pdf. Accessed on November 3, 2017.

City of Richmond. 2017. Riparian Management Area Info-23 Bulletin. Available: https://www.richmond.ca/__shared/assets/info_2332212.pdf. Accessed on November 8, 2017.

City of Richmond. 2018. Richmond Interactive Map. Available: https://maps.richmond.ca/rim/. Accessed, January, 9, 2018.

iMapBC. 2017. British Columbia iMapBC. Web application. Available: http://maps.gov.bc.ca/ess/sv/imapbc/. Accessed November 2, 2017.

Fraser River Estuary Management Program (FREMP). 2007. FREMP Habitat Inventory (2007 edition). Spatial Data. Available for viewing: http://cmnmaps.ca/FREMP/map.php?agree=0#. Accessed November 10, 2017.

FREMP. 2012. Colour Code Segments. Spatial Data. Available for viewing: http://cmnmaps.ca/FREMP/map.php?agree=0#. Accessed November 10, 2017.

HB Lanarc-Golder and Raincoast Applied Ecology. 2012. City of Richmond 2012 Environmentally Sensitive Area Management Strategy (BackGround Technical report for the 2041 OCP). Available: https://www.richmond.ca/__shared/assets/esamgmtstratbtr33976.pdf. Accessed on November 3, 2017.

Richmond Interactive Map (RIM). 2017. Richmond interactive map – Aerial Photos 2016. Available: http://map2.richmond.ca/Html5Viewer_2_0/Index.html?viewer=RIM. Accessed November 3, 2017.

KERR WOOD LEIDAL
consulting engineers

Appendix A

Plans and Sections for Richmond Dike Master Plan – Phase 3

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City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

- Parcel (from BC Data Catalogue Parcel Map BC)
- Easements
- Active ROW
- City Owned Lots
- Dike Footprint Encroachment onto Non-municipal Parcels

Water Network
- Water Service Lateral
- Watermain
- Alternate Node
- Blow Off
- Cap
- Hydrant
- PRV Chamber
- Valve
- Valve Chamber

Storm Network
- Storm Main
- Service Lateral
- Culvert
- Perimeter Drain
- Drainage Ditch
- Chamber
- Catch Basin
- Storm Manhole
- Headwall
- Rain Gauge
- Drainage Pump

Sanitary Network
- Service Lateral
- Forcemain
- Sanitary Main
- Trunk Sewer
- Alternate Node
- Cap
- Chamber
- Sanitary Manhole
- Sanitary Pump

- Fish Habitat Compensation Sites

Habitat Quality
- High Quality Intertidal Habitat
- High Quality Riparian Habitat

- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2016 Imagery Shown.

Potential Secondary Dike Alignment

FRASERWOOD WAY

BOUNDARY RD

HIGHWAY 91A

13

14

Current Sheet

Dike Reach

PWT - 166

Project No. 651.122
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 13 and 14

1

City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

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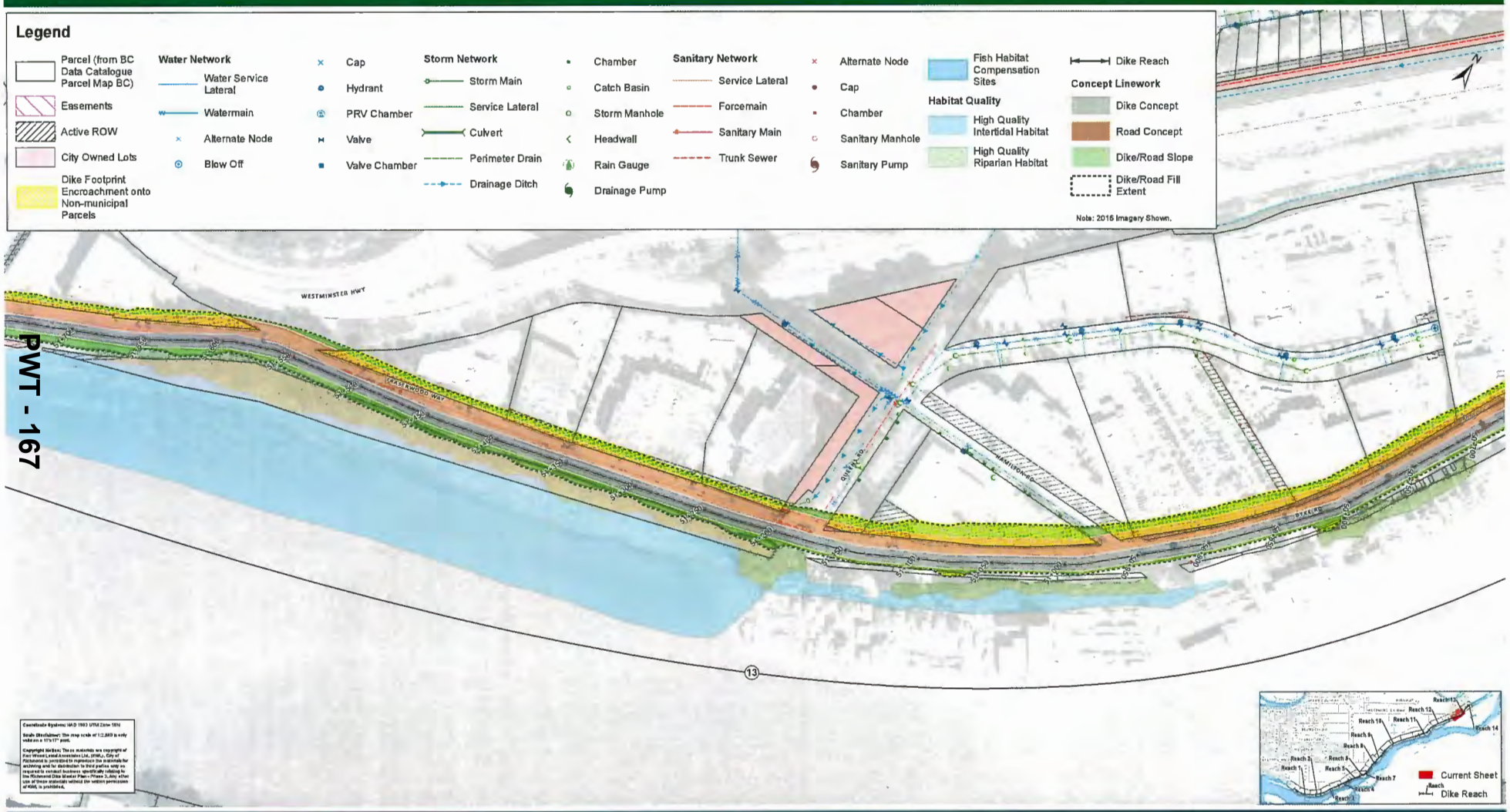

Coordinate System: NAD 1983 UTM Zone 10N

Scale (Disclaimer): The map scale of 1:2,500 is only valid on a 17"x11" print.

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Project No. 651.122
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 13

2

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City of Richmond

Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

- Parcel (from BC Data Catalogue Parcel Map BC)
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- Sanitary Pump

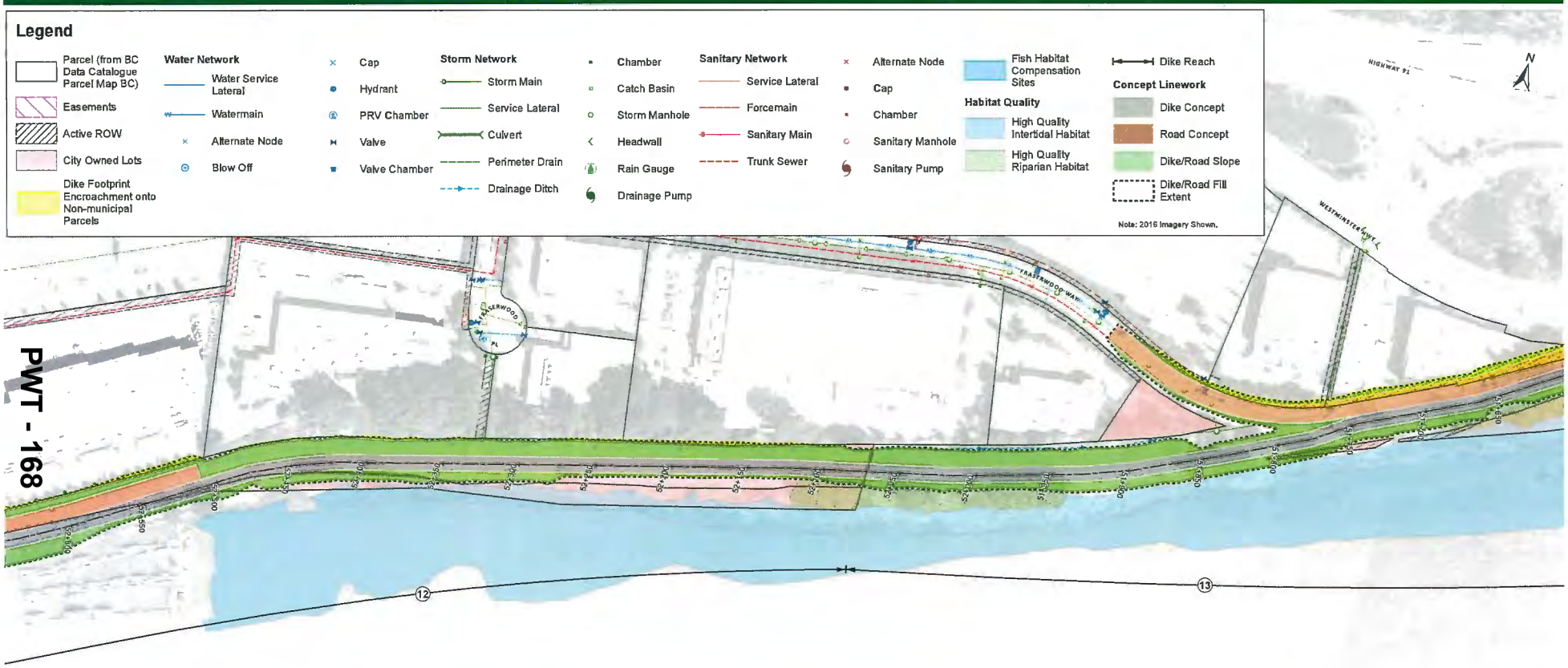
- Fish Habitat Compensation Sites

Habitat Quality
- High Quality Intertidal Habitat
- High Quality Riparian Habitat

- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2016 Imagery Shown.



PWT - 168

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:2,500 is only valid on a 11"x17" print.

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Project No. 651.122

Date February 2019

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Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment Reach 12 and13

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City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

- Parcel (from BC Data Catalogue Parcel Map BC)
- Easements
- Active ROW
- City Owned Lots
- Dike Footprint Encroachment onto Non-municipal Parcels

Water Network
- Water Service Lateral
- Watermain
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Sanitary Network
- Service Lateral
- Forcemain
- Sanitary Main
- Trunk Sewer
- Alternate Node
- Cap
- Chamber
- Sanitary Manhole
- Sanitary Pump

- Fish Habitat Compensation Sites

Habitat Quality
- High Quality Intertidal Habitat

- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2016 Imagery Shown.

PWT - 169

12

Current Sheet
Reach
Dike Reach

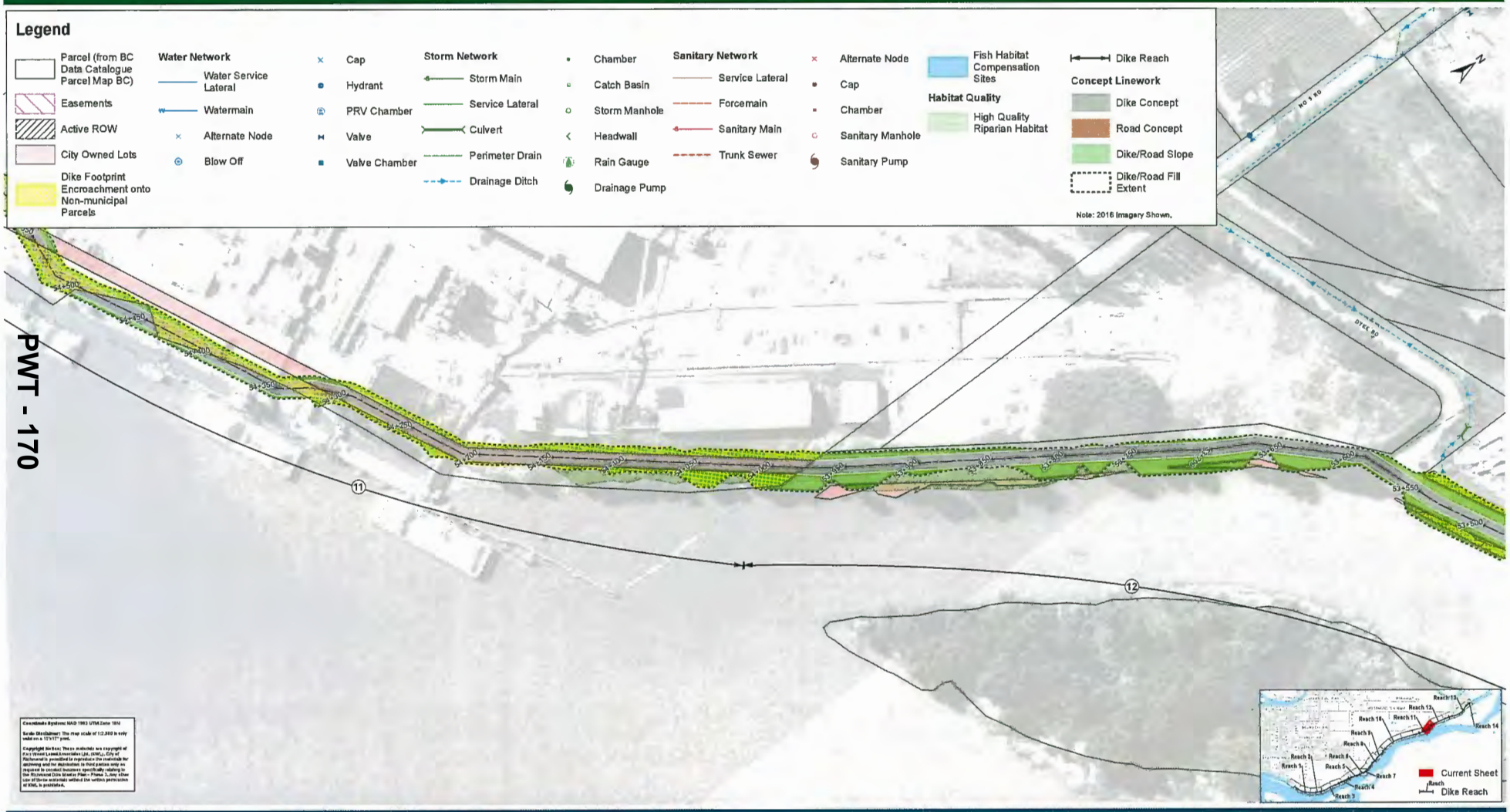
Project No. 651.122
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 12

City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



PWT - 170

Project No. 651.122
Date February 2019
Scale 1:2,500

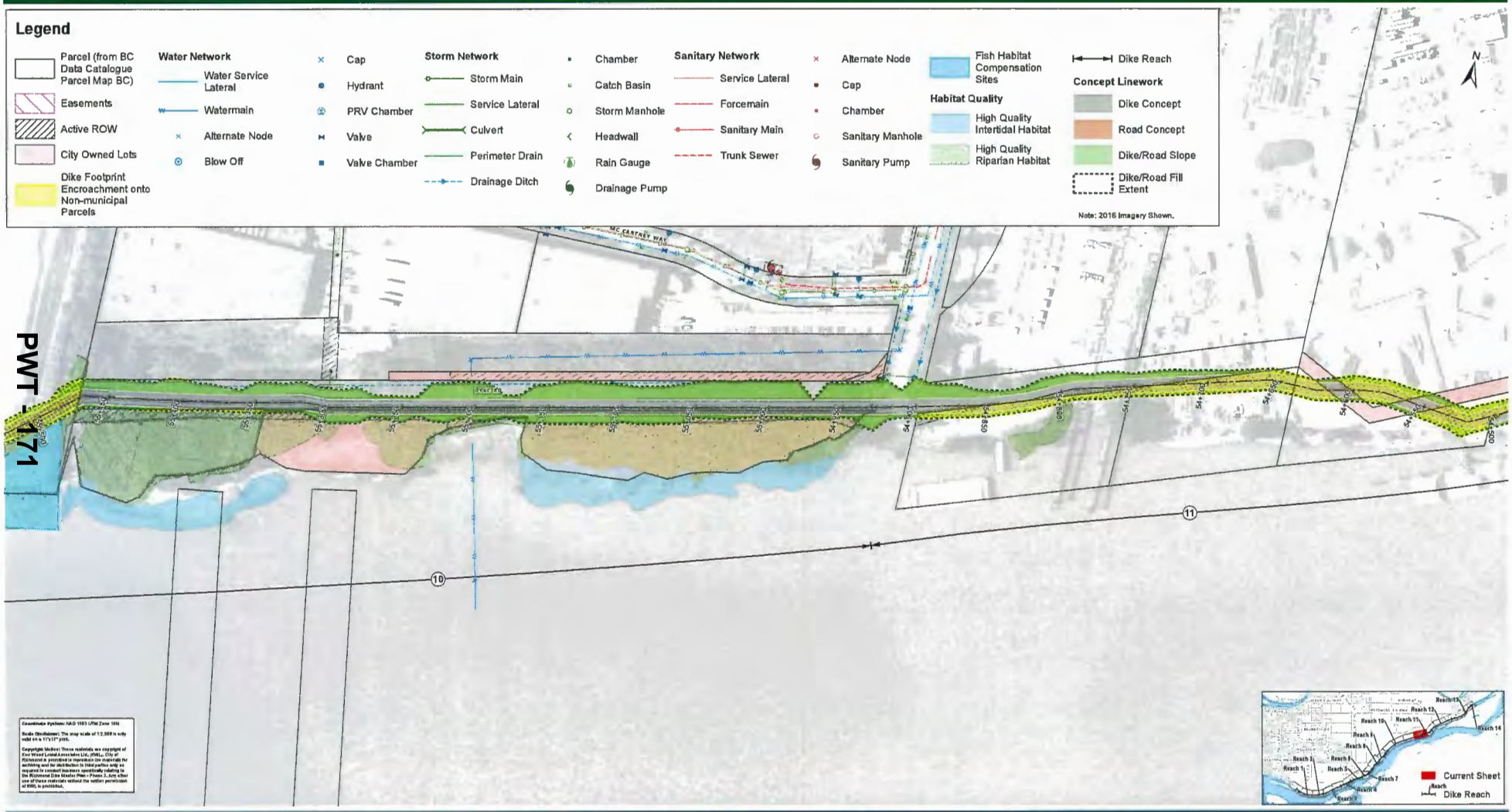
50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 11 and 12

Path: O:\0600-0699\651-122\430-GIS\MXD-Rp\Phase3\651122_Phase3_Appendix_Preferred_Road_Mapping.mxd Date Saved: 2/19/2019 2:27:52 PM | Author: jlau

City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



PWT - 171

Project No. 651.122
Date February 2019
Scale 1:2,500
50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 10 and 11

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City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

- Parcel (from BC Data Catalogue Parcel Map BC)
- Easements
- Active ROW
- City Owned Lots
- Dike Footprint Encroachment onto Non-municipal Parcels

Water Network
- Water Service Lateral
- Watermain
- Alternate Node
- Blow Off
- Cap
- Hydrant
- PRV Chamber
- Valve
- Valve Chamber

Storm Network
- Storm Main
- Service Lateral
- Culvert
- Perimeter Drain
- Drainage Ditch
- Chamber
- Catch Basin
- Storm Manhole
- Headwall
- Rain Gauge
- Drainage Pump

Sanitary Network
- Service Lateral
- Forcemain
- Sanitary Main
- Trunk Sewer
- Alternate Node
- Cap
- Chamber
- Sanitary Manhole
- Sanitary Pump

- Fish Habitat Compensation Sites

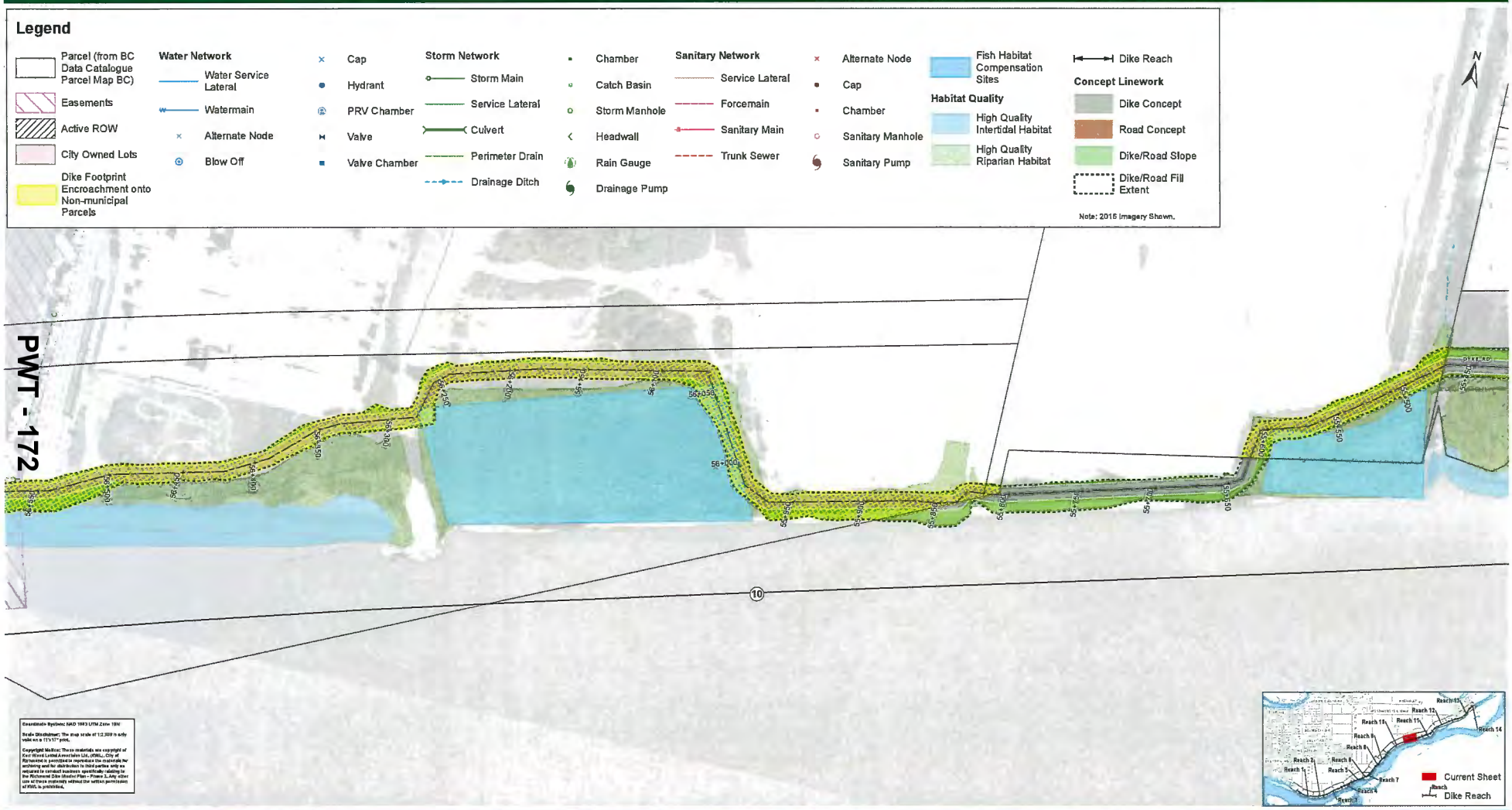
Habitat Quality
- High Quality Intertidal Habitat
- High Quality Riparian Habitat

- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2015 Imagery Shown.

PWT - 172



Coordinate System: NAD 1983 UTM Zone 10N

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Project No. 651.122
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 10

City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

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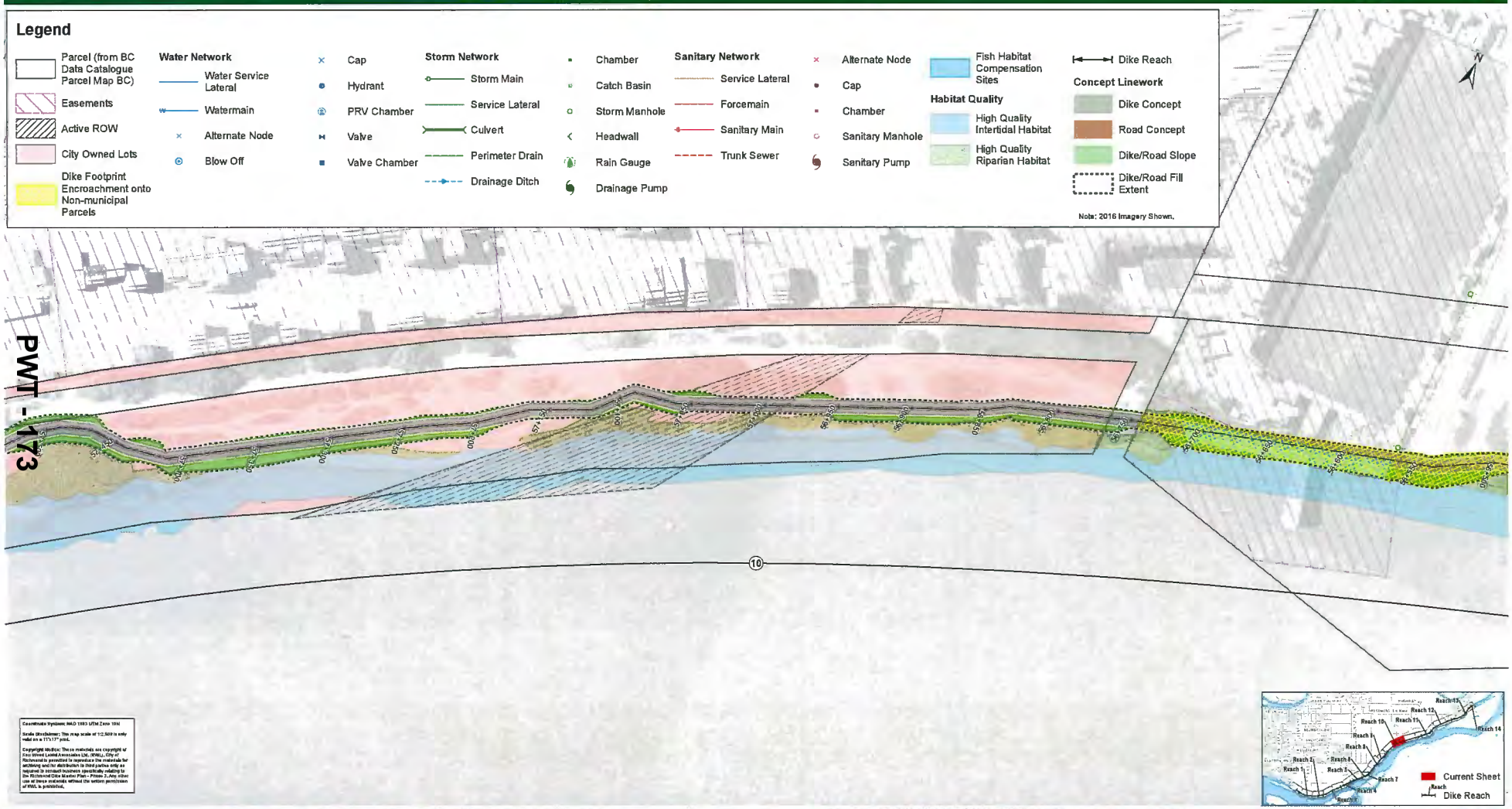
- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2016 Imagery Shown.

PWT - 173



Project No. 651.122
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 10

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City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

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- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2016 Imagery Shown.

PWT - 174

10

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 Reach 14

Current Sheet
Dike Reach

Project No. 651.122
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 10

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City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

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- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2016 Imagery Shown.

PWT - 175

RIVERPORT WAY

9

10

Coordinate System: NAD 1983 UTM Zone 10N

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Project No. 651.122
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 9

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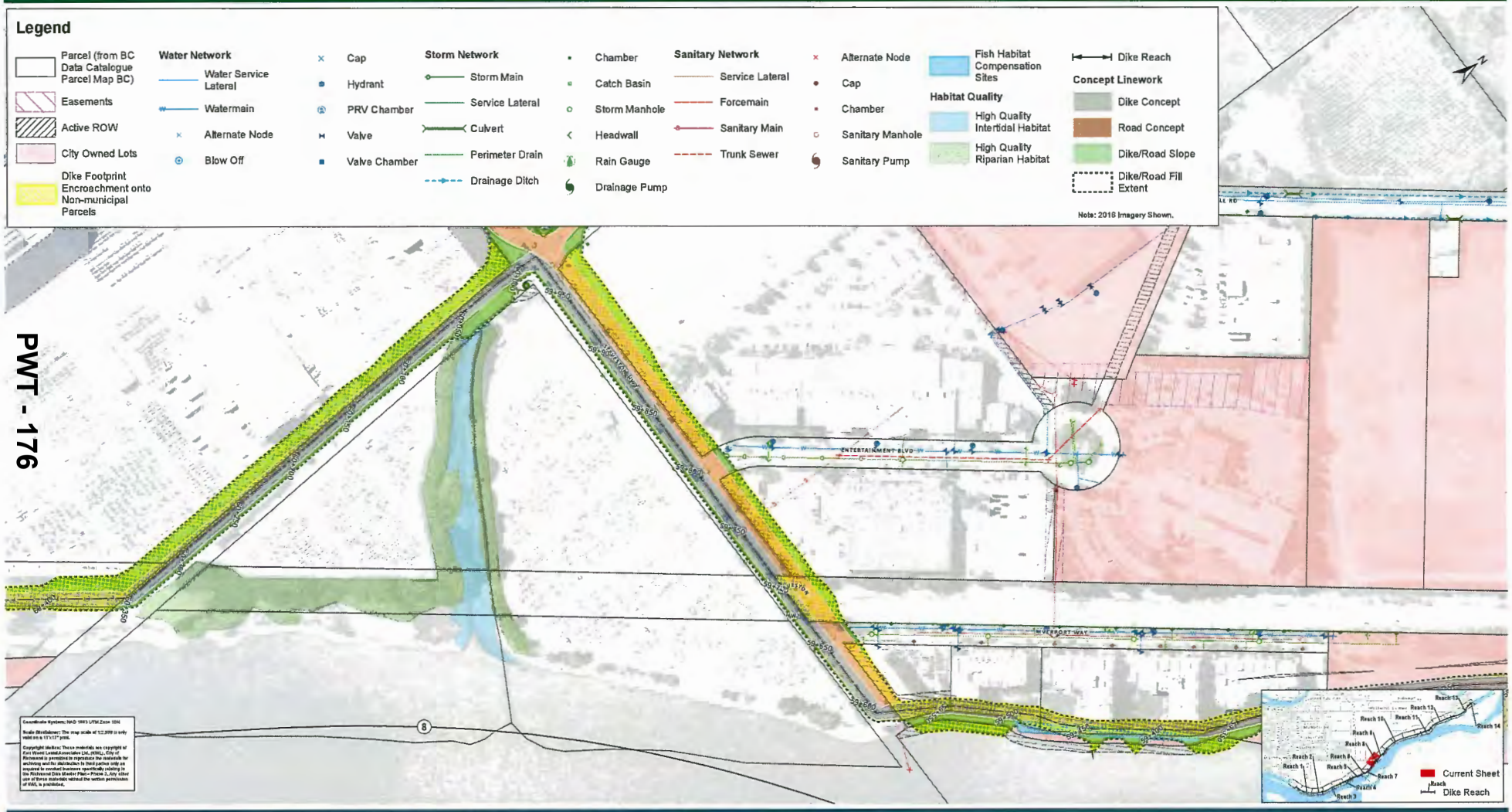
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



PWT - 176

Project No. 651.122
Date February 2019
Scale 1:2,500
50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 8

City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

- Parcel (from BC Data Catalogue Parcel Map BC)
- Easements
- Active ROW
- City Owned Lots
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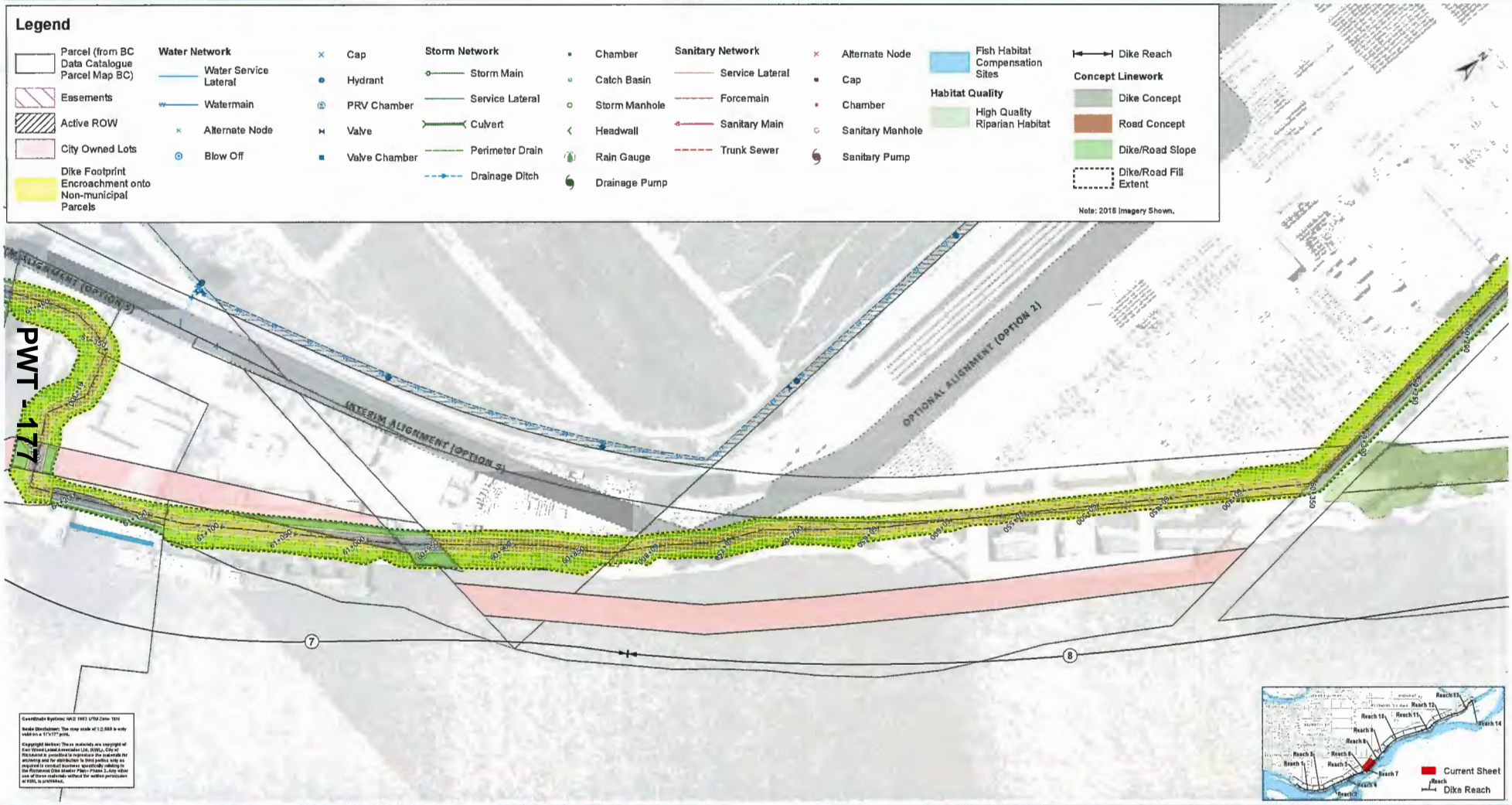
- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2015 Imagery Shown.



PWT - 177

Project No. 651.122
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 7 and 8

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City of Richmond

Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

- Parcel (from BC Data Catalogue Parcel Map BC)
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- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2016 Imagery Shown.

PWT - 178

INTERIM ALIGNMENT (OPTION 5)

INTERIM ALIGNMENT (OPTION 5)

Coordinate System: NAD 1983 UTM Zone 10N

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Reach 1 Reach 2 Reach 3 Reach 4 Reach 5 Reach 6 Reach 7 Reach 8 Reach 8A Reach 9 Reach 10 Reach 11 Reach 12 Reach 13 Reach 14

Current Sheet

Dike Reach

Project No. 651.122

Date February 2019

Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 5, 6 and 7

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City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

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Concept Linework
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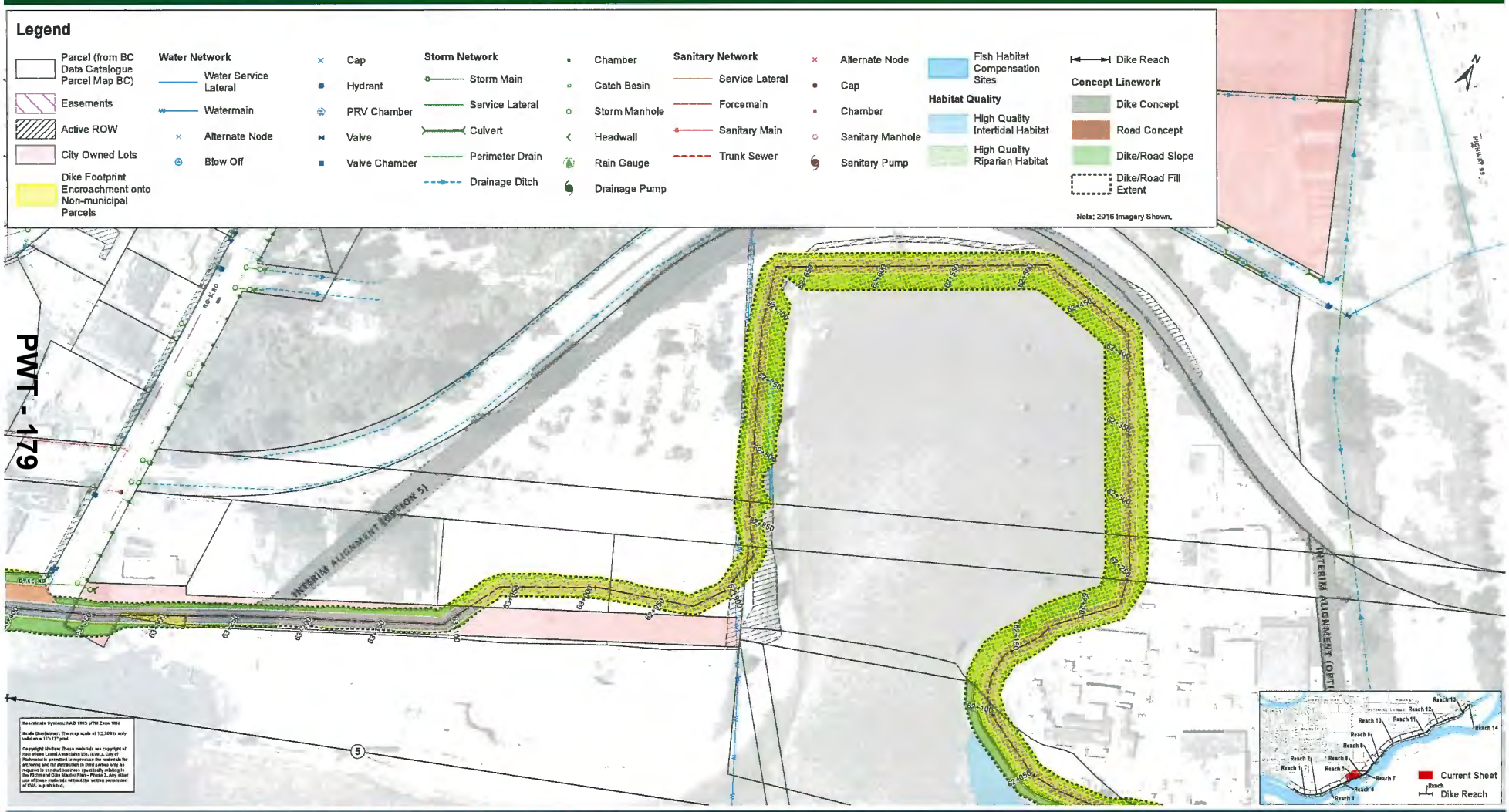
- Dike/Road Fill Extent

Note: 2016 Imagery Shown.

PWT - 179



Project No. 651.122
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 5

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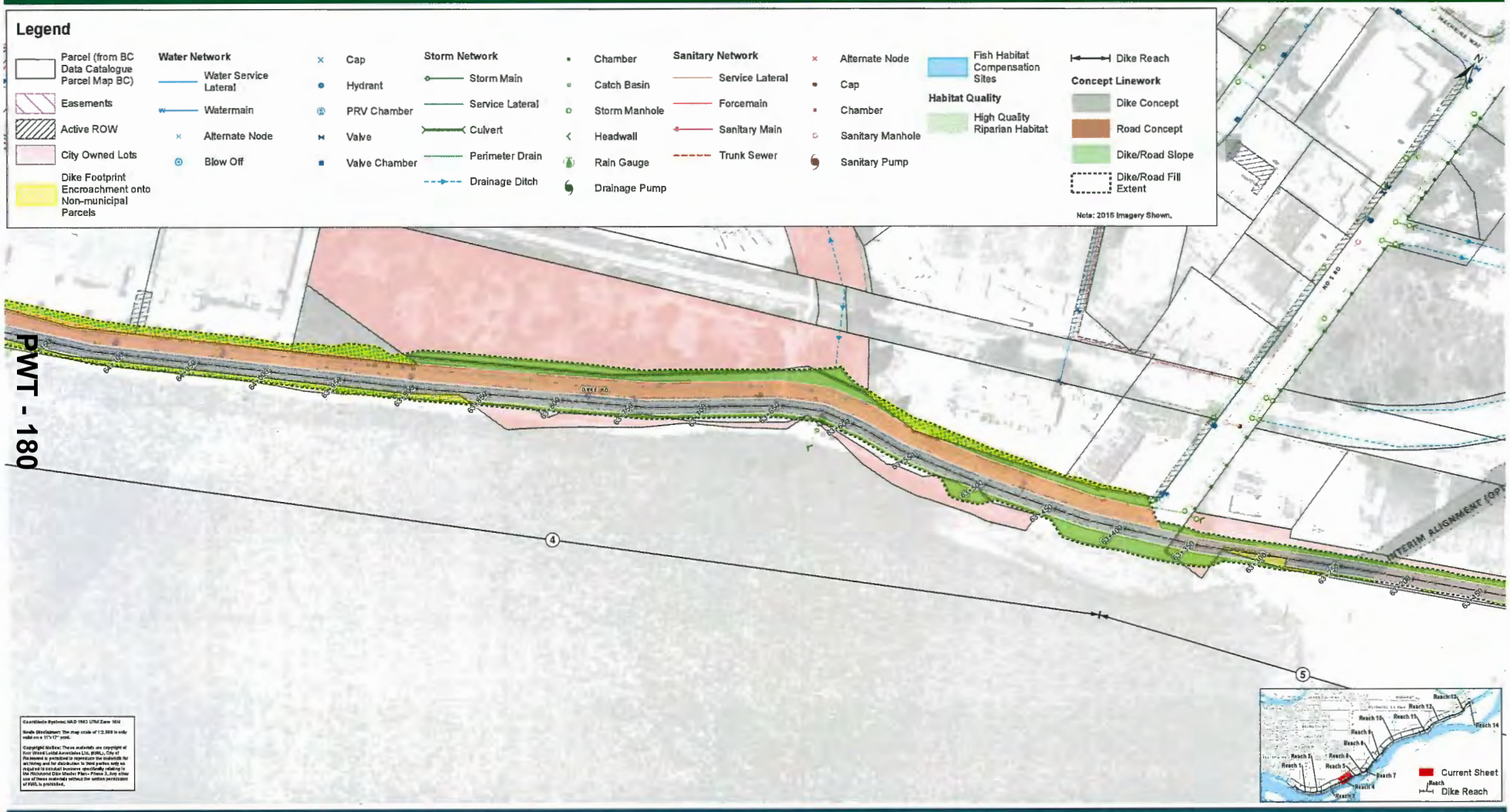
City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



PWT - 180

Project No. 651.122
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 4 and 5

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City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

Legend

- Parcel (from BC Data Catalogue Parcel Map BC)
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- Dike Reach

Concept Linework
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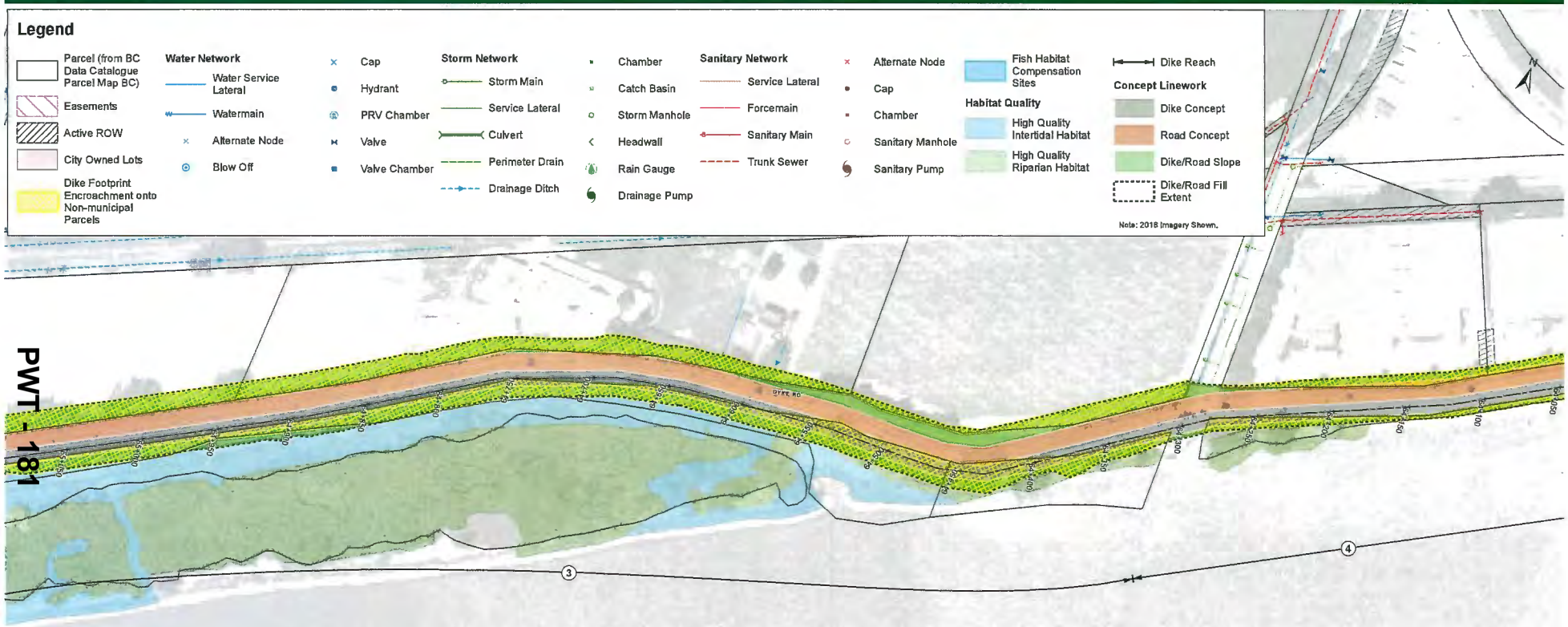
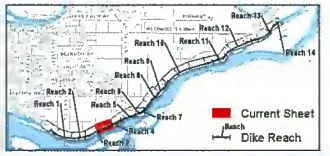
- Road Concept
- Dike/Road Slope
- Dike/Road Fill Extent

Note: 2018 Imagery Shown.



PWT - 181



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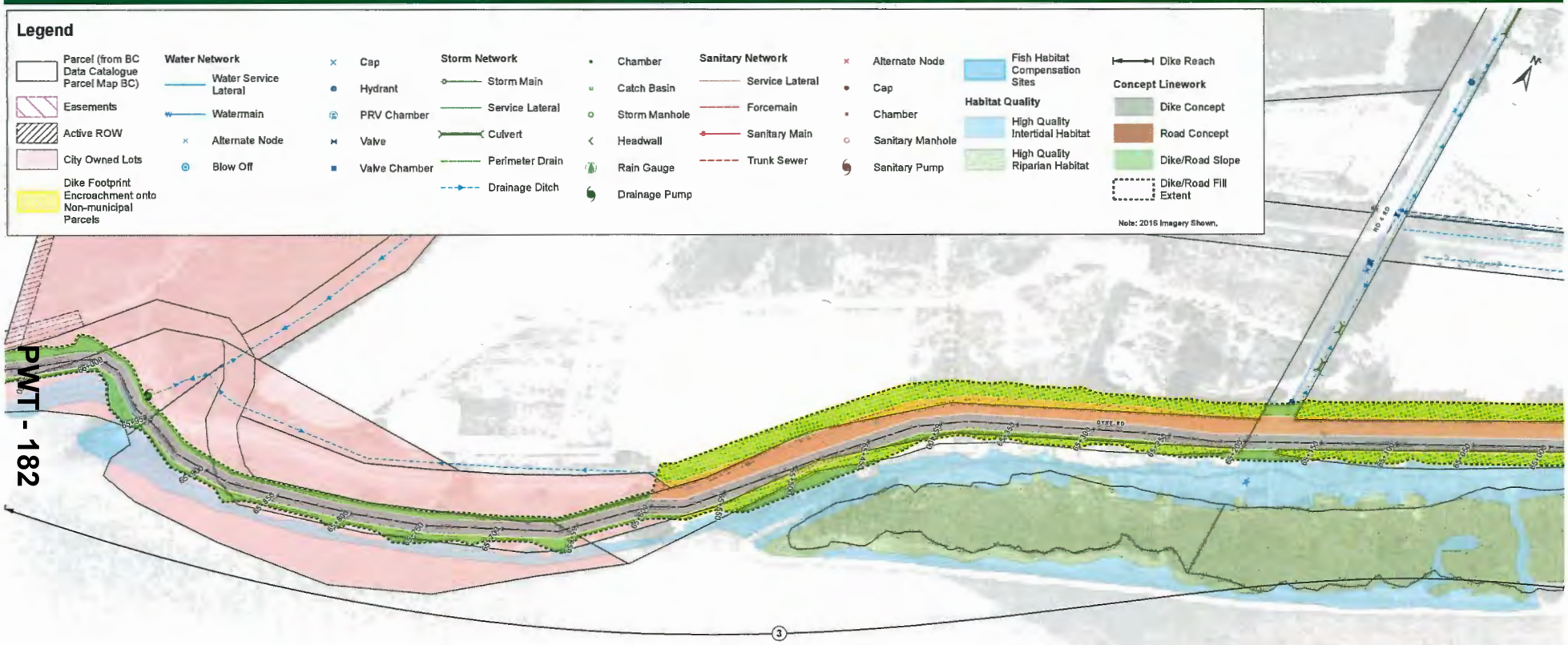
Project No. 651.122
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 3 and 4



Coordinate System: NAD 1983 UTM Zone 10N
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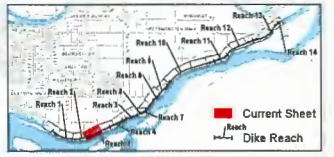

Project No. 651.122
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 3

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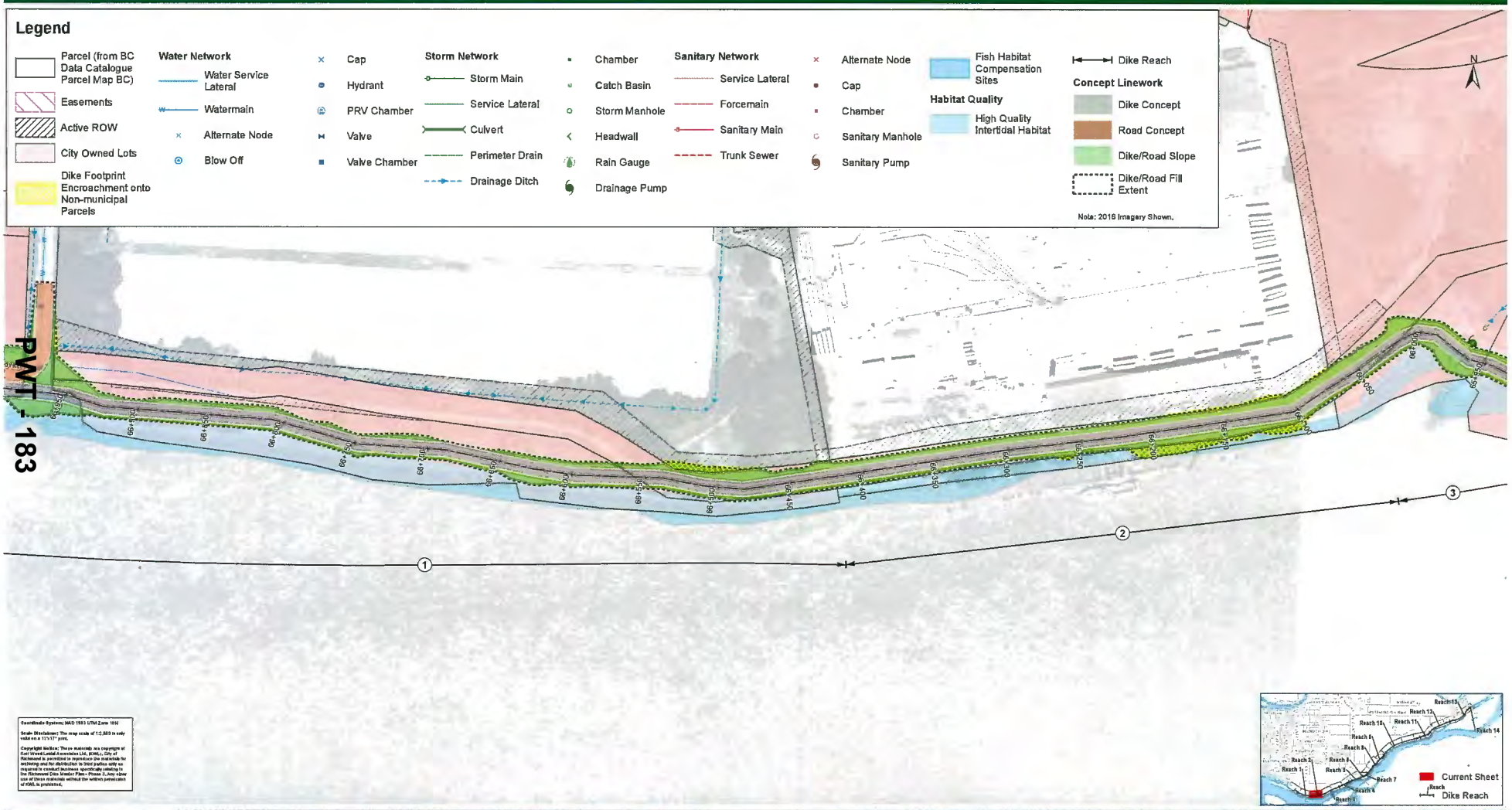
City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers



PWT - 183

Project No. 651.122
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 1 and 2

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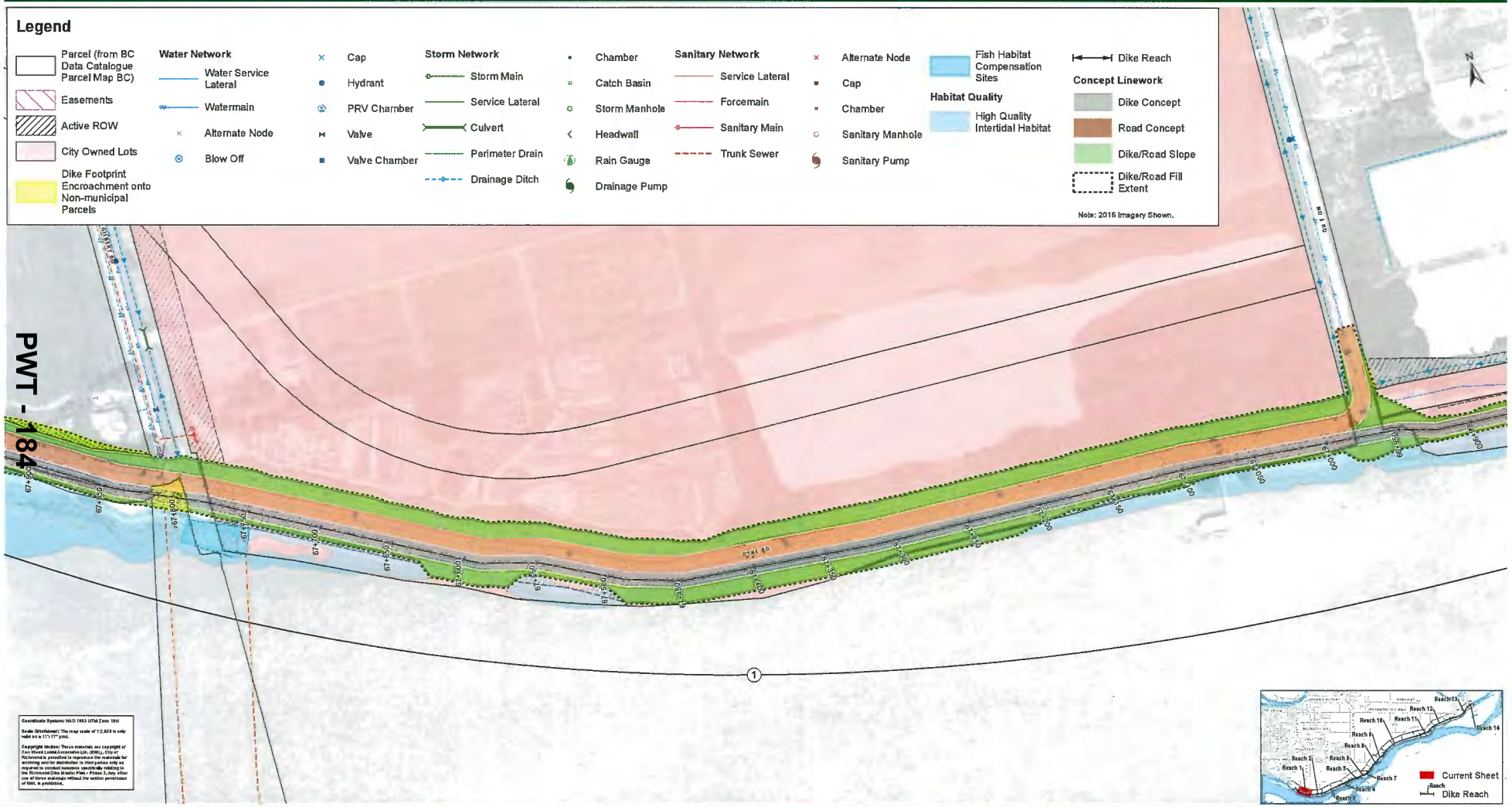

PWT - 184

Project No. 651.122
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 1

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City of Richmond
Richmond Dike Master Plan - Phase 3

KERR WOOD LEIDAL consulting engineers

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- Dike Reach

Concept Linework
- Dike Concept
- Road Concept
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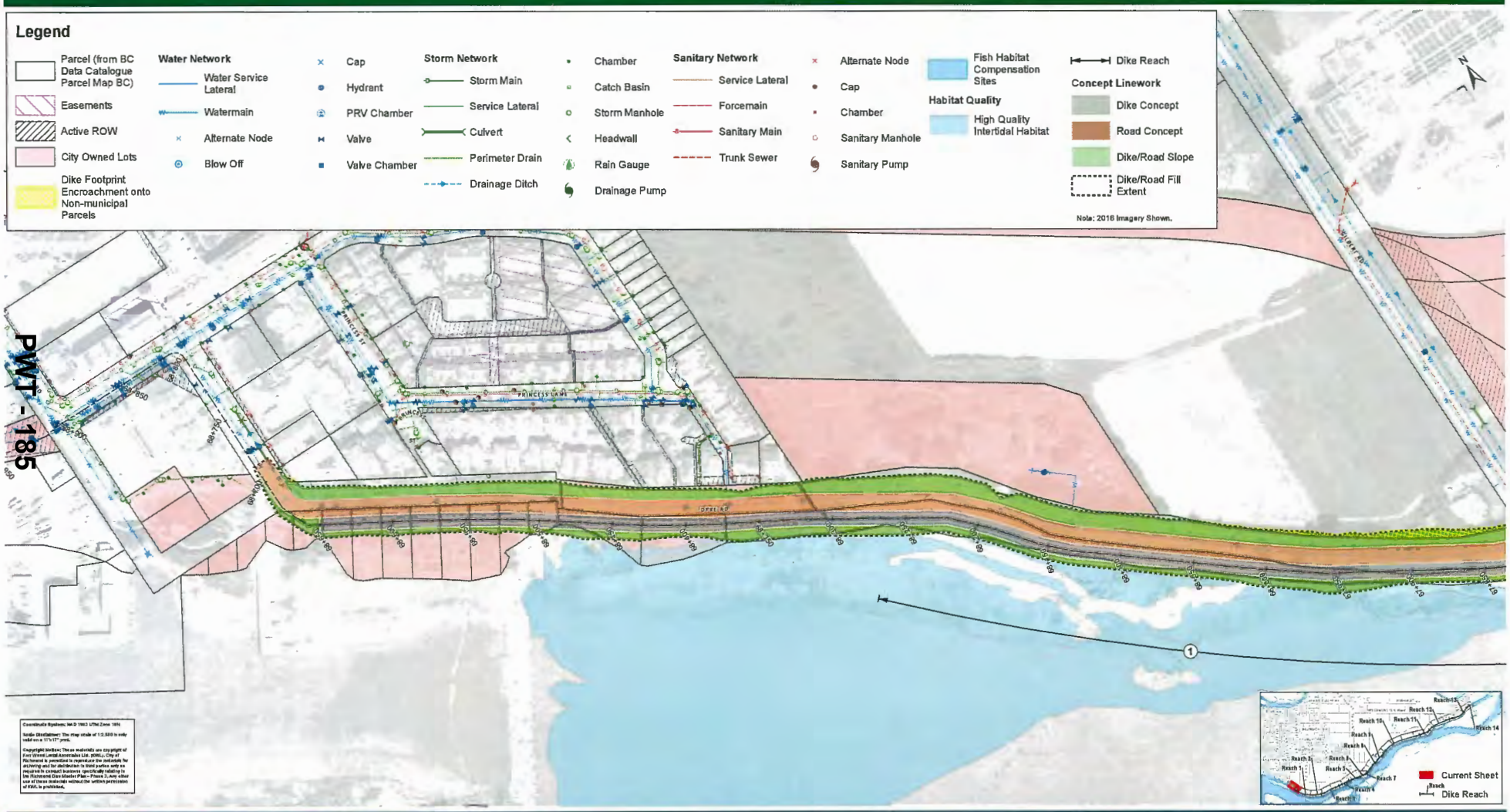
Note: 2016 Imagery Shown.



Project No. 651.122
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 3 Initial Road/Dike Alignment
Reach 1

20

PWT - 185

KERR WOOD LEIDAL
consulting engineers

Appendix B

Richmond Dike Master Plan - Concept Plan

RICHMOND DIKE MASTER PLAN
CONCEPT PLAN

PWT - 187

KERR WOOD LEIDAL
consulting engineers

Appendix C

Geotechnical Engineering Analysis Report (Thurber)

THURBER ENGINEERING LTD.

October 16, 2018 File: 17991

Kerr Wood Leidal Associates Ltd.
200 4185A Still Creek Drive
Burnaby, BC V5C 6G9

Attention: Colin Kristiansen, P.Eng.

LULU ISLAND DIKE MASTER PLAN - PHASES 3, 4 AND 5
GEOTECHNICAL SEISMIC ASSESSMENT OF FLOOD CONTROL DIKES
PRELIMINARY REPORT

Dear Colin:

As requested, Thurber Engineering Ltd. (Thurber) has carried out numerical seismic deformation analyses for the above project using the software program Plaxis. This report presents the results of the deformation analysis and a preliminary assessment of the performance of flood control measures in the context of provincial design requirements for high-consequence dikes. It is a condition of this report that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

1. INTRODUCTION

The City of Richmond (the City) requires input to identify dike upgrade options for Phases 3, 4 and 5 of the Lulu Island Dike Master Plan. The purpose of the Dike Master Plan is to address the short, medium and long-term needs of the Lulu Island diking system. Phase 1 of the plan was carried out in 2012 and included input on the Steveston Dike and south section of the West Dike. Phase 2 of the plan included the north section of the West Dike and the North Dike.

Phase 3 comprises about 20 km of the South Dike on the south arm of the Fraser River. Phase 4 includes the North Dike, extending from No. 6 Road to Boundary Rd. Phase 5 includes Mitchell Island, Richmond Island, and the Richmond part of Sea Island (from the southern end of the BCIT campus North to the Moray Rd. Bridge).

These high-consequence dikes are required to consider seismic performance as described in the Ministry of Forests Lands and Natural Resource Operations' (MFLNRO's) 2014 Seismic Design Guidelines for Dikes. (2014 Seismic Guidelines). Additionally, the dikes are anticipated to be raised in the future to address sea level rise.

Accordingly, this report presents the preliminary results of our numerical seismic deformation analyses for eight dike sections: three in each of the Phase 3 and Phase 4 study areas, and two in the Phase 5 study area. The analyses presented below follow the analytical methods described in the 2014 Seismic Guidelines.

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2. SEISMIC ASSESSMENT BASIS

Seismic assessments were carried out for the eight dike sections at the locations in the table below. The assessments for the Phase 3 dike sections were carried out using cone penetration test (CPT) data provided by the City. Geotechnical investigations were carried out specifically for this project at the five sections in the Phase 4 and 5 study areas. The locations of the dike sections were selected by KWL. Profile drawings showing the section analysed at each location were prepared by KWL and are included in Appendix A. Our analyses followed the analytical methods described in the 2014 Seismic Guidelines.

Section	Phase	Test Hole
53+900	3	Tetra Tech CPT17-02
61+900	3	GeoPacific CPT06-03, CPT 06-06
67+600	3	MEG CPT17-03
11+700	4	CPT 18-03
16+400	4	CPT 18-04
18+750	4	CPT 18-05
1+000	5	CPT 18-01
5+700	5	CPT 18-02

The 2014 Seismic Guidelines recommend designing high-consequence dikes and appurtenant structures to control seismic deformations within prescribed limits. The seismic deformation limits vary depending on the seismic hazard return period as shown in the table below.

Seismic hazard return period (year)	Maximum allowable displacement (mm)	
	Horizontal	Vertical
1 in 100	<30	<30
1 in 475	300	150
1 in 2,475	900	500

The analyses used earthquake time-histories that were developed for the George Massey Tunnel replacement project. The earthquake time-histories were scaled for each dike section location using Natural Resources Canada's on-line seismic hazard calculator. The analyses were carried out for the crustal, inslab, and interface (i.e. Cascadia subduction event) scenario earthquakes. Three earthquake time histories for each scenario earthquake were developed for each of the 1 in 100, 475 and 2,475-year return period seismic hazards.

We carried out 1-dimensional site-specific response analyses (SSRAs) using each of the time histories. The SSRAs were carried out using the software program DEEPSOIL published by the University of Illinois. The SSRAs were completed using three crustal, three in-slab and three interface earthquake time-histories for each of the 1 in 100, 475 and 2,475-year return period

seismic hazards, for a total of 27 SSRAs per dike section. The results of the SSRAs were used in both the liquefaction assessment and numerical deformation analysis. The SSRAs used the shear wave velocity data from the CPTs to estimate the site-specific seismic accelerations and seismically induced shear stresses and strains.

The numerical deformation modelling analyses were completed using one crustal, one inslab and one interface earthquake for each of the slope sections analysed. The time history for each scenario earthquake type (i.e. crustal, inslab and interface/subduction) used in the numerical analyses was selected by choosing the earthquake that had the median maximum shear stress profile obtained from the SSRAs. The soil stiffness and damping parameters used in the numerical deformation analyses were calibrated based on the maximum shear strain profile and ground response obtained from the SSRAs.

The seismic assessment included liquefaction analyses and numerical deformation analyses using the results from the SSRAs and the data from the CPTs. The numerical deformation analyses were based on the dike sections provided by KWL.

3. GEOTECHNICAL INVESTIGATION

3.1 Program of work

The field investigation was carried out July 5 and 6, 2018 and comprised a combination of auger drilling and CPT profiling. The CPTs included two seismic CPTs (i.e. SCPTs), which are CPTs with the addition of shear wave velocity profiling. The CPT profiles, test hole logs and a test hole location plans (Drawings 17991-1 to 17991-5) are attached in Appendix B.

The CPTs were advanced to depths of 30 m. Two CPTs (CPT 18-02 to 18-05) were supplemented with shear wave velocity measurements. The CPT provides a continuous trace of cone tip resistance, sleeve friction and pore pressure. This data was used to interpret the soil stratigraphy and estimate soil properties (e.g. strength and density). The SCPT includes shear wave velocity measurements that were used to estimate the small-strain shear modulus of the soil. The small-strain shear modulus has been used in the SSRAs and numerical deformation analyses. The CPTs were drilled out to depths of nominally 7.5 m with a solid stem auger to confirm the soil profile and obtain disturbed samples.

The soil and groundwater conditions in the test holes were logged in the field by an experienced geotechnical engineer and representative disturbed samples were collected for routine moisture content testing and visual classification in our laboratory. Fines content analyses (% passing 75 µm sieve) and Atterberg limit testing were carried out on select representative samples.

All test holes located on the dike and within the dike right-of-way were grouted in general accordance with B.C. groundwater protection regulations and MFLNRO requirements.

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3.2 Results

The results of the investigation and laboratory testing are summarized on the attached test hole and CPT logs. The logs provide a complete, detailed description of the conditions encountered and should be used in preference to the generalized descriptions given below. The soil descriptions provided on the CPT logs are Gregg Drilling and Testing Canada's interpretations of the CPT data using generally accepted correlations and should be considered approximate.

At TH/CPTs 18-04 and 18-05, which are at the east end of Lulu Island, the conditions encountered comprised a thick silt layer at the surface underlain by Fraser River sand. The silt layer was about 17 m to 20 m thick and comprised clayey organic silt to sandy silt. The underlying Fraser River Sand was encountered to the maximum depth investigated (30 m).

At TH/CPTs 18-01, 18-02 and 18-03 the subsurface conditions comprised a silt crust that varied from about 4 m to 7 m thick. Below the crust, Fraser River sand was encountered to depths of about 23 m to 24 m. Silt was encountered below this to the maximum depth investigated.

The interpretation of the CPT data provided by the City for the three Phase 3 dike sections indicates the subsurface conditions at these locations are similar to the conditions encountered at TH/CPTs 18-01, 18-02 and 18-03. We expect that conditions in this phase typically comprise a 2 m to 7 m thick clay first overlaying Fraser River sand to depths of about 20 m to 25 m.

The results of the investigation were consistent with the British Columbia Geological Survey's Map 2010-2 "Quaternary Geology of Richmond, British Columbia", which is attached for reference. This map indicates that surficial geology of most of Lulu Island comprises a silt crust at the surface that is typically 2 m to 7 m thick, underlain by Fraser River sand extending to depths of about 25 m. The map shows that the surficial geology on the east end of Lulu Island comprises organic silts and peat up to 12 m thick underlain by Fraser River Sand.

Groundwater levels are anticipated to generally follow water levels in the Fraser River and can be expected to vary with rainfall, drainage and infiltration.

4. SEISMIC PERFORMANCE

4.1 Liquefaction Assessment

Liquefaction assessments using empirical methods were carried out to assess the degree of liquefaction under each of the seismic hazard return periods for each earthquake scenario type and to provide estimates of reconsolidation settlement. These liquefaction assessments were also used to compare the liquefaction predicted using empirical methods against the liquefaction predicted from the 1D numerical models.

Liquefaction assessments were carried out for flat ground (i.e. 1D) conditions for each of the three design earthquake levels using the software program CLiq published by Geologismiki.

These assessments followed the methods described by Idriss and Boulanger (2008 and 2014) to evaluate the resistance to liquefaction (i.e. the cyclic resistance ratio (CRR)). The shear stress triggering liquefaction (i.e. the cyclic stress ratio (CSR)) was calculated by averaging the maximum stress ratio profiles for each scenario earthquake (e.g. the CSR for the 1 in 100-year crustal earthquake was calculated using the average of the maximum stress ratio profiles from the three crustal time-histories).

The results of the liquefaction triggering analyses are presented on the plots generated by CLiq in Appendix C. These plots show layers where liquefaction is anticipated (i.e. where the CSR is greater than the CRR, or the factor of safety is less than one against liquefaction) and also provide estimates of post-liquefaction reconsolidation settlement.

The liquefaction triggering assessment shows that liquefaction is anticipated to be insignificant under all of the scenario earthquakes for the 1 in 100-year return period seismic hazard. This corresponds to "No liquefaction (L0)" per the 2014 Seismic Guidelines. The assessment also indicates that the sand encountered is generally liquefiable under all of the scenario earthquakes for the 1 in 475 and 2,475-year return period seismic hazards. We have inferred that the extent of liquefaction of the sand layers under the 1 in 475-year return period earthquakes is "Mild liquefaction (L1)" to "Moderate liquefaction (L2). The extent of liquefaction under the 1 in 2,475-year return period seismic hazards is inferred be "High liquefaction (L3)".

The reconsolidation settlements under the 1 in 475 and 2475-year return period seismic hazards are anticipated to be typically between about 400 mm to 1000 mm. The exception to this is at the sections at the east end of Lulu Island where a thick layer of surficial silt was encountered. At these locations, reconsolidation settlements are anticipated to be about 50 to 400 mm under the 1 in 475 and 2475-year return period seismic hazards. For the 1 in 100-year return period seismic hazard, reconsolidation settlements are anticipated to be less than 100 mm at all of the dike sections analysed for all earthquake scenario types. The reconsolidation settlements typically nominally meet or exceed the performance requirements of the 2014 Seismic Guidelines.

For reference we have attached the British Columbia Geological Survey's Map 2010-3 "Liquefaction Hazard Map of Richmond, British Columbia" which shows a qualitative assessment of the liquefaction risk. The results of our liquefaction assessment are consistent with the information shown on the map.

4.2 Numerical Deformation Analysis

We carried out seismic numerical deformation analyses using the software program Plaxis 2D. Plaxis 2D is an advanced finite element modelling program that allows for complex modelling of cyclic soil behaviour, similar to the software program FLAC, but with a user-friendly interface that allows for more rapid model construction and a faster computation routine. The deformation analyses incorporated complex cyclic soil behaviour using the UBCSand soil model, which is the same model used in FLAC for similar numerical deformation analysis.

The numerical deformation analysis used the site-specific earthquake acceleration time histories output from the SSRAs. The numerical deformation analyses were carried out for the 1 in 100, 475 and 2,475-year return period seismic hazards for each of the earthquake scenario types.

One time-history was run for each of the scenario earthquakes for each return period seismic hazard. The time histories were selected by taking the scenario earthquake time-histories that had the median CSRs for each scenario earthquake type.

In keeping with the intent of the concept that the dikes must perform under a uniform hazard framework consistent with the NRC's probabilistic seismic hazard assessment, we have taken the performance under each earthquake return period as the largest displacements of the scenario earthquakes. The largest displacements for all of the sections analysed was the crustal scenario earthquake for the 1 in 100-year return period seismic hazards. For the 1 in 475 and 2,475-year return period seismic hazards, the subduction scenario earthquake resulted in the largest displacements for all of the dike sections.

The output from the Plaxis analyses provided in Appendix D presents the results from the earthquake scenario type that had the largest seismic displacements. The output includes plots of vertical and horizontal displacements for comparison with the performance requirements of the 2014 Seismic Guidelines. We have also included plots showing total displacement as this provides a clearer interpretation of the pattern of displacements.

The numerical deformation analyses indicate that the dikes will not meet the performance requirements of the 2014 Seismic Guidelines for any of the return period seismic hazards. The analyses indicate that typically the required dike setback will be about 50 m to 100 m. The actual setback will depend on the dike height and configuration and site-specific conditions.

5. DISCUSSION

We understand that the intent of the 2014 Seismic Guidelines is for construction of conventional dikes using alignments or reasonable design features to meet the required seismic performance criteria. However, extensive ground improvement is not necessarily required if the seismic performance criteria are not met. The 2014 Seismic Guidelines acknowledge that ground improvement methods are "costly and may only be practical for short sections or at appurtenant structures", such as pump stations or flood gates. Accordingly, if cost-prohibitive ground improvement is the only way to conform to the guidelines, alternatives should be considered.

The 2014 Seismic Guidelines suggest alternatives such as: 1) realigning dikes to less seismically vulnerable areas, 2) overbuilding dikes to accommodate seismic displacements, 3) building very wide "superdikes", and 4) developing comprehensive flood risk and flood protection strategies, including post-earthquake dike repair plans.

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The analysis indicates that ground improvement or other remedial measures will be required to meet the performance requirements of the 2014 Seismic Guidelines for dikes near riverbanks.. The critical location for ground improvement is under the waterside toes/slopes of the dikes, where the shear stress bias is the highest. In some situations, such as where the dikes are high, ground improvement may also be required under the landside toes/slopes of the dikes. Sufficient deformation control could probably be achieved using ground improvement with an aspect ratio of between 0.75H:1V and 1H:1V extending to the bottom of the deepest liquefiable layer (i.e. in profile view, the width of the ground improvement should be 75% to 100% of the depth of liquefaction).

It is our opinion that ground improvement using stone columns is probably the most suitable ground improvement method for the contemplated dike upgrade. Stone columns typically cost about $\$15/m^3$ on a treated volume basis. Compaction piles, soil mixing and jet grouting are other alternatives to increase the strength of the sand to limit liquefaction. These alternatives typically cost more and could be more difficult to adapt to changing or unexpected subsurface conditions than stone columns.

Compaction piles would also probably need to be straight (i.e. without taper) displacement piles. Although timber piles are commonly used as compaction piles, because they are tapered they may not be able to densify the soil at depth. Accordingly, they are not recommended. Compaction piles comprising precast concrete or steel pipe piles are expected to cost about 20 times stone columns on a volume basis.

Soil mixing methods include deep soil mixing (DSM) and cutter soil mixing (CSM). These methods are typically about five times the cost of stone columns per treated soil volume. Jet grouting also costs more, at about seven times the cost of stone columns.

As a potential alternative to ground improvement, the dikes could be set back from the river bank. Based on the results of the Plaxis deformation analyses, the required distance could be in the order of 50 m to 100 m. Setback dikes could either require flat slopes or some ground improvement to mitigate seismic deformations (i.e. lateral spreading of the dike embankment).

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6. CLOSURE

We trust that this letter provides sufficient information for your needs at this time. Should you require clarification of any item or additional information, please do not hesitate to contact us.

Yours truly,

Thurber Engineering Ltd.
David Regehr, P.Eng.
Review Principal

Steven Coulter, P.Eng.
Project Engineer

Attachments

- Statement of Limitations and Conditions (1 page)
- Appendix A – KWL Dike Sections (9 pages)
- Appendix B – Geotechnical Investigation (15 pages)
- Appendix C – Liquefaction assessment CLiq output (72 pages)
- Appendix D – Numerical deformation analyses Plaxis output (72 pages)
- British Columbia Geological Survey Map 2010-2 "Quaternary Geology of Richmond, British Columbia"
- British Columbia Geological Survey Map 2010-3 "Liquefaction Hazard Map of Richmond, British Columbia"

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STATEMENT OF LIMITATIONS AND CONDITIONS

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This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

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a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and the Report is delivered subject to the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. If special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

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d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

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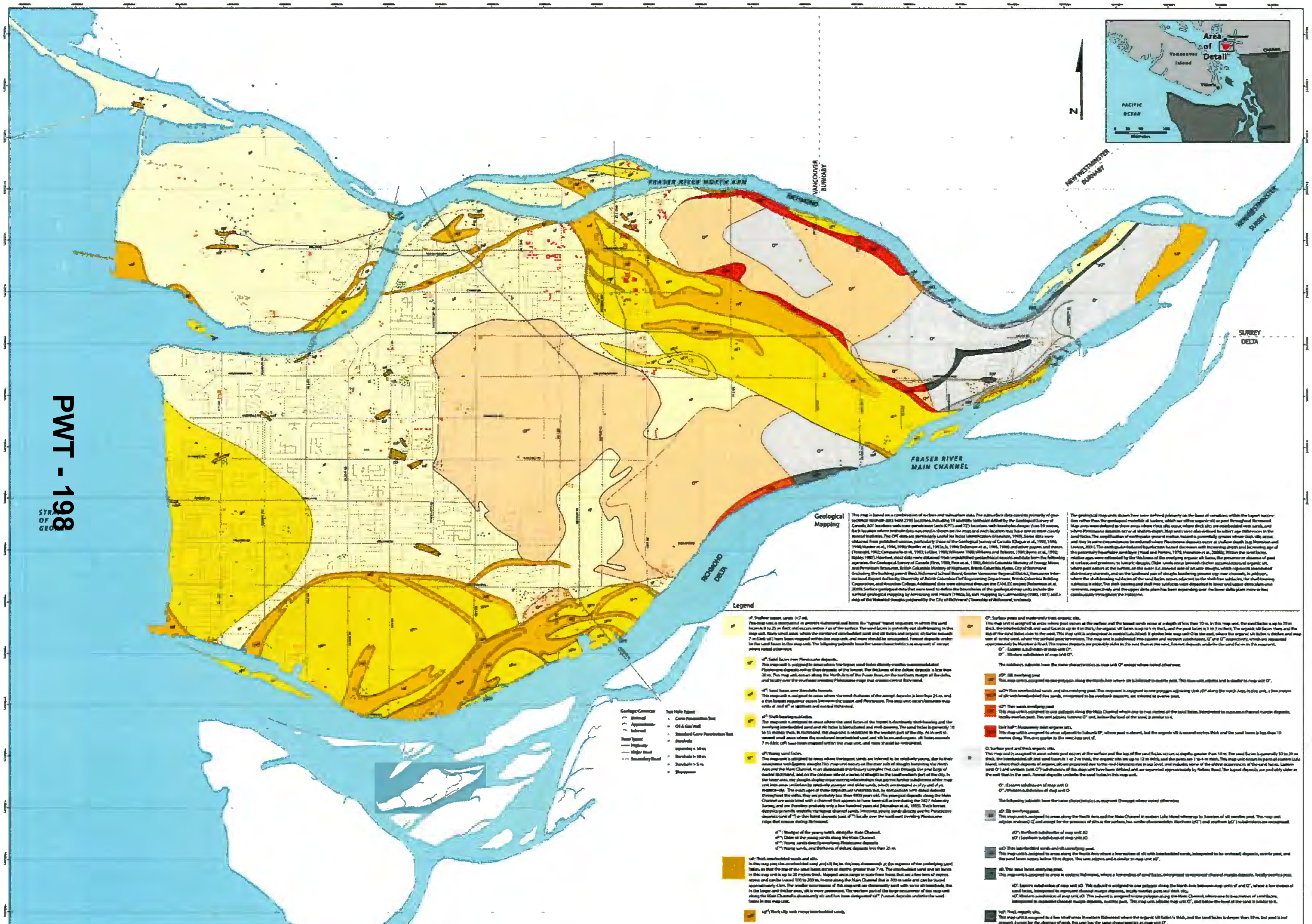
British Columbia Geological Survey
Geoscience Map 2010-2

QUATERNARY GEOLOGY OF RICHMOND, BRITISH COLUMBIA

Patrick A. Monahan, Victor M. Levson and Ben Kerr



This map shows geological variation in the Quaternary deposits underlying the City of Richmond, British Columbia, and has been prepared as part of an earthquake hazard mapping project in the city. Richmond is located in one of the most seismically active regions in Canada (Rogers, 1998), and the deltaic sediments on which the city is built can amplify ground motions and are susceptible to earthquake induced liquefaction (e.g. Byrne, 1978; Finn et al., 1989; Byrne and Anderson, 1991; Clague et al., 1992, 1997, 1998b; Watts et al., 1992; Rogers et al., 1998; Harris et al., 1995, 1998; Cassidy et al., 1997; Cassidy and Rogers, 1999; Levson and Monahan, 2004). Because the variation in earthquake hazards is most affected by geological conditions in the upper 20 to 30 metres, this map primarily reflects geological variation in the upper 20 to 30 metres of the Quaternary sequence.

Quaternary Geology Framework

Fraser Delta Topset Deposits

Geological Mapping

Legend

References

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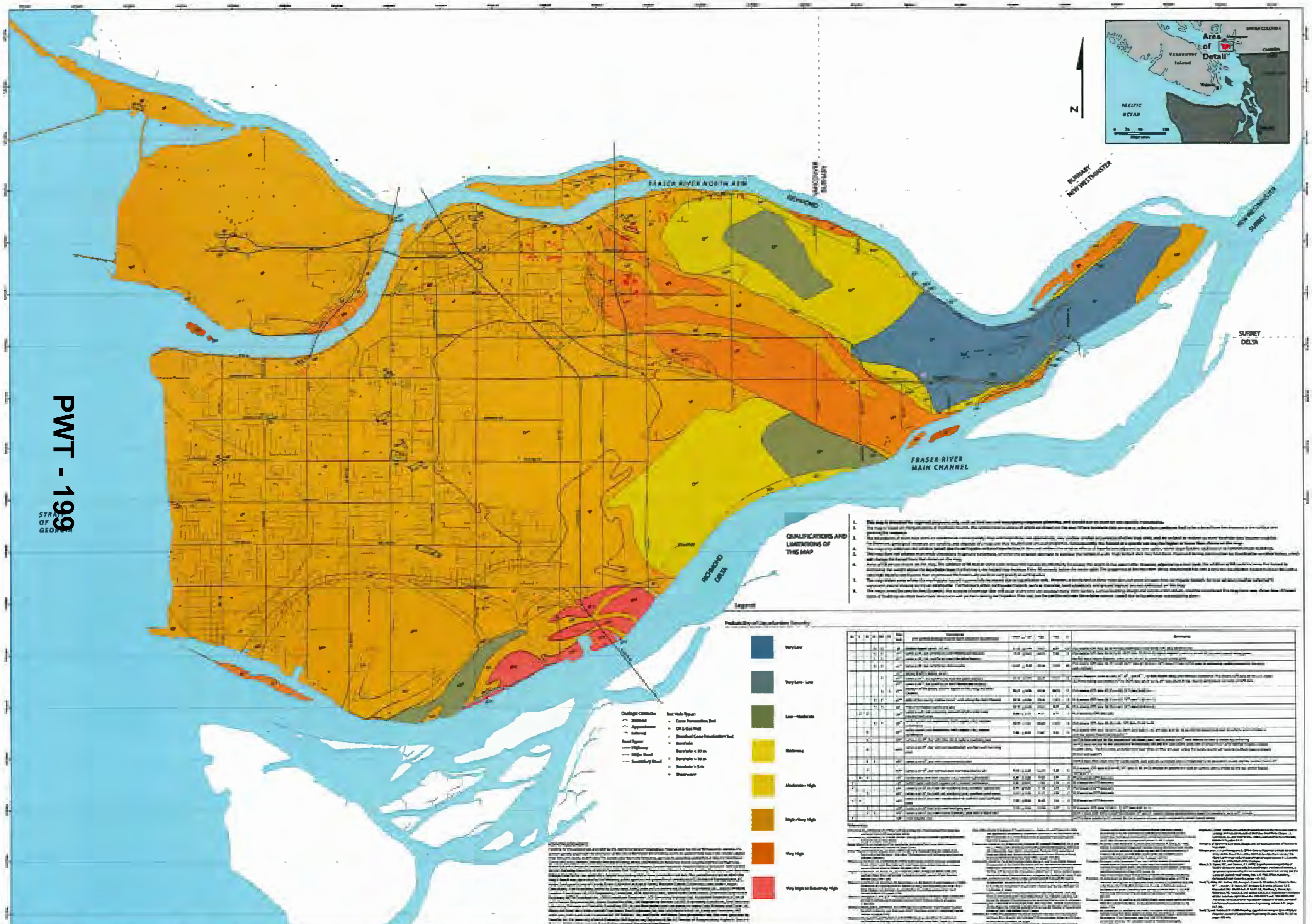
British Columbia Geological Survey
Geoscience Map 2010-3

LIQUEFACTION HAZARD MAP OF RICHMOND, BRITISH COLUMBIA

Patrick A. Monahan, Victor M. Levson and Ben Kerr



The City of Richmond, British Columbia, is located in one of the most seismically active regions in Canada (Rogers, 1998). The effects of earthquakes are not only dependent upon the magnitude of the earthquake and the distance from the source, but can vary considerably due to local geological conditions. These conditions can be mapped using existing geological and geotechnical data. This map shows the variation in the earthquake-induced liquefaction hazard in City of Richmond, British Columbia. The city is located entirely within the modern Fraser River delta, and the deltaic sediments on which the city is built are particularly susceptible to earthquake induced liquefaction (e.g. Byrne, 1978; Finn et al., 1989; Byrne and Anderson, 1991; Clague et al., 1992, 1997, 1998b; Watts et al., 1992). This map has been prepared as part of an earthquake hazard mapping project in the city. An accompanying map shows the Quaternary geology of the Richmond area.

This map is intended for regional purposes only, such as land use and emergency response planning, and should not be used for site-specific evaluations. This map can be used with other criteria to help planners select potential areas for development, avoid geologically vulnerable areas, and prioritize seismic upgrading programs. *However, this map does not replace the need for site-specific geotechnical evaluations* prior to new construction or upgrading of buildings and other facilities. The qualifications and limitations of this map are discussed in more detail below.

Liquefaction Hazard Mapping

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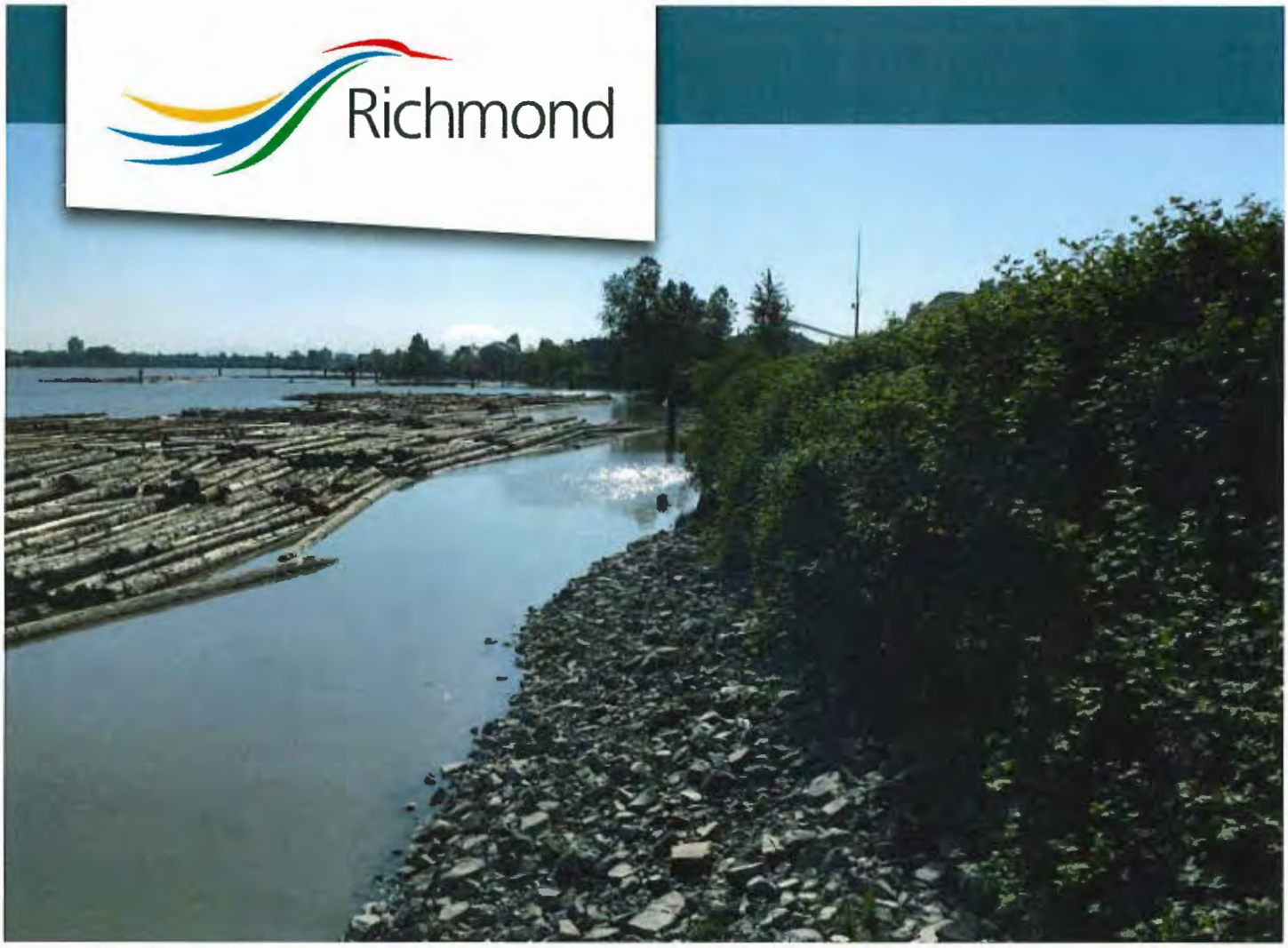
Richmond



Final Report

Dike Master Plan - Phase 5

February 2019
KWL File No. 0651.129-300
Richmond File No. 631343

Submitted by:

KERR WOOD LEIDAL
consulting engineers

Contents

Figures

Tables

Appendices

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 in Richmond, and an additional 5th phase for Sea Island, Mitchell Island, and Richmond Island. The goal is to raise the dikes to 4.7 m CGVD28 to allow for 1 m of sea level rise and 0.2 m of land subsidence, while allowing for further upgrading in the future. The long-term vision is to provide the City with a world-class level of flood protection to keep pace with the rapidly growing population and assets within the dikes.

This Phase 5 Dike Master Plan covers Mitchell Island, Sea Island and Richmond Island. The Sea Island 15 km perimeter dike is shared with Vancouver Airport Authority (YVR), with the City managing a 1.1 km section south of the Moray Channel Bridge plus three road rights-of-way through the YVR sections of the dike. Mitchell Island is not currently protected by a dike, although most of the island is above 2.5 m CGVD28. Richmond Island is a single property that is above the design flood level with flood protection responsibility remaining with the property owner.

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 5 are described below.

Mitchell Island

- Raise roads to the design dike crest elevation to provide emergency egress.
- During redevelopment, require properties to be raised to the design dike crest elevation and acquire rights-of-way along the river bank. Such rights-of-way will allow for a future dike and/or bank protection works.

Sea Island

- Widen the dike on the land side rather than into the Fraser River Middle Arm. Consider retaining walls or extending the dike towards the riparian area in site-specific constrained areas. Coordinate dike improvements with YVR and establish agreed upon dike jurisdictions.
- Coordinate upgrades to the dike with upgrades to Miller Road Pump Station and the Moray Channel Bridge.
- As an interim measure along the Pacific Gateway Hotel (until the site redevelops), raise the dike to 4.7 m CGVD 28 with a sheetpile wall embedded along the river bank and a land-side retaining wall.

Richmond Island

- No changes by the City are proposed as the island is almost entirely above the future dike elevation (5.5 m CGVD28). It is recommended that flood protection responsibility remain with the property owner.

It is also recommended that the City prepare a comprehensive implementation plan for dike upgrading that incorporates the elements of the Phase 5 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.

For all Dike Master Plan phases, the City should continue to investigate alternative ways to achieve seismic performance objectives, including soil densification research, custom design criteria, and filling a wide swath of land inside the dike.

1. Introduction

Flood protection in Richmond is guided by the City's 2008-2031 Flood Protection 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 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 5.

Phase 5 encompasses the islands on the north side of Lulu Island within the City of Richmond, along the Fraser River North Arm. This includes Richmond Island, Mitchell Island, and Sea Island (primarily under Vancouver Airport Authority (YVR) jurisdiction). These are three distinct islands that require consideration of separate constraints and opportunities, independent of each other, but within the overall context of the Dike Master Plan. Figure 1-1 presents the extent of the City's Dike Master Plan phases and existing ground elevation, based on Emergency Management BC (EMBC) 2016 LiDAR. Figure 1-2 shows the reaches of the Phase 5 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). 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.

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 climate change), subsiding land, and increasing development.

The 2008-2031 Flood Protection 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 Flood Protection Strategy is currently in the process of being updated.

While Lulu Island is the most populous and developed Richmond island, Mitchell Island and Sea Island are also very important to the success of Richmond and the region. Mitchell Island and Sea Island are economic and employment hubs with light to medium industrial uses on Mitchell Island and the Vancouver International Airport and associated industries located on Sea Island. There is also a residential community (Burkeville) located on Sea Island. Richmond Island is currently occupied by a single business operating a marina and a pub.

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 dikes. Unlike the previous Dike Master Plan phases, which focus on the Lulu Island perimeter dike, Phase 5 focuses on areas outside of Lulu Island, including both diked and undiked islands. In diked areas (Sea Island), the Phase 5 Dike Master Plan will focus on upgrading of the City's portion of the existing perimeter dike. In undiked areas (Mitchell Island and Richmond Island), alternative flood protection strategies may be warranted, such as land raising or relying only on non-structural measures (Flood Construction Levels (FCLs), covenants, flood insurance).

The master plan defines the City's preferred and minimum acceptable structural flood protection works upgrading concepts (dikes, land raising, erosion protection). 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/construction;
- 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 addressed in the City's 2008-2031 Flood Protection Strategy. The City is currently working on an updated 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 (Vancouver Airport Authority, 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 provides implementation strategy, including costs, phasing, and coordination;
- Section 5 is a compilation of 2-page summary sheets highlighting existing conditions and key features of the preferred option for each reach; 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 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;
- Amir Taleghani, M.Eng., P.Eng. – Water Resources Engineer;
- Allison Matfin, EIT – Project Engineer
- Laurel Morgan, M.Sc., P.Eng., P.E. – Drainage Engineer;
- Daniel Brown, B.Sc., B.Tech., BIT – Project Biologist;
- Patrick Lilley, M.Sc., R.P.Bio., BC-CESCL - Senior Biologist and
- Jack Lau - GIS/CAD Analyst.

This report was primarily written by Allison Matfin with direction from Amir Taleghani. The report was reviewed by Mike Currie and Colin Kristiansen.

Thurber Engineering Ltd. (Steven Coulter, M.Sc., P.Eng.) provided geotechnical engineering 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
- Chris Chan, B.A.Sc. EIT – 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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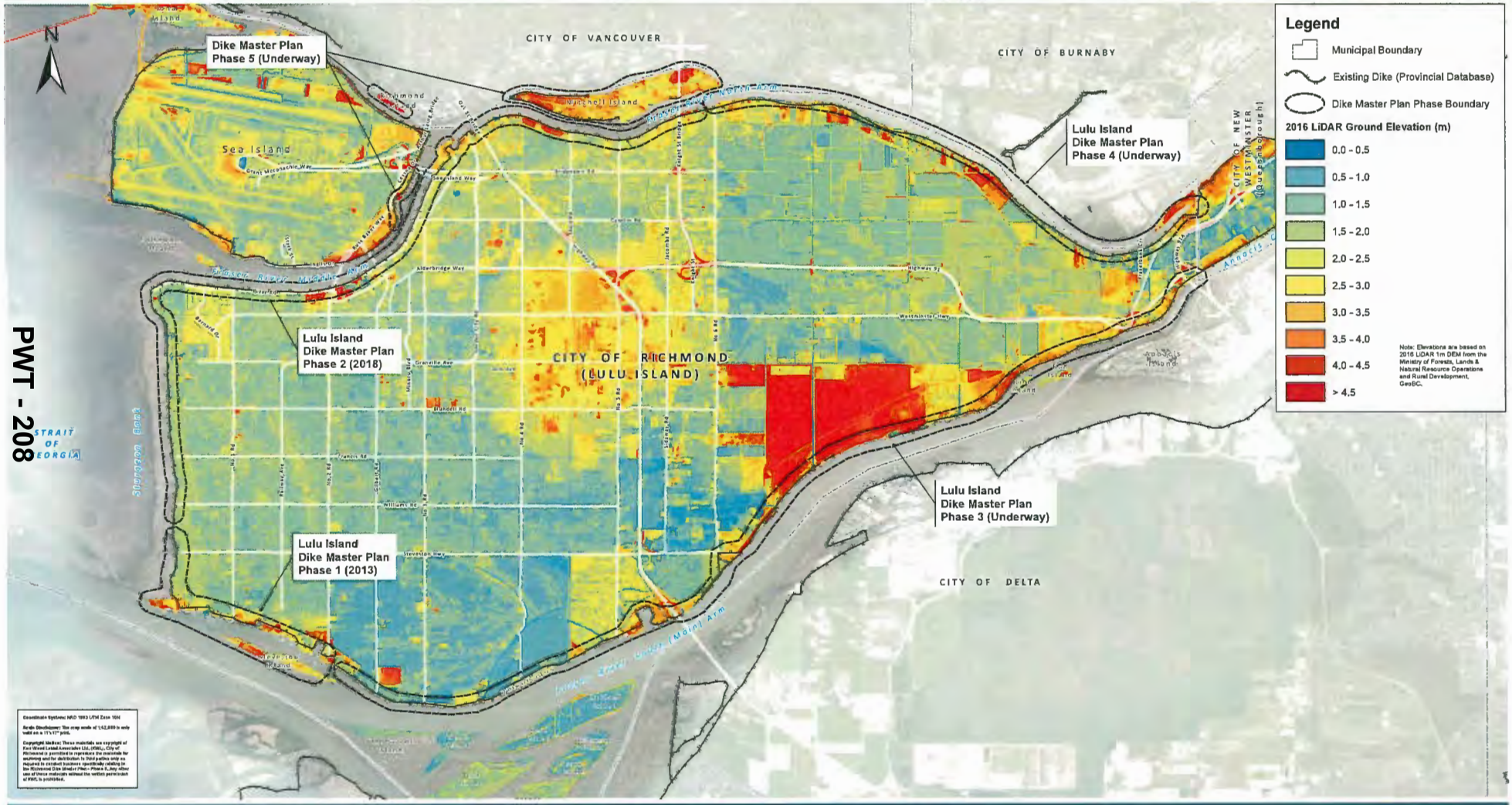

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Dike Master Plan Phases

Figure 1-1

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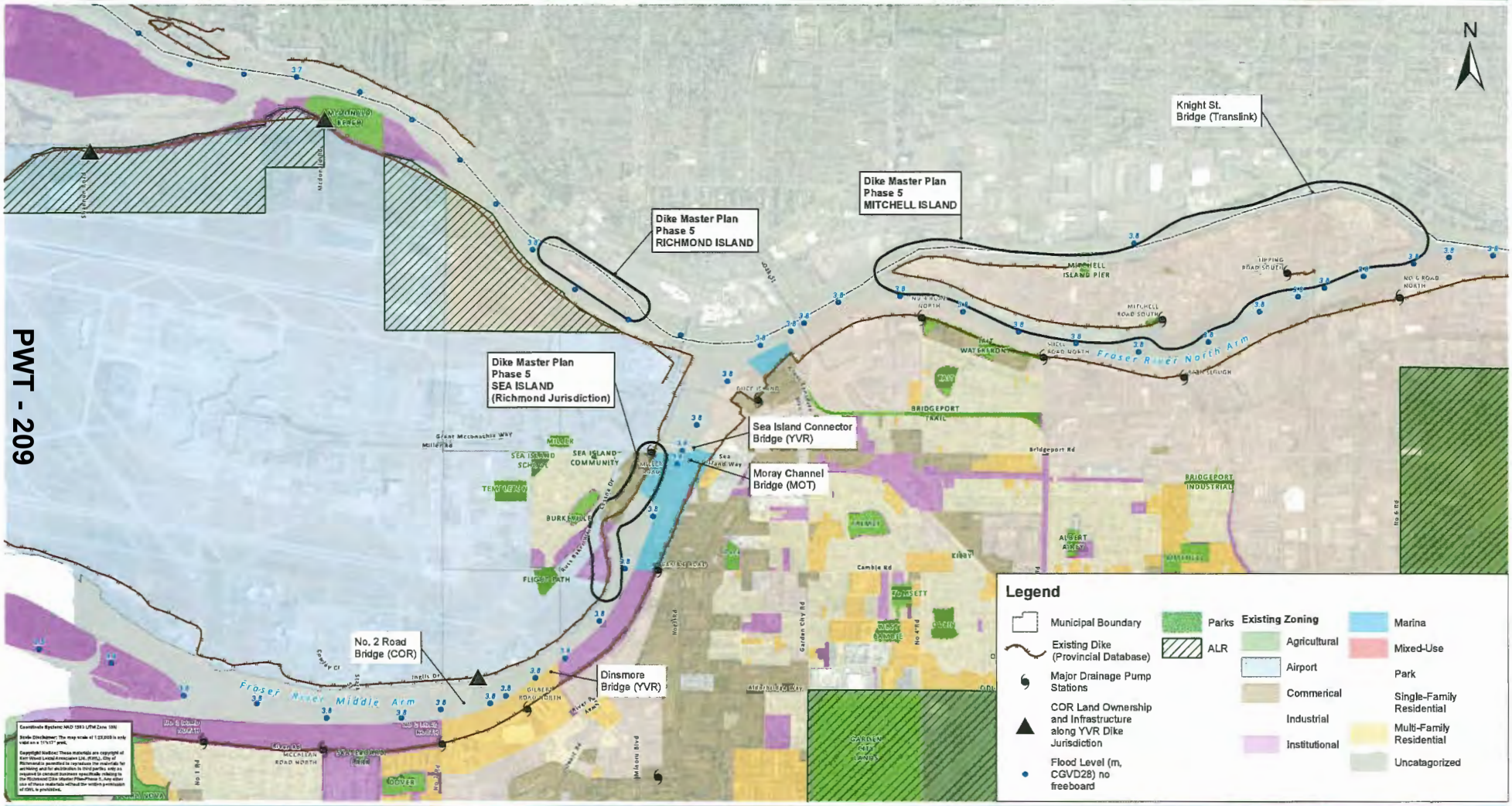

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Phase 5 Dike Master Plan Study Area

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

Mitchell Island, Sea Island, and Richmond Island are unique areas with varying types and degrees of flood protection. Mitchell Island has an old and unmaintained private dike along the western extent, with areas of private erosion protection and small sections of sheetpile elsewhere on the island. Conversely, Richmond Island has no flood protection works, though private bank protection works are in place. Sea Island is protected by an approximately 15 km long perimeter dike, though diking responsibility largely rests with the Vancouver Airport Authority (YVR) with one eastern reach under the City's responsibility. As a result, these three distinct islands require consideration of separate constraints and opportunities, independent of each other, but within the overall context of the Dike Master Plan.

Phase 5 is divided by Island as each Island has relatively uniform conditions with several locations with unique constraints. Islands/reaches are presented on Figure 1-2.

The sections below and Table 2-1 describe the existing conditions and features of each island. Mitchell Island may need to be further subdivided for future dike upgrading implementation phasing.

Appendix A provides a set of figures showing the existing dike alignment, proposed upgrading, adjacent land tenure, municipal infrastructure, and existing habitat.

Reach 1 - Mitchell Island

Mitchell Island was created by filling in the river between three separate islands (Twigg, Eburne, and Mitchell Islands).

Mitchell Island is densely developed with industrial and commercial businesses, and some residences that are not in compliance with current zoning. The City's Official Community Plan (OCP) indicates that Mitchell Island will be maintained as industrial and commercial zoning, to preserve space in the City for these types of economic activities. A private dike was constructed on the western end of Mitchell Island many decades ago and was passed to the City by the Province of British Columbia (the Province); however, the dike has not been maintained nor inspected and is no longer apparent on the island. The elevation of the island ranges from 2.5 to 4.5 m CGVD28 generally, and private bank protection works and sheetpile walls are in place in many locations.

Implementing structural flood protection works on Mitchell Island would have a significant impact on the existing conditions, as no access or rights-of-way currently exists for the City to complete these works. However, flood protection for Mitchell Island is beneficial as not implementing flood protection would result in economic loss for the region, risk public life at current residences, and could result in contamination from flooding of industrial sites.

Reach 2 - Sea Island

Sea Island has an existing perimeter dike that is largely under the responsibility of YVR. Only one eastern reach is under the City's responsibility, from the south side of the Moray Channel Bridge to the southern property boundary of BCIT (approximately 1.1 km). Dike crest elevation in this reach ranges from 4.7 m to as low as 2.7 m CGVD28 and is set back from the river in a few locations. Little to no bank protection is in place, and ongoing invasive vegetation (knotweed) treatment is resulting in damage to the river bank near the setback dike. The current dike alignment ties into the Moray Channel Bridge, owned by the City of Richmond. Based on 2016 EMBC LiDAR data, the bridge deck on Sea Island is below 4.7 m CGVD28 and would not be sufficient for dike upgrades. The dike borders four large commercial lots with major transportation corridors and the community of Burkeville located behind the commercial areas.

The City also owns the land the dike traverses at McDonald Beach Park road, the No. 2 Road Bridge, and Shannon Road, though YVR is responsible for the dike in these locations. In addition to these noted locations of Richmond ownership with YVR dike responsibility, there may be additional locations where Richmond owns the land the dike crosses (such as Grauer Road or Ferguson Road). This mixed ownership and uncertainty is the result of historic proposed and completed land exchanges with the federal government on Sea Island, as part of the development of the airport. The Phase 5 Dike Master Plan does not resolve long-standing land ownership uncertainties on Sea Island; however, consultation has contributed to the process of resolving dike land ownership, with these efforts continuing beyond the Dike Master Plan.

Reach 3 - Richmond Island

No existing dike is in place on Richmond Island. The only flood protection works is riprap bank protection works along the southern bank. The total perimeter of Richmond Island is approximately 1.2 km. The land elevation of Richmond Island ranges from 6.4 m CGVD28 at the north end to 3.4 m CGVD28 at the south end, where the Island is connected to the City of Vancouver. The entire island is one lot currently leased by Milltown Marina & Boatyard Ltd. which includes a restaurant, marina, and private utilities. Richmond Island is not included in the current OCP.

A restrictive covenant[1] attached to the land title was created in November 27, 2012 with North Fraser Terminals Inc., the Milltown Marina & Boatyard Ltd., and the City of Richmond that:

- acknowledges the risk of flooding and erosion on Richmond Island;
- notes that the City has no plans to protect the island from flood and erosion; and
- releases the City from any damage or losses caused by flooding or erosion.

As a result of the terms of this covenant, the City may consider implementing no flood protection measures for Richmond Island.

[1] CA2885848 RCVD: 2012-11-27

Table 2-1: Phase 5 Reaches and Features

Reach ID and Name	Extent / Length	Existing Dike Alignment	Major Features
1- Mitchell Island	Entire Island (7.8 km perimeter)	None	• Condition and elevation of existing dike and bank protection on western half of Mitchell Island is unknown (no available background information, no inspections or maintenance) • Dense industrial development on the entire island • Mitchell Road South Drainage Pump Station • Tipping Road South Drainage Pump Station • Large number of industries and businesses as stakeholders • Active water lots used by industry • Two City watermains to Mitchell Island from Lulu Island • Metro Vancouver Twigg Island Forcemain underneath existing dike on north side • Land elevation generally between 2.5 m and 4.5 m CGVD28 but as low as 1.5 m CGVD28 • Intermittent bank protection works in some locations • Two City parks along the river bank, no other public access to the river bank • Bathymetry suggests potential scour on the foreshore and scour holes on the north side
2 - Sea Island	South end of BCIT to south side of Airport Connector Bridge (1.1 km)	Walking and cycling trail	• Dike is a pedestrian path • Miller Road Drainage Pump Station • Commercial development directly abuts existing dike in several locations • Marina and restaurant access on the river-side • Tie in and jurisdiction boundaries with YVR adjacent to the Moray Channel Bridge and South of BCIT • Lowest area of dike north of Lysander Lane (<3.5 m CGVD28 elevation) • Low area directly adjacent to Cessna Drive with no established dike right-of-way • One section of dike already upgraded to 4.7 m CGVD28 elevation at 3600 Lysander Lane • Drainage outfall with flap gate at North end of BCIT campus not identified in City drainage utilities

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Reach ID and Name	Extent / Length	Existing Dike Alignment	Major Features
			• Sanitary forcemain crossing near BCIT • Little to no bank protection • High value marsh habitat from BCIT to hotel • North of BCIT, there is an old water connection to the foreshore where industrial activity used to take place on the river • The Moray Channel Bridge that the dike currently connects to is below 4.7 m CGVD28 (based on 2016 EMBC LiDAR).
3 - Richmond Island	Entire Island (0.55 km length)	None	• No existing dike • Connected to City of Vancouver via a short causeway, which provides utilities from Vancouver • Majority of the land is higher than the current dike elevation of 4.7 m CGVD28 and future elevation of 5.5 m CGVD28. The only exception is the causeway to Vancouver. • Existing private bank protection works visible on the south side • The north arm of the Fraser River along Richmond Island is a location of channel scour, with elevations as low as -11 m CGVD28. • All of the land on Richmond Island is one lot and is owned by Milltown Marina Moorage Co Ltd. • Restrictive covenant in place as of 2012 (CA2885848): ○ *"the City currently does not have any plans to install a Dike system on or near the Lands or to otherwise protect the lands from flooding and/or erosion."*

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2.2 Land Tenure

Land tenure on each island in Phase 5 includes a mixture of rights-of-way, private property, and City-owned land. Flood and erosion covenants have been established in the past for various properties in Phase 5, which are summarized in Table 2-2. Land tenure along the river bank or existing dike is described below for each island and shown on Figure 2-1.

Mitchell Island

Though a private dike was constructed in the past, no land tenure is established on Mitchell Island for a dike. The majority of the river bank is located on either private property or on aquatic Crown land (designated as Fraser River foreshore) where the City has no existing right-of-way. The City owns land along the river bank at two-small parks and at the Knight Street Bridge off-ramps, and there is a short right-of-way immediately west of the Knight Street Bridge on the south side of the island.

Sea Island

Sea Island is protected by an approximately 15 km long perimeter dike, but diking responsibility largely rests with the Vancouver Airport Authority (YVR). Only one eastern reach is under the City's responsibility, from the Moray Channel Bridge to the southern property boundary of BCIT (approximately 1.1 km). An active right-of-way is in place from BCIT to Lysander Lane, with one gap north of BCIT, but there is no right-of-way north of Lysander Lane.

The City also owns the land the dike traverses at McDonald Beach Park road, the No. 2 Road Bridge, and Shannon Road, though YVR is responsible for the dike in these areas. In addition to these noted locations of Richmond ownership with YVR dike responsibility, there may be additional locations where Richmond owns the land the dike crosses (such as Grauer Road or Ferguson Road). This mixed ownership and uncertainty is the result of historic proposed and completed land exchanges with the federal government on Sea Island, as part of the development of the airport.

The transition points for dike responsibility are not clearly defined, and the City and YVR have discussed this matter during consultation (see Section 3.6 for further discussion).

Richmond Island

Richmond Island has no existing land tenure in favour of the City (ownership or right-of-way). Richmond Island is one lot owned by North Fraser Terminals Inc., which is leased by Milltown Marina & Boatyard Ltd. The development is connected to the City of Vancouver and its utility network.

A restrictive covenant[2] attached to the land title was created in November 27, 2012 with North Fraser Terminals Inc., the Milltown Marina & Boatyard Ltd., and the City of Richmond that:

- acknowledges the risk of flooding and erosion on Richmond Island;
- notes that the City has no plans to protect the island from flood and erosion; and
- releases the City from any damage or losses caused by flooding or erosion.

[2] CA2885848 RCVD: 2012-11-27

Flood and Erosion Covenants

The City provided a title and covenant information for properties along the Phase 5 dike sections under their authority. This information was provided to the City by Dye and Durham, a legal process serving company. The following table summarizes the covenants that pertain to flood and erosion protection, for future awareness and consideration while developing flood protection works.

Table 2-2: Existing Flood and/or Erosion Covenants

Covenant ID	Date Established	PIDs	Address
Mitchell Island			
BB2020219	2012/08/22	None	11060 & 11200 Twigg Place
BK187446	1996/06/17	003-684-539 003-684-547 003-684-652 003-684-687	Group 1 New Westminster District Lots: 528, 5587, 1014, 459, 5091, 5782
BP304365	2000/12/19	008-591-857	Group 1 New Westminster District Lots 459, 1014
BX10111	2005/09/06	003-679-837	Group 1 New Westminster District Lot 459
Sea Island			
BB843923	2006/03/25	017-560-616	3800 Cessna Drive
CA3630774	2014/03/13	None	3600 Lysander Lane
CA3630776	2014/03/13	026-601-621	3600 Lysander Lane
Richmond Island			
CA2885848	2012/11/27	025-409-018 003-335-232	Richmond Island and Group 1 New Westminster District Lots 3869 and 3871

2.3 Infrastructure

There is limited municipal infrastructure along the existing dike corridor / island perimeters. This includes pump stations summarized in the table below.

Table 2-3: Phase 5 Pump Stations and Locations

Pump Station	Location
Miller Road	Sea Island - North end of City reach
Tipping Road South	Mitchell Island – South end of Tipping Road
Mitchell Road South	Mitchell Island – South end of Mitchell Road

On Mitchell Island, there may be private infrastructure associated with industrial uses, particularly water-oriented industries, which may conflict with potential diking options. This will be explored through stakeholder consultation.

2.4 Habitat

Desktop Review

A desktop review was conducted of the ecological setting along and adjacent to the existing dikes in Phase 5. The study area includes the existing dike alignment and adjacent land or intertidal area. Spatial data were used to identify overlap of known environmental values with the study area.

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), and
- City of Richmond aerial photographs and Riparian Area Regulation 5 m and 15 m buffer layers (Richmond Interactive Map 2017).

For the purposes of the desktop review, and to allow for a concise description of the different habitat types in the locations within the Phase 5 study area, seven discrete focal areas were defined. Results of the desktop review are presented below and listed by focal area in Table 2-3.

The location and extent of high-quality Fraser River riparian and intertidal habitat were identified to inform the 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 and interpretation of recent aerial photography (City of Richmond 2017).

Aquatic and Riparian Habitat

High quality intertidal and riparian habitat is present in all three Phase 5 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 all three Phase 5 reaches. These sections provide limited habitat value and construction here would have less of a negative impact on fish.

Eight existing fish habitat compensation projects have been completed between 1988 and 2007 in the Phase 5 study area. These included the creation of intertidal marsh and mudflat habitat and riparian habitat to compensate for damage to habitat elsewhere. More information on these compensation projects is provided in Table 2-4.

Wildlife and Terrestrial Habitat

Terrestrial habitat types in Phase 5 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 six reaches of Phase 5. Orthoimagery review identified potential raptor nesting trees in all three reaches of the Phase 5 study area.

Drainage channels that may serve as amphibian breeding habitat were not identified in orthoimagery used for the desktop review. It is possible that amphibian habitat is present in small ponds or ditches 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 5 study area, but several occurrences exist on nearby 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 Phase 5 study area.

FREMP mapping (2007) indicates the presence of intertidal marsh communities in Reaches 2 and 3. Many of these communities in British Columbia are considered at-risk (i.e. Blue-Listed, meaning they are considered of special concern, or Red-Listed, meaning they are 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.

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 ID and Name	Location	Environmental Setting (organized by inland side and shoreline side of existing dike)	Construction Constraints	Construction Opportunities	FREMP Habitat Types	Richmond ESA Types Present	Known Species at Risk Occurrence Near Dyke Alignment	Potential Raptor Nesting Trees	Potential Migratory Bird Nesting Habitat	Existing Habitat Compensation Sites Present
1 - Mitchell Island	Inland Side	• Low-quality herbaceous habitat at the west end of the island • Small patch of deciduous treed woodland near centre of south side • Sections with no existing dike • Low quality disturbed habitat or paved (no habitat value) along rest of reach	Existing infrastructure Existing habitat compensation site	n/a	Paved Vascular meadow Deciduous tree woodland	Shoreline	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	Project: Canada Line Year Created: 2005 Industrial development Year Created: 2007 McQueen's Boat Works Year Created: 1989 Project: Miller Road Pump Station Year Created: 1991 Bridgeport Market Year Created: 1988 Project: Arrow Transportation Soil Remediation Year Created: 2007
	Fraser River Side	• High quality deciduous tree riparian habitat in patches along length north side of Island • Moderate quality low shrub riparian habitat for most of length north side of island • Sections of moderate quality riparian habitat along south-east side of island (low shrub woodland, deciduous tree woodland) • Sections of high quality mudflat and sandflat intertidal habitat along north and south sides of island • High quality intertidal marsh, on southwest side of island • Low quality armored bank along south west side of island	Moderate-quality riparian along most of length of shoreline on north side of island High-quality intertidal habitat along majority of length of shoreline	n/a	Paved Mud Sand Marsh Gramonoids and forbs Vascula meadow Low shrub woodland Tall shrub woodland Deciduous tree woodland	Shoreline Intertidal				
2 -Sea Island	Inland Side	• Sections of low quality lawn • Sections of paved parking lots with no habitat value	Existing infrastructure	n/a	Mowed grass Mostly parking lot	Shoreline	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	
	Fraser River Side	• Sections high quality marsh and mudflat intertidal habitat concentrated around centre of reach • High quality deciduous woodland riparian habitat at south half of reach	High-quality riparian and intertidal habitat in centre of reach Existing habitat compensation site at north end of reach	n/a	Mud Marsh Deciduous tree woodland Shoreline in front of Marina not included in FREMP mapping	Shoreline Intertidal				
3 - Richmond Island	Inland Side	• No existing dike	No existing dike	n/a	Not included in FREMP mapping	Shoreline	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	Y	Project: Canfor Year Created: 1988
	Fraser River Side	• High quality mudflat intertidal habitat along full length on north side • Moderate quality low shrub woodland riparian habitat above armoured bank on south side low quality armoured bank along full length of south side	High-quality intertidal habitat along full length north side Moderate-quality riparian habitat along south side Existing habitat compensation site	n/a	Mud Low shrub woodland Sand	Shoreline Intertidal				

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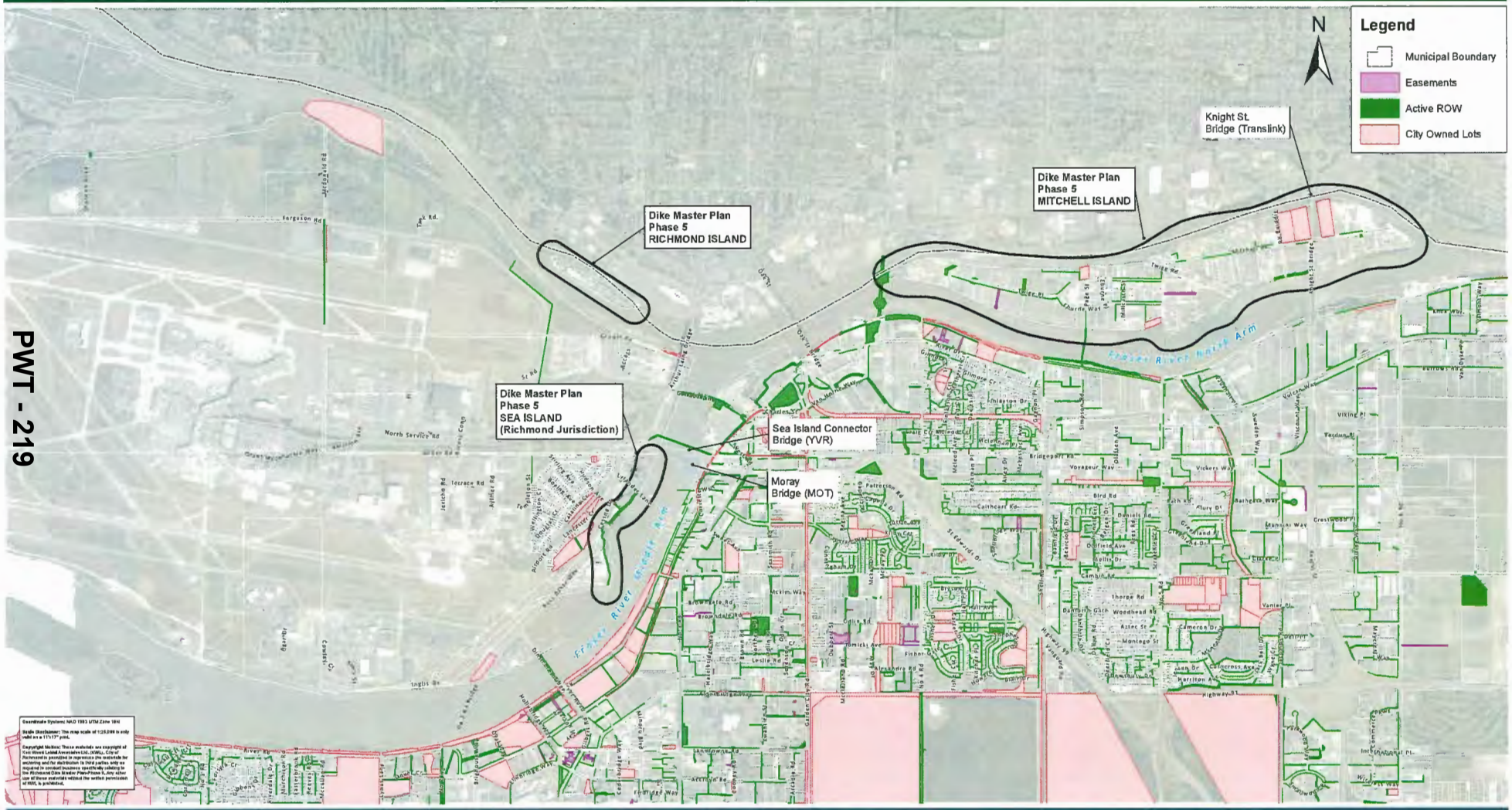

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Existing Land Tenure

Figure 2-1

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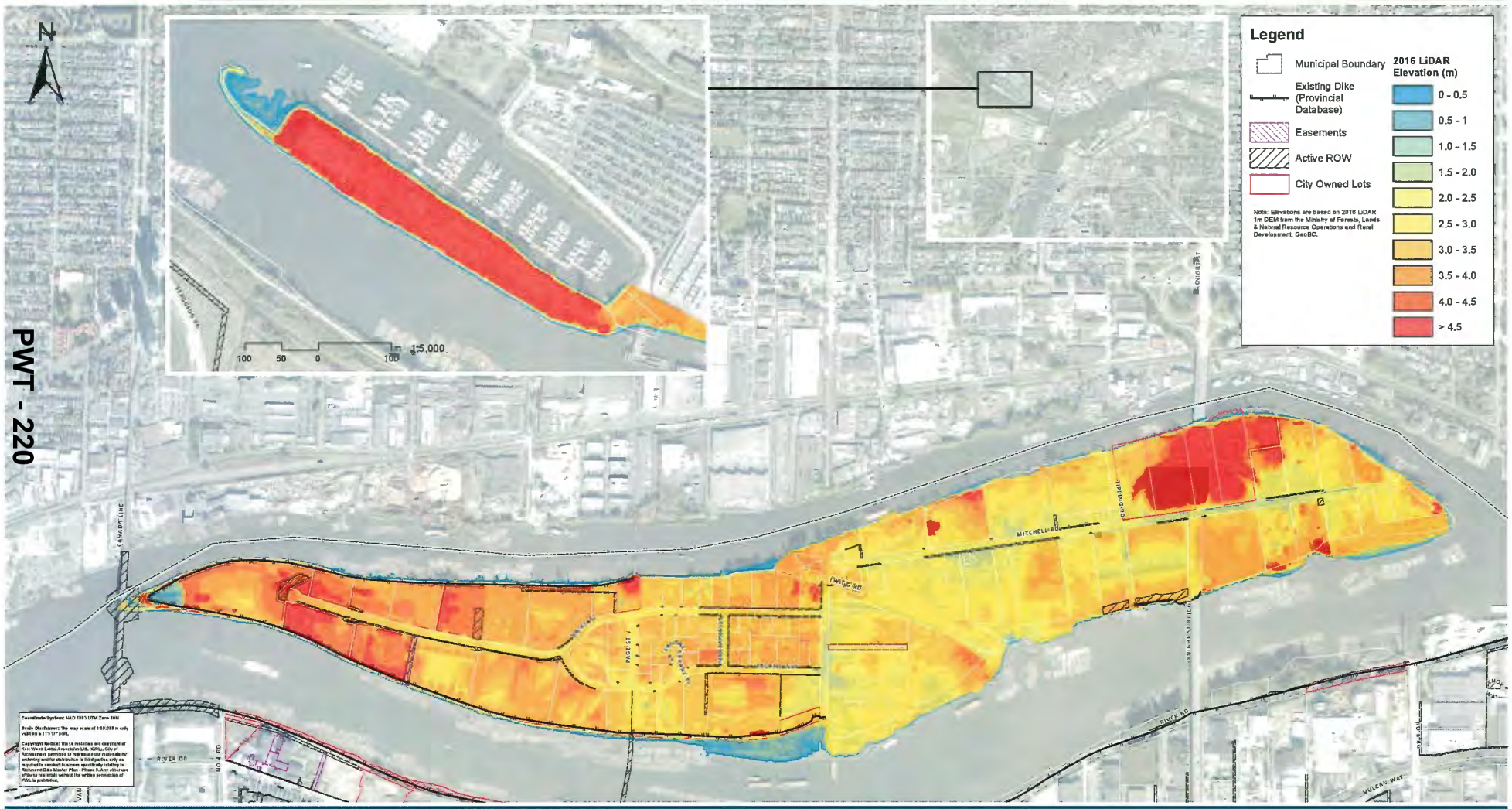

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Mitchell Island and Richmond Island Existing Ground Elevations

Figure 2-2

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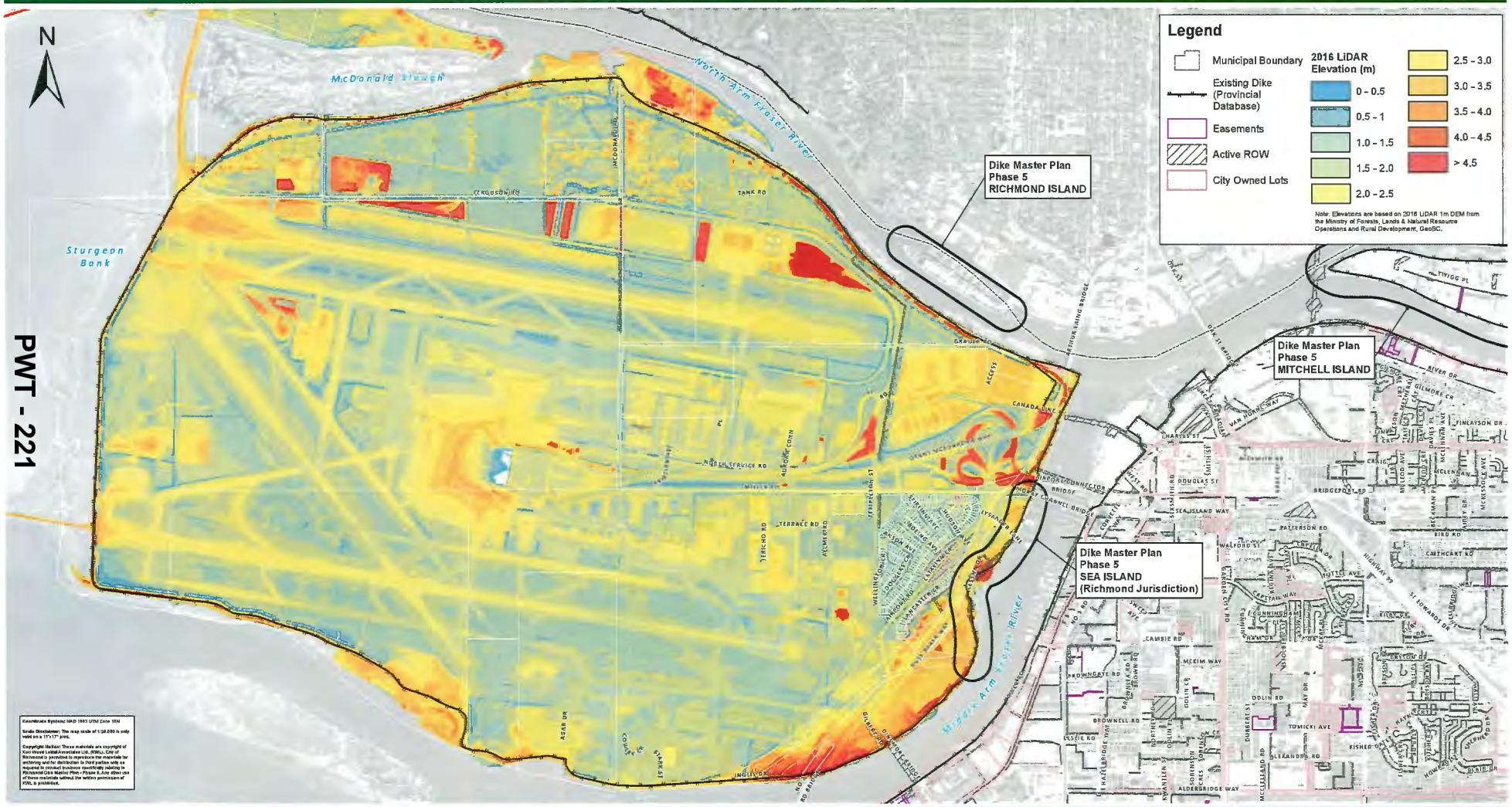

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Sea Island Existing Ground Elevations

Figure 2-3

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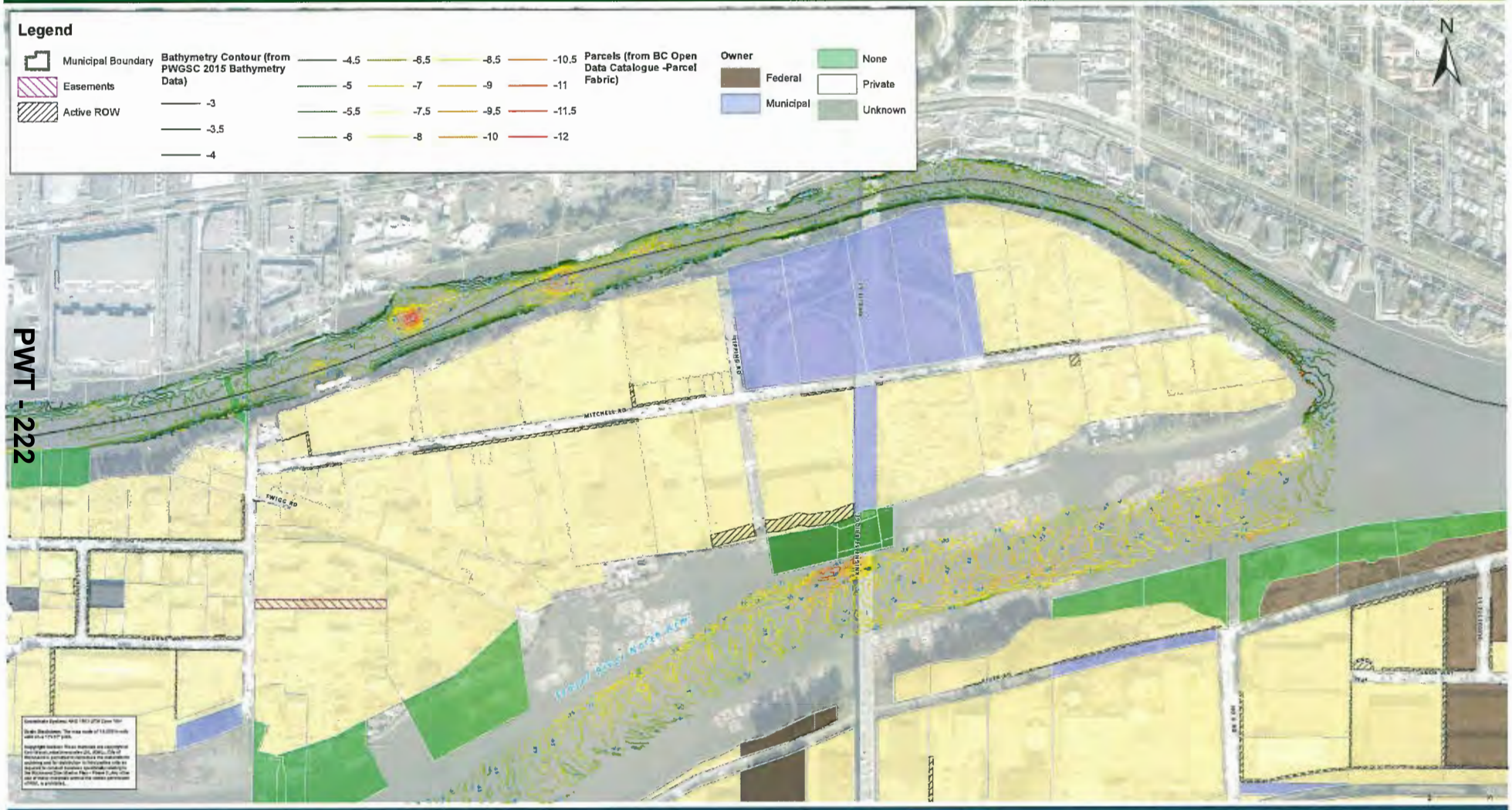

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Bathymetry Contours - Mitchell Island

Figure 2-4

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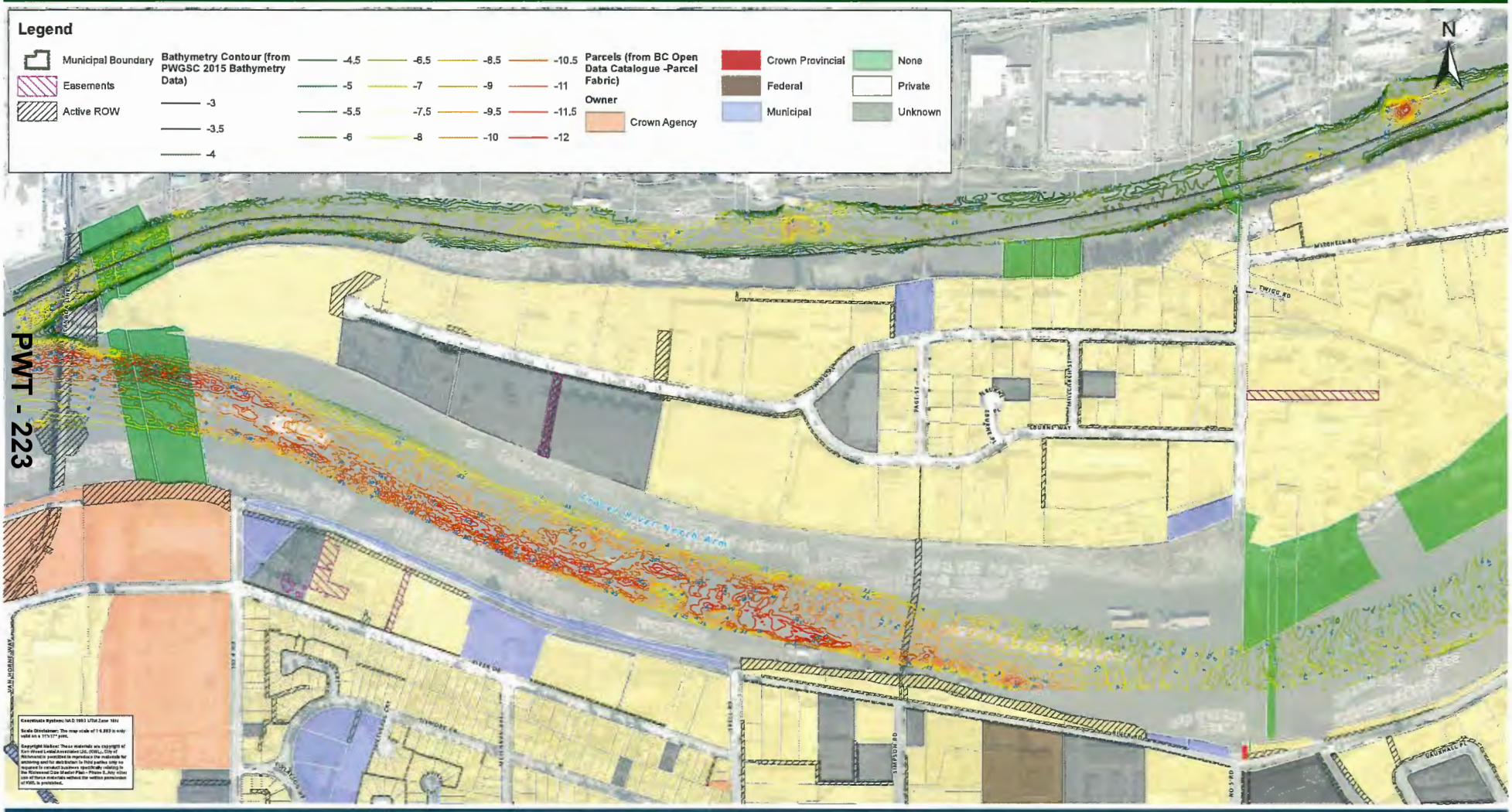

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Bathymetry Contours - Mitchell Island

Figure 2-5

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Bathymetry Contours - Sea Island

Figure 2-6

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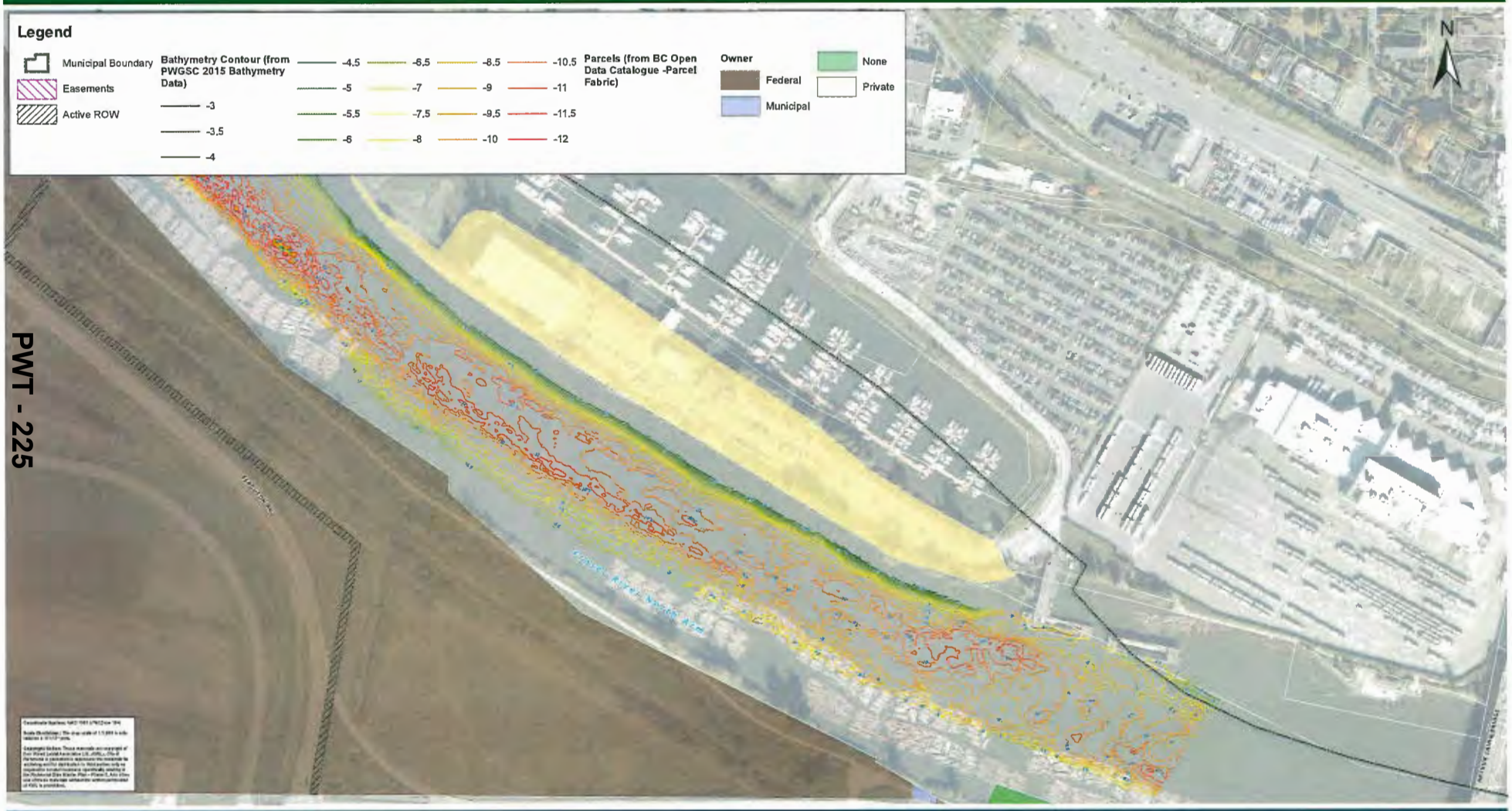
KERR WOOD LEIDAL consulting engineers



PWT - 225

Project No. 651.129

Date February 2019

Scale 1:3,000

50 25 0 50 m

Bathymetry Contours - Richmond Island

Figure 2-7

3. Options Assessment

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

- design considerations and design criteria;
- upgrading strategies;
- upgrading options and concepts;
- summary of external stakeholder consultation;
- options evaluation; and
- recommended options for implementation.

3.1 Design Considerations

This section summarizes the main themes and issues that have informed the development of upgrading strategies and options for Phase 5. This includes general design considerations applicable for all three islands, and site-specific considerations for each island as described below.

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 an 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 City's perimeter dikes 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. For the river dikes, including those in Phase 5, this is determined as the site-specific maximum of spring freshet flood and a coastal winter flood (combination of tide/storm surge with Fraser River winter flow). However, the Dike Master Plan should be flexible to accommodate a future change in the design flood scenario in the future.
2. **Form and Performance:** The preferred form of a 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. Phase 5 considers alternative structural flood protection options apart from a dike in undiked areas. The level of performance of flood protection works for Sea Island, Richmond Island, and Mitchell Island should be in line with the moderate population (mainly Sea Island) 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). The dike design should consider the need for regular and emergency maintenance.
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)**:** There will always be uncertainties in dike design and performance, and completely preventing any dike failures cannot be guaranteed. However, 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 results in a sudden and full failure of the dike cross-section into the river, referred to as a 'flowslide failure'. Other conditions where the dike crest settles, but still provides sufficient freeboard and factors of safety until repairs can be conducted may be acceptable. 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. The specifics of post-earthquake protection requirements are dependent on the seismic performance criteria currently under review as part of the Richmond Flood Protection Management Strategy update.
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	• 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 against stability • Minimal infrastructure within the dike corridor • Adequate bank protection works 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

Design Principle	Ideal Design Principles and Considerations
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

Dikes are often located adjacent to or under roads. The safety of drivers, cyclists, and pedestrians on existing roadways is a consideration in Phase 5. In Phase 5, some design options consider relocating the dike to an existing road (Sea Island) or raising roads to provide emergency egress (Mitchell Island). This includes Cessna Drive, Russ Baker Way, Lysander Lane, and Hudson Avenue on Sea Island, and potentially the entire road network on Mitchell Island.

City transportation engineering staff were consulted during the master plan development to provide input on dike upgrading concepts that will also improve road safety. Current options include providing the same level of service for vehicles, pedestrians, and cyclists as already provided. Travel lane and multi-use path widths are documented in the design criteria in Section 3.2.

Vehicle access to properties located along proposed upgrade areas is also an important consideration. Dike raising alignments that raise roadways will impact driveway access for commercial and industrial landowners. Land-use on these properties includes industrial and commercial. As such, a variety of vehicles, including semi-trailer trucks, need safe access from the roadways to these properties. Currently, these properties are generally at grade with and access is provided via asphalt or gravel driveways.

Driveway access was considered in options development by identifying several access upgrading concepts including land filling to raise sites to the dike/road level and raising driveways to tie-in with the upgraded roadways.

Shared Dike Responsibility with YVR on Sea Island

As previously noted, YVR and the City of Richmond share responsibility for the Sea Island perimeter dike. The options development and assessment only include concepts for the reach of the dike that the City is responsible for: from the Moray Channel Bridge to the southern property boundary of BCIT (approximately 1.1 km). The boundaries of YVR and Richmond jurisdiction have been discussed during consultation for the Dike Master Plan, and the figures in the report represent the discussed boundaries based on property ownership along this reach. Shared responsibility requires coordination with YVR at tie-in locations, and to ensure consistent dike upgrade criteria are used for the dike system.

Other reaches of the dike where the City owns land (discussed in Section 2) are understood to be YVR's responsibility, and the City will be consulted as YVR plans upgrades to the dike on City land. YVR has met with the City and noted its plans and progress to upgrade the Sea Island dike to 4.7 m CGVD28. YVR has already upgraded portions of the dike to this elevation along the south airfield and near Grauer Road. YVR plans to complete its own Dike Master Plan in the coming years to guide long-term dike upgrading.

As part of consultation with YVR, it was agreed that the two parties would work toward formalizing an agreement on dike jurisdiction.

Existing Commercial and Industrial Developments

Sea Island

The dike on the eastern side of Sea Island is closely hemmed in by the river and existing development. Dike improvements will impact waterfront access, the existing developments, and pedestrian access. Major developments along the dike include BCIT, Pacific Autism Family Center, Lysander Holdings Ltd, and the Pacific Gateway Hotel (Van-Ari Holdings Ltd). In addition, the dike closely parallels Cessna Drive in one location with no established dike right-of-way and a low crest elevation. Dike upgrading options consider limiting impacts to these developments while maintaining flood protection.

Mitchell Island

Mitchell Island is tightly constrained by industrial and commercial facilities, including private water-oriented industries and other commercial and industrial sites along the river bank with little setback or access. Dike construction would require significant land acquisition (discussed further below), and consideration of the functionality of industrial sites.

Future dike construction on Mitchell Island may be challenging due to conflicts with site functionality for water-oriented industries as the dike height increases, lack of existing or need for new dike rights-of-way, and limited access to the river bank. The Dike Master Plan considers non-standard dike structures to reduce space required, opportunities to separate the dike alignment from water-oriented industries, and land raising by property owners to allow for continued use of the industrial spaces.

Internal Drainage System

As with any diked area, the drainage for the protected interior 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.

The Phase 5 islands have limited locations where drainage infrastructure is located within likely dike upgrade / construction areas. Drainage infrastructure along the current or potential future dike alignment is limited to pump stations with associated drainage ditches and several drainage pipes that cross the dike with outfalls in the Fraser River. Existing drainage pipes that cross dike upgrades may need to be relocated or upgraded to accommodate the proposed section. As part of upgrades at pump stations, the existing intakes, associated ditch, and outfall may need to be modified or extended, and the pump station piping should be reviewed to consider structural impacts of the preferred dike section. In addition, pump station upgrades in the future should consider higher outfall water levels due to sea level rise and the associated higher required pump capacity.

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 and river bank (in undiked areas) is confined on both sides by private property with little to no room for expansion of the dike footprint or construction of a new dike. On Mitchell Island in particular, the river bank is very densely developed with no existing dike corridor and minimal land tenure in favour of the City. In options development, the City noted it would prefer securing rights-of-way over acquiring land.

The master plan identifies land acquisition needs for various upgrading options for comparison.

An alternative to land acquisition may be land use planning and development control tools to raise private properties to the dike elevation to create a wide raised platform (similar to recent developments along the Middle Arm (e.g. Olympic Oval).

River Scour

Dike design along the Fraser River should consider the potential for scour that may undermine the dike. Bathymetry data is collected by the Vancouver Fraser Port Authority ("Port") in the main channel of the river to ensure navigation is unimpeded. Due to the navigational focus of the data collection, near-shore bathymetry along the islands in the Fraser River is not collected. In further stages of design beyond the Dike Master Plan, dike upgrades should consider local scour risks and potential collection of additional near-shore bathymetry data where the Port data indicates scour may be occurring. Due to the large size of the river, constructing bank protection works (riprap or other), below the scour depth is often not practical. Design could consider filling scour holes (see existing scour holes on Figures 2-4 to 2-7), or investigation of site-specific scour protection.

Sea Island Bridges

The Sea Island dike alignment at the north end of the City's reach ties into the Moray Channel Bridge (Ministry of Transportation ownership). The land between the Moray Channel Bridge and the Airport Connector Bridge (YVR ownership) is above the current dike level of 3.5 m CGVD28, based on 2016 EMBC LiDAR data. For future raises, the land between the bridges would need to be raised, but more significantly, the Moray Channel Bridge deck is below 4.7 m CGVD28 and poses a gap in the dike for the future design flood level. In the long term, it would be preferred if the bridge was replaced with a higher deck structure that at least meets the upgrade dike elevation of 4.7 m CGVD28 and exceeds the future dike elevation of 5.5 m CGVD28. The area north of the Miller Road right-of-way is on federal land and the dike in this area is understood to be YVR's responsibility. The City should consult with YVR and MOTI regarding raising the dike north of the Miller Road, the land between the two bridges, and Moray Channel Bridge in the long-term.

Mitchell Island Contamination

As a result of the long history of industry and fill from unknown sources, it is expected that a significant portion of Mitchell Island may be contaminated (according to City staff). This has implications for dike design in that material excavated may be contaminated and land acquisition would have greater cost and liability to address potential contamination. In addition, current land use on the island includes industries with oil, fuel, metals, and other potential pollutants, which present an environmental risk if the island were flooded.

Environmental Considerations

City of Richmond Bylaws

The City's Official Community Plan (OCP) bylaw (2012) includes an Ecological Network Management Strategy (ENMS) that identifies ecologically important areas in the City's Ecological Network (EN). These areas include Environmentally Sensitive Areas (ESAs), 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 (City of Richmond 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 Regulation* of the *Riparian Areas Protection Act* (formerly the *Fish 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 higher value drainage channels or more natural watercourses and are to remain free from development unless authorized by the City (City of Richmond, 2017). RMAs are not present in Phase 5 reaches.

Hubs, sites, and corridors are components of the City of Richmond's EN, which aren't specifically afforded protection, but often overlap ESAs and RMAs, which are protected. These components are present on Sea Island and Richmond Island.

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	All	• Preserve existing shoreline vegetation and soils, and increase natural vegetation in developed areas during development or retrofitting
Upland Forest	None	• 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	None	• 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: (City of Richmond 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 measures may include habitat restoration or enhancement and habitat creation, and must be proportional to the loss caused by the project.

Often, the amount of offsetting habitat created is greater than the area of habitat impacted. The area of offsetting may need to be increased to account for uncertainty with the effectiveness and time lag between impacts and offsetting. Selecting offsetting locations and beginning habitat creation works prior to all impacts occurring can help to reduce requirements for additional offsetting area required due to lag time. Creation of a smaller number of larger area habitat restoration, enhancement, or creation sites would allow for a more efficient use of resources and potentially reduce uncertainty.

Where possible, impacts to existing habitat compensation sites should be avoided. Where impacts to these sites are not avoidable, habitat offsetting will likely be required, and requirements will be determined through discussions with Fisheries and Oceans Canada (DFO).

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 disturb or harm 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 may use the drainage channels on the land side of the dike at certain times of year. These species are protected by the provincial *Wildlife Act* and detailed design should also consider potential impacts to these species

3.2 Design Criteria

This section describes the main design criteria used in the Phase 5 Dike Master Plan. These criteria were developed and reviewed in collaboration with City staff.

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: Phase 5 Design Criteria Summary

Item	Value and Description	
	Minimum Acceptable	Preferred
Proposed Dike Crest Elevation	4.7 m CGVD28 downstream of Nelson Road (all of Phase 5)	
Future Dike Crest Elevation (for proof-of-concept design)	5.5 m CGVD28 downstream of Nelson Road (all of Phase 5)	
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
Land Adjacent to Dike	Land is raised as much as is practical	Land is raised to meet or exceed dike crest elevation
Seismic Performance	Seismic performance criteria currently under review as part of the pending Richmond Flood Protection Management Strategy update and further consultation with the Province.	
River-side Slope, Setback, and Vegetation	2H:1V bank slope with riprap revetment designed for freshet flow velocities and vessel-generated waves Vegetation in/near the dike should adhere to provincial guidelines	>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, Land-side Slope Treatment, and Vegetation	Crest surfacing: 150 mm thick road mulch Land-side slope treatment: hydraulically seeded grass Vegetation in/near the dike should adhere to provincial guidelines	Meet or exceed provincial dike standard and City dike standard Consider paved crest and land-side slope vegetation/armouring to add robustness against overtopping
Road Design Width[a]	0.5 m allowance for barrier & 0.6 m min horizontal clearance on road shoulders 3.5 m travel lanes (to existing service level) 3.0 m multi-use path for non-industrial Total width (2-lanes): 9.2 m	0.5 m allowance for barrier & 0.6 m min horizontal clearance on road shoulders 1.5 m min. boulevard along shoulders 1.5 m sidewalks or 3 m two-way path [b] 3.0 m two-way cycling path to replace existing facilities [b] 3.5 m travel lanes (to existing service level)

a. Based on City of Richmond Engineering Design Specifications for Roadworks (2008) and City staff input. https://www.richmond.ca/__shared/assets/Roadworks20127.pdf
b. For industrial areas (Mitchell Island), cycling facilities and two-way paths are not included (maintains current level of service).

Dike Crest Elevation

At this time, the Province has not established an official 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 (MFLNRO, 2014).

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

- 500-year return period coastal water level with 1 m of sea level rise (no wind/wave effects) with winter Fraser River flood flow; 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 wind/wave effects and 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. Adequate information on wind/wave effects is not available at this time and is a consideration in the pending Richmond Flood Protection Management Strategy update. However, it is generally assumed that the dike reaches within Phase 5 are not significantly impacted by wind/wave effects. This assumption should be confirmed during detailed design. Table 3-4 presents the components that sum to the proposed dike crest elevation for Phase 5, which is entirely located in the area governed by the coastal flood hazard.

Table 3-4: Phase 5 Flood Levels and Dike Crest Elevations

Item	Downstream of Nelson Road
Governing Flood Hazard	Tide + storm surge (with historic winter Fraser River flow)
Level of Performance	500-year return period (0.2% annual exceedance probability)
Climate Change Allowance	1 m sea level rise
Designated Flood Level (m, CGVD28) [a]	3.8
Wind/Wave Effects Allowance (m)	None
Freeboard (m)	0.6
Land Subsidence Allowance (m)	0.2
Minimum Dike Crest Elevation (m, CGVD28) [b]	4.7[d]
Future Dike Crest Elevation (m, CGVD28) [c]	5.5[d]

Notes:
a) From (BC MFLNRO, 2014).
b) The City's adopted downstream design crest elevation (4.7 m) exceeds the minimum required elevation (4.6 m). This is a result of updated coastal water level analysis methods (joint probability analysis) that result in a discrepancy when compared to previous methods (additive method).
c) Expandable for an additional 1 m of sea level rise (no additional freeboard or land subsidence allowance).
d) Dikes may need to be overbuilt to achieve target crest elevation following post-construction settlement. This should be addressed by an additional site-specific crest elevation allowance to be determined during detailed design.

The master plan also allows for further upgrading by providing proof of concept for raising to between 5.5 m downstream of Nelson Road (coastal).

Seismic Performance

The current provincial seismic performance criteria for dikes[3] 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. In January 2019[4], the Province released a status update for the two components of the review and clarifications on the existing guidelines:

- Dike Consequence Classification (anticipated to be completed in 2019); and
- Seismic Assessment and Geotechnical Investigation of Lower Mainland Dikes (anticipated to be completed in 2021).

The seismic performance criteria for dikes in Richmond are currently under review as part of the pending update to the Richmond Flood Protection Management Strategy, with consideration of potential alternative performance approaches. As a result, City-specific seismic performance criteria are not established as a part of Dike Master Plan Phase 5, with the expectation that this will be further developed and discussed as part of the Flood Protection Management Strategy, and in discussion with the Province.

Vegetation

Vegetation on and adjacent to the dike should adhere to provincial vegetation guidelines[5]. These guidelines limit vegetation on the dike crest, side slopes, and landside toe predominantly to trimmed grass, with specific situations where other vegetation may be allowed (overwide dikes, natural levees, setback dikes). The guidelines include consideration for variations that may be considered for sensitive habitat:

> "Where environmental agencies have significant concerns for areas of sensitive habitat (such as historically overgrown works and/or FREMP red-coded areas), variations from these guidelines may be considered to increase protection of habitat where practical and economic, provided public safety is not compromised."

Richmond could consider developing more prescriptive City-wide dike vegetation management guidelines, which would require acceptance by the Province. Such guidelines could consider opportunities to increase the robustness of dikes, while accommodating vegetation beyond trimmed grass (e.g. exploring methods to armour dikes against overtopping erosion while accommodating shrubs and small trees).

[3] Seismic Design Criteria for Dike. 2nd Edition, June 2014. Ministry of Forests, Lands, and Natural Resource Operations Flood Safety Section. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/seismic_guidelines_dikes-2014-2nd_edition.pdf
[4] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/iod_letter_re_seismic_2019.pdf
[5] Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment. http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/env_gd_veg_man.pdf

3.3 Alternative Upgrading Strategies

Several high-level upgrading strategies, summarized in Table 3-5, were considered to inform the development of specific options for the Dike Master Plan.

Table 3-5: High-level Dike Upgrading Strategies

Strategy	Advantages	Disadvantages
Road Dike *Raise adjacent 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
Raise Riverbank Dike *Conventional dike along riverbank extending land-side*	• Minimize footprint	• Limited space • Impacts to river side riparian and intertidal habitat and land 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	• Larger impacts to river side 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
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
Bank Protection Works Only *Protect the river bank from erosion*	• No City responsibility for a dike • Reduced impacts to industrial and commercial activities	• Reliance on private development reliance for land raising • Acceptance by property owners of flood risk • Environmental impact (river works and flooding related contamination)

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 that may be appropriate for each island. The broad overall options developed for Phase 5 are listed below, with specific options by island in the following sections.

- Option 1: Build/raise dike
    - Option 1a: Build/raise standard river dike and extend land-side
    - Option 1b: Build/raise standard river dike and extend river-side
    - Option 1c: Build/raise dike with land-side retaining wall
- Option 2: Raise land
    - Option 2a: Raise land to dike elevation
    - Option 2b: Raise land to acceptable level of flood protection
- Option 3: Maintain/install bank protection works only
- Option 4: No structural improvements

In addition to the above general options, the following options have been developed to address site-specific issues at water-oriented industries and at select other locations.

- Option 1d: Build/raise dike with sheetpile wall on river-side (Mitchell Island water-oriented industry)
- Option 1e: Build setback dike along Cessna Drive North of BCIT
- Option 1f: Build setback dike around hotel on Sea Island
- Option 1g: Raise dike with river-side sheetpile wall and land-side retaining wall along hotel on Sea Island (interim option)
- Option 2c: Raise roadways with required land raising on private property on Mitchell Island

Table 3-6 presents a summary of the options as applied to each island based on discussions with City staff and is followed by a discussion of the options.

Table 3-6: Major Dike Alignment and Cross-section Options

Reach ID & Name	Alignment and Cross-section Options
Mitchell Island: General	• Option 1a: Build standard river dike and extend land-side • Option 1b: Build standard river dike and extend river-side • Option 1c: Build dike with land-side retaining wall • Option 2a: Raise land to dike elevation • Option 2b: Raise land to acceptable flooding level • Option 2c: Raise roadways with required land raising on private property • Option 3: Maintain/install bank protection works only • Option 4: No structural improvements
Mitchell Island: Water Oriented Industries	• Option 1d: Build dike with sheetpile wall on river-side
Sea Island: General	• Option 1a: Raise standard river dike and extend land-side • Option 1b: Raise standard river dike and extend river-side • Option 1c: Raise dike with land-side retaining wall (at constrained locations) • Option 2a: Raise land to dike elevation

Reach ID & Name	Alignment and Cross-section Options
Sea Island: Pacific Gateway Hotel and at Cessna Drive north of BCIT	• Option 1e: Build setback dike on Cessna Drive North of BCIT • Option 1f: Build setback dike around hotel • Option 1g: Raise dike with sheetpile wall on river-side and land-side retaining wall (interim option)
Richmond Island: General	• Option 2a: Raise land to dike elevation • Option 2b: Raise land to acceptable flooding level • Option 4: No structural improvements

Option 1A: Build/Raise Standard River Dike and Extend Land-side

The primary option developed for Mitchell Island and Sea Island involves raising or constructing a standard dike and extending the footprint of the fill towards the land-side. Figure 3-2 presents a typical cross-section for this option, and Appendix A contains plan and section views of the footprint of this option for Sea Island.

Figure 3-2 shows a 10 m wide dike crest for a dike elevation of 4.7 m CGVD28. This overwide dike allows for raising to 5.5 m CGVD28 without additional dike footprint needs. Alternatively, the dike could be narrowed to a 4 m crest initially, which would require additional land for future raises. The river bank slope of the dike would include riprap bank protection works. This option is favourable as it would provide a standard dike as per the provincial dike design guidelines without impacting the foreshore beyond the installation of bank protection works. Where bank protection works is not already present, its installation will result in the loss of riparian habitat, which will require offsetting. There is no loss of riparian or aquatic habitat anticipated on the land side of the dike.

On Sea Island, this option is feasible for the majority of the City's dike reach and requires on average an additional 10 to 12 m beyond the current dike toe. However, there are several locations where this dike option could not currently be constructed due to limited space available for the dike (near hotel buildings/infrastructure, the marina, and Cessna Drive immediately north of BCIT). There may also be insufficient space in some additional locations for the future raise to 5.5 m CGVD28 (along BCIT and near Lysander Lane). Rights-of-way or land acquisition is required north of Lysander Lane and for a small section immediately north of the BCIT property. The dike upgrade may require upgrades at the Miller Road Drainage Pump Station, and relocation existing utilities and lighting along the dike path. The existing multi-use path would be maintained at the crest.

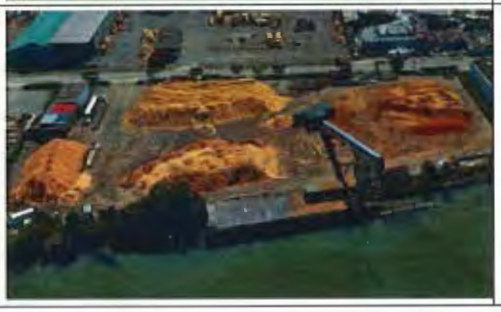
On Mitchell Island, there is currently no dike (or the previous dike has not been maintained or inspected). As a result, building a standard dike would require land acquisition or right-of-way for the entire perimeter of the island, with the exception of one small section where a right-of-way already exists. On average, this option would require 7 to 8 m of land from the riverbank landwards. There are several locations on Mitchell Island where construction of a dike would impact permanent or temporary structures, and many more where it would impact industrial operations. For some industrial sites, water access is required, and a standard dike may not be preferable. Any dike upgrade would require upgrades at the Tipping Road South and Mitchell Road South drainage pump stations. For all options, the Twigg Island sanitary forcemain (north side) and a watermain south of Paige Street underly the proposed dike and would need to be considered during detailed design. As Mitchell Island is industrial, a multi-use path would not be included along the dyke crest.

The areas with the most severe space limitations and potential options to address the access issues are presented in Table 3-9.

Table 3-7: Significant Space Limitations and Access Issues

Reach / Location / Description	Photo	Options to Address Footprint and Access
Sea Island Cessna Road north of BCIT property STA 0+430 to 0+460 (refer to Appendix A)		• Retaining wall on landside • Move dike towards River (see Option 1B) • Replace pump station during dike upgrades
Sea Island Pacific Gateway Hotel and Marina STA 0+850 to 1+000 (refer to Appendix A)		• Retaining walls and raised Marina access (see Option 1C) • Relocation of existing utilities and movement of temporary infrastructure
Sea Island Moray Channel Bridge and Airport Connector Bridge STA 1+070 to 1+130 (refer to Appendix A)		• Consider dike elevation in future bridge replacement deck elevation • Raise the land between the two bridges to dike elevation in the interim

Reach / Location / Description	Photo	Options to Address Footprint and Access
Mitchell Island Lafarge 13340-13360 Mitchell Rd STA 0+320 to 0+520 (refer to Appendix A)		• Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D)
Mitchell Island Terminal Forest Products Ltd. (south side) 12480-12380 Mitchell Rd STA 1+200 to 1+350 (refer to Appendix A)		• Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D)
Mitchell Island Richmond Steel Recycling - Broadway Properties Ltd 11760 Mitchell Road STA 1+400 to 1+450 (refer to Appendix A)		• Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D)
Mitchell Island Ontrack Systems Inc. (Container West & Platinum Marine) 11660-11580 Mitchell Rd STA 1+900 to 1+700 (refer to Appendix A)		• Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D)

Reach / Location / Description	Photo	Options to Address Footprint and Access
Mitchell Island Tipping Road South Drainage Pump Station STA 2+000 (refer to Appendix A)		• Replace pump station during dike upgrades
Mitchell Island Mitchell Road South Drainage Pump Station STA 2+000 (refer to Appendix A)		• Replace pump station during dike upgrades
Mitchell Island Grand Hale Marine Products Ltd. 11551-11571 Twigg Pl STA 5+150 to 5+400 (refer to Appendix A)		• Raise existing access points and provide dike crest access • Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D)
Mitchell Island Terminal Forest Products Ltd. (south side) 12191 Mitchell Rd STA 5+800 to 5+950 (refer to Appendix A)		• Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D)

Reach / Location / Description	Photo	Options to Address Footprint and Access
Mitchell Island Lehigh Hanson Materials Ltd. 12571 Mitchell Rd STA 6+150 to 6+350 (refer to Appendix A)		• Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D)
Mitchell Island Goldwood Industries Ltd. 12691 Mitchell Rd STA 6+350 to 6+520 (refer to Appendix A)		• Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D) *currently operating partially on City of Richmond road dedication
Mitchell Island Savo Lazarian (owner) 13611 Mitchell Rd STA 7+300 to 7+400 (refer to Appendix A)		• Raise existing access points and provide dike crest access • Raise parcel of land at time of redevelopment (see Option 2) • Install sheetpile wall on the riverbank to allow continued river access (see Option 1D)

Option 1B: Build/Raise Standard River Dike and Extend River-Side

A secondary option developed for Mitchell Island and Sea Island involves raising or constructing a dike by extending the footprint of the fill towards to the river-side (onto the Fraser River foreshore in some locations. Figure 3-3 presents a typical cross-section for this option.

Figure 3-3 shows a 10 m wide dike crest, which would be wide enough to accommodate a dike upgrade to 5.5 m CGVD28 without increasing the footprint. This approach would reduce the frequency of impact to the riparian or intertidal habitat by disturbing it more initially to prevent disturbance again when it is upgraded. Alternatively, the dike could be only 4 m wide initially, and require extension for future upgrades. Option 1B would result in the loss of aquatic habitat, which would need to be offset. The river bank slope of the dike would include riprap bank protection works at a minimum, but it could also include a riparian planting bench, saltmarsh, or bioengineering bank protection works to offset riparian habitat impacts. Work in the foreshore would require land acquisition, rights-of-way, or lease from the Province. This option provides a standard dike as per the provincial dike design guidelines and reduces impacts to adjacent properties; however, it would have negative environmental impacts and is not preferred for stability considerations building onto the river foreshore.

On Sea Island, this option could be considered in specific locations that are presently constrained (Cessna Drive north of BCIT), or locations that will be constrained in the future (Lysander Lane and BCIT). This option is generally not preferred for the entire dike reach, due to constraints near the hotel and at the Miller Road pump station, stability building on the foreshore, and habitat impacts. At Cessna Drive north of BCIT, only a small length of the dike runs directly along Cessna Drive and the dike is set back from the river bank. As a result, Option 1B could be selected for a short length in this location with relatively limited environmental impacts and without requiring any construction down the river bank itself. The existing multi-use path would be maintained at the crest.

On Mitchell Island, this option would reduce the need for land acquisition but the need for rights-of-way and access remains the same, given the present lack of access to the riverbank. Option 1B could be considered to reduce impacts to existing operations, though it was not preferred by the City in options development. As Mitchell Island is industrial, a multi-use path would not be included along the dyke crest.

The significant access and space constraints described in Table 3-8 are generally applicable to Option 1B as well.

Option 1C: Build/Raise Dike with Land-Side Retaining Wall

Option 1C involves building a dike with a landside retaining wall. This option was developed for specific locations on Mitchell Island and Sea Island where space is constrained by existing buildings on the land-side. No habitat impacts are anticipated on the land side of the dike in these locations. Riprap installation would, however, impact riparian habitat on the river side. Figure 3-4 presents a typical cross-section for this option.

Figure 3-4 shows a 7 m wide dike crest and retaining wall, which would be wide enough to accommodate a dike upgrade to 5.5 m CGVD28 without increasing the footprint. Alternatively, a narrower (~4.5 m) retaining wall dike could be considered as an interim measure and an alternative option be implemented when a site is redeveloped. Retaining walls should consider the need for handrails for safety, in accordance with applicable regulations.

On Sea Island, this option could be considered in several locations, as described below. The existing multi-use path would be maintained at the crest.

- Along the northern end of the BCIT building where the existing space may not be sufficient for a future raise to 5.5 m CGVD28.
- Immediately north of the BCIT property at Cessna Dr, where the existing space is not sufficient for a dike upgrade without impacting Cessna Dr. or moving the dike towards the river side. A retaining wall would likely not be sufficient to raise to 5.5 m without moving the dike towards the river.

On Mitchell Island, retaining walls are commonly used, and the City has recently approved a development with lock block walls used to reach the required elevation for flood protection. Dikes with retaining walls could be considered as an interim measure until redevelopment, or in locations where water access for industry is not required but the footprint needs to be narrower than a standard dike. As Mitchell Island is industrial, a multi-use path would not be included along the dyke crest.

The significant access and space constraints described in Table 3-8 are generally applicable to Option 1B as well, though it may be able to address some of the concerns on Sea Island.

Option 1D: Build/Raise Dike with Sheetpile Wall on River-Side

Option 1D involves building a dike with a river-side sheetpile wall. This option is only considered for specific locations on Mitchell Island where access is required for water-oriented industries (see Table 3-8), or potentially at pump stations to reduce space requirements. Figure 3-5 presents a typical cross-section for this option.

Figure 3-5 shows a 4 m wide dike crest and sheetpile wall, which would require raising and an increase in footprint for future upgrades. This approach reduces the overall footprint at first. Alternatively, the dike could be widened to a 7 m crest initially, which would allow for future upgrading to 5.5 m CGVD28 without extending the footprint. The sheetpile wall could provide a vertical surface for easier barge access (as it is in several locations currently on Mitchell Island), or it could be setback and the existing river bank slope maintained. A sheetpile wall could also be considered in conjunction with land raising (Option 2). This option would limit impacts to riparian and aquatic habitat. As Mitchell Island is industrial, a multi-use path would not be included along the dyke crest.

Option 1E: Build Setback Dike on Cessna Drive North of BCIT (Sea Island)

This option considers an alternative dike alignment on Sea Island that follows Cessna Drive from the northern end of the BCIT property to Miller road and ties back into the dike at the Miller Road drainage pump station. Figure 3-6 presents a typical cross-section and Figure 3-7 presents a plan conceptual alignment.

Cessna Drive directly parallels Russ Baker Way with only a concrete no-post barrier between, and as a result, creating a setback dike along Cessna Drive would also require raising Russ Baker Way. An alternative to raising Russ Baser Way would be to construct a retaining wall for Cessna Drive, which has not been shown in the attached figures. Figure 3-6 shows Cessna Drive raised with an 11.7 m wide crest, with two driving lanes and a sidewalk on the east side, to match existing amenities. The existing utilities that run along Cessna Drive would need to be relocated. Russ Baker Way would be raised to the 4.7 m CGVD28, with three lanes of traffic on either side of the road and a 1.2 m wide median diving the road. The raised road would tie into the existing high-ground/berm that around the eastern side of Burkeville. To better allow for future raises on Cessna Drive and to improve cycling safety, this option proposes that the north and southbound bike lanes be separated from the roadway and located on the berm above Burkeville. This option would require realignment of the existing drainage ditch and pump station, or relocation closer to Russ Baker Way.

The benefits of this option are that it creates a wide "superdike" (more stable), reduces the risk of dike erosion by setting it back from the river bank, does not require impacts to aquatic or riparian vegetation, and raises an important transportation corridor that could provide egress in a dike breach scenario. However, this option has significant drawbacks as it would be a significant cost to raise such a major roadway and relocate utilities, disrupt traffic on a busy corridor, and it would leave four properties outside of the dike without City flood protection, one of which recently built a 4.7 m CGVD dike.

Option 1F: Build Setback Dike around Hotel (Sea Island)

Option 1F considers an alternative dike alignment on Sea Island around the Pacific Gateway Hotel, which would place the hotel outside of the dike. The existing dike is closely hemmed in by the hotel and the marina and restaurant on the landside. There is no room for a standard dike raise in this location without relocating buildings and infrastructure or constructing a non-standard dike with a retaining wall or similar. In the long term (to achieve 5.5 m CGVD28), maintaining the current dike alignment would require removal or relocation of some buildings and on-site infrastructure, which could occur when the site is eventually redeveloped. In addition, ongoing work along this section has installed infrastructure in or along the dike without consideration of impacts to the dike. Figure 3-7 presents a plan conceptual alignment for the setback dike.

Figure 3-7 shows the setback dike following Lysander Lane, connecting to Cessna Drive, and tying back into the existing dike alignment at the Miller Road drainage pump station. Land acquisition on the border of the hotel property could be considered to avoid raising Cessna Drive where it is directly adjacent to Russ Baker Way, to avoid also needing to raise Russ Baker Way. Alternatively, Russ Baker Way could also be raised, similar to the description in Option 1E. The existing utilities that run along Cessna Drive, and Lysander Lane would need to be relocated to the water or landside toe. This option would require realignment of the existing drainage ditch and pump station or relocation closer to Russ Baker Way.

This option could provide a wider and more stable dike setback from the river and associated erosion risk and impacts to riparian and aquatic habitat would be limited. However, the dike in its current location is already afforded some protection by the adjacent Marina and setting back the dike leaves the hotel property unprotected from flooding.

Option 1G: Raise Dike with River-Side Sheetpile Wall and Land-Side Retaining Wall (Interim Option on Sea Island by Hotel and Marina)

Option 1G involves an interim non-standard dike raise to 4.7 m CGVD28 with a sheetpile wall on the along the river bank and a landside retaining wall. This option would only be appropriate for the Sea Island dike along the Pacific Gateway Hotel and adjacent marina, where the developments limit raising a standard dike without redevelopment. When the site is developed, a standard dike (Option 1A) could be established. An interim option is considered for this location as it is currently one of the lowest elevation areas on the Sea Island dike, with several locations below the current dike design elevation of 3.5 m CGVD28. Figure 3-8 presents a conceptual cross-section for the interim dike.

Figure 3-8 shows a 4 m wide dike crest with sheetpile wall along the top of the existing river bank and a landside retaining wall. Retaining walls should consider the need for handrails for safety, in accordance with applicable regulations. The existing multi-use path would be maintained at the crest. This option would require raising the access ramps to the marina restaurant. This reduced footprint would result in less loss of riparian and aquatic habitat area.

Option 2: Raise Land to Dike Elevation (2A) or Lower Acceptable Level (2B)

Option 2A and 2B both involve raising the land adjacent to the riverbank, rather than building a dike. For option 2A, land would be raised to the dike elevation or higher, and in Option 2B land would be raised to a lower level that would result in an acceptable level of flood protection, which could be determined by the City during the Dike Master Plan and through stakeholder consultation. It is expected that land raising would either be required by the City when sites redevelop (cost to owners) or that the City would purchase land, raise it, and resell it as improved land. This could be considered on Mitchell Island or Richmond Island. Option 2B would not be considered for Sea Island. Figure 3-9 shows a typical section of land raising.

In both options, bank protection works would be recommended, and it could be installed and maintained by property owners or by the City. The benefit of this option is that it would provide more robust flood protection by raising all of the land on the river bank rather than constructing only a perimeter dike; however, the City would likely need to stipulate acceptable fill and compaction standards to avoid the use of unacceptable or contaminated fill. The downside of this option is that it would likely delay flood protection upgrades until a site develops (in some instances this may not occur for a significant length of time. In such instances, the City may need to consider interim flood protection options or purchasing of the land to expedite upgrades. Riprap bank protection works would result in the loss of riparian habitat which will need to be offset.

On Sea Island, Option 2A could be considered along the entire reach in the long-term, but it might be particularly applicable for the hotel property due to the tight constraints for the existing dike alignment. In this location, the dike could be raised with a retaining wall or similar in the short-term, with a long-term plan to raise the property. On Mitchell Island, raising the land is favourable as the City does not have access or a right-of-way to establish a dike. In addition, land raising by owners would likely have fewer impacts on water-oriented industries than a perimeter dike, which would require appropriate access for the industrial activities. Land raising in these instances could be considered with a sheetpile wall along the waterfront, as exists in several locations already.

Option 2C: Raise Roadways with Required Land Raising on Private Property (Mitchell Island)

Option 2C involves raising the entire road network on Mitchell Island to the dike elevation or lower level and providing access to property owners, with the requirement for private properties to raise their land to dike elevation through redevelopment. This would provide flexibility to properties where land raising is in conflict with industrial activities, but it would maintain an egress route (raised road) for all properties. In addition, this option would include progressive right-of-way acquisition for a future perimeter dike as properties redevelop. Figures 3-10 and 3-11 show a conceptual plan and section of raising the roads on Mitchell Island to 4.1 m CGVD28 (dike elevation less freeboard of 0.6 m); raising roads to the full dike elevation of 4.7 m CGVD28 could be considered in the longer term as sites raise land. Figure 3-12 shows a typical cross-section for right-of-way acquisition along the river.

Figures 3-10 and 3-11 show a 12 m wide roadway with sidewalks and boulevards on both sides, to match existing conditions, which results in an approximately 18 m wide roadway, as per the City of Richmond Engineering Design Specifications for Roadworks. No cycling facilities would be provided given the industrial zoning of Mitchell Island. Driveway accesses would be 13 m wide at a maximum grade of 8%. The current road elevations are 2 to 3 m CGVD28, and as a result raising the roads to the dike elevation would 1 to 2 m of road raising, as shown on Figure 3-10. For road raising with adjacent low properties, the design would need to consider narrowing roadways or constructing retaining walls to avoid impacting private property. Right-of-way acquisition around the riverbank would allow for

maintenance or construction of bank protection works if required and construction of a perimeter dike in the future for dike elevations beyond 4.7 m CGVD28.

The most challenging aspects of this option would be balancing road raising with site access and existing building located along the roadways. As the island is largely industrial, acceptable grades and widths are important for industrial traffic and operations, and there are many locations where current buildings are located directly along the roads with little to no setback. As a result, the implementation would need to consider impacts to adjacent properties, timing of property redevelopment with roadways, and acceptable access. However, this option would provide a raised emergency egress in the event of a flood and allows property owners to raise lands to meet the road over time. Fraser River riparian or aquatic habitat are not anticipated to be impacted by this option, though impacts of private property raising would need to be assessed by land owner.

Option 3: Maintain/Install Bank Protection Works Only (Mitchell Island)

Option 3 considers the alternative where the only flood protection works the City is responsible for is installation and maintenance of bank protection works. This is only considered an option for Mitchell Island, as Sea Island has an existing dike, and Richmond Island is one private lot. On Mitchell Island, all bank protection works are private works and there is no requirement for owners to protect their properties from erosion. However, erosion starting at one unprotected property may place adjacent properties at risk as erosion progresses. City installation and maintenance of bank protection works would provide consistent protection around the island and reduce the risk of erosion and damage to adjacent property as a result of a neighbouring property's negligence. Figure 3-13 shows a section of Option 3.

This option could be considered in conjunction with other flood protection strategies, such as land raising and FCL's or restrictive covenants (covered in the 2008-2031 Flood Protection Strategy and the pending update ,and not the Dike Master Plan). Bank protection works in areas where not already present would result in impact to riparian habitat and require offsetting.

Option 4: No Structural Improvements

Option 4 is considered to be the status quo for Mitchell Island and Richmond Island, both of which only have private flood protection infrastructure in place. The Province's dike database indicates an unregulated dike on Mitchell Island under Richmond's authority, though no evidence of a dike is apparent on the island.

On Richmond Island, as described previously, a covenant is in place that acknowledges that the City has no plans to protect the Island from flooding and releases the City from any damage or losses caused by flooding or erosion. In addition, the majority of Richmond Island is located above 5.5 m CGVD28, with the exception of the causeway that connects the island to the City of Vancouver. The more significant flooding and erosion concern is expected to be the ongoing scour along the Fraser River North Arm in this location, which the City may wish to notify the owner of, if they are not already aware.

On Mitchell Island, this option would maintain status quo and would not infringe on industrial and commercial operations. In the absence of structural flood mitigation works, consideration could still be given to non-structural measures such as increasing FCL's or covenants that acknowledge that the property is not protected against flooding or erosion. For Mitchell Island, this option is not expected to be preferred as it does not meet the City's general vision of not allowing any part of Richmond to flood. In addition, flooding of the island would have economic and property losses and may cause environmental contamination.

3.5 Stakeholder Engagement

Stakeholder engagement for Phases 3 and 5 of the Dike Master Plan was completed jointly in two stages. Prior to initial City Council review, initial stakeholder engagement was completed that included meetings with internal City departments and some government agencies (also including Phase 4). This initial stakeholder engagement allowed for input from City groups on options developed, additional background, and future coordination, with the goal of informing the preferred upgrade options. Following Council review, additional stakeholder engagement was completed, which included reaching out for meetings with specific stakeholder groups and several public consultation events. The second stage of stakeholder engagement was intended to inform the public on the draft recommended options and seek any feedback the City may wish to consider in finalizing the Dike Master Plan and moving toward implementation.

For Phase 5, the City engaged the following parties:

- City of Richmond internal stakeholders:
    - Transportation,
    - Development Applications,
    - Policy Planning,
    - Engineering and Public Works,
    - Real Estate,
    - Parks Planning, Design & Construction,
    - Parks Operations;
- Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRO), including Inspector of Dikes, Flood Safety, and Water Authorizations staff;
- Fisheries and Oceans Canada (DFO);
- Ministry of Transportation and Infrastructure;
- Environment Canada;
- Sea Island commercial interests;
- Sea Island Community Association;
- Vancouver Airport Authority (YVR);
- Mitchell Island Business Association;
- Urban Development Institute (UDI);
- Translink; and
- general public.

The City and KWL met with internal stakeholders, YVR, and MFLNRO and hosted public open houses. All other parties contacted requested engagement closer to project planning in areas that may affect their operations. DFO declined to meet with the City, stating that input would be provided during later stages in the established review and approvals process. Additionally, Richmond is within the traditional territory of the Coast Salish people and the City works with Nations on various projects where appropriate. Feedback from external stakeholders is summarized in Table 3-8.

Table 3-8: External Stakeholder Feedback

Stakeholder	Summary of Comments
Vancouver Airport Authority (YVR)	It was noted that land use does not always correspond to property ownership along the dike. Based purely on land ownership along the eastern reach, Richmond's portion of the dike extends from the northern end of the Miller Road right-of-way to the south end of the BCIT property. However, Richmond also has several other rights-of-way and land ownership that crosses the dike in areas typically maintained by YVR. The City and YVR agreed to continue discussions and work with their respective legal departments to establish a formal agreement for dike responsibility on Sea Island. It was noted that this is not a simple matter as the airport development involved complex right-of-way and land swapping between the provincial and federal governments, which has not been resolved in some areas. YVR is currently working on upgrading its perimeter dike to 4.7 m CGVD28 and intends to complete a Dike Master Plan in the coming years.
Ministry of Forests Lands and Natural Resource Operations and Rural Development (MFLNRO) Inspector of Dikes	Currently there are two projects that may impact the application of the Seismic Design Guidelines for Dikes: The Dike Consequence Classification (lead by the Province), and the Seismic Assessment and Geotechnical Investigation of Lower Mainland Dikes (lead by the Fraser Basin Council). Until this work is completed, all applicants for Dike Maintenance Act approvals are to continue to follow the 2014 Seismic Design Guidelines for Dikes – 2nd Edition, where the dike is considered a high consequence dike. IOD is generally open to flexibility in specific scenarios but is looking for consistency with seismic standards. It is unlikely that an expedited application process would be considered. The flood protection structure noted in the provincial dike database on Mitchell Island is not regulated; it is possible that there were private works at one point that were documented in the case that they became flood protection works. The Dike Maintenance Act (DMA) does not apply to a single property and as a result would not apply to Richmond Island.
Ministry of Forests Lands and Natural Resource Operations and Rural Development (MFLNRO) Water Authorizations	Noted that the Province provides emergency bulletin to property owners to remove harmful substances in the floodplain in high water/flood scenarios, in order to reduce risk of environmental contamination from flooding. Generally interested in larger scale compensation for impacts of large-scale dike upgrades in Richmond to achieve more meaningful compensation. There is still a need to compensate locally. This could potentially include approval of overall compensation program and plan, but it would still require project by project approvals (approval in principle of the plan already). This method hasn't been developed before and would need to be developed with Richmond.

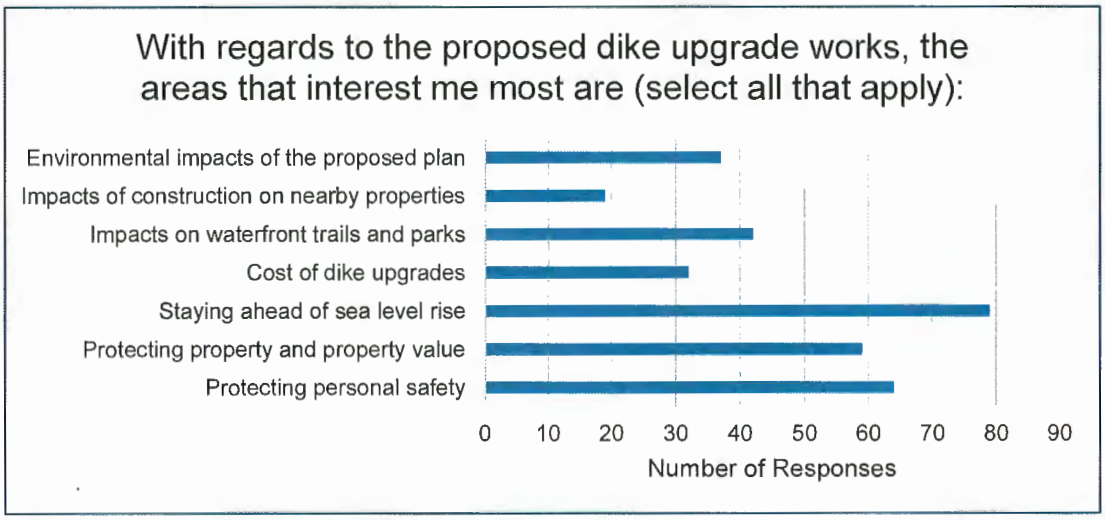
Stakeholder	Summary of Comments
Translink	No further engagement is required unless the proposed dike improvements result in any new trucking prohibitions, changes to the major road network, or impacts bus stops. In these situations, TransLink is to be contacted prior to finalizing detailed drawings.
Urban Development Institute (UDI)	No comments at this time. UDI requested a general presentation on the Dike Master Plans when they are endorsed by Council.
Ministry of Transportation and Infrastructure (MOTI)	No further comments at this time.
Fisheries and Oceans Canada (DFO)	DFO declined meeting regarding the Richmond Dike Master Plans. DFO expects that engagement with regards to fish habitat will take place through the established federal review process.

Two public open houses were held for Phase 3 and 5 jointly, including one event at the City Centre Community Centre on January 15, and another event at City Hall on January 23. In addition, City staff participated at a Smart Cities event with the public consultation materials on January 17. A total of 75 people attended the open houses. Draft reports and information poster boards were also available online at LetsTalkRichmond.ca with 518 visits to the site during the consultation window (January 14 to February 2). A survey to seek feedback was provided at open houses and online, and a total of 92 responses were received. Feedback from public consultation is summarized in Table 3-9 and Infographic 3-1.

Table 3-9: Summary of Public Consultation Feedback

Topic	Summary of Comments
Proactive Planning / Flood Protection	Many comments appreciating the proactive approach for dike planning, the robust concepts, and the long-reaching strategies. Several comments relating to expediting the dike raising process in anticipation of accelerated sea level rise. A couple questions received on earthquake effects, the application of a secondary inland diking system, and the role of internal drainage related to flood protection. Over 80% of participants rank perimeter dike upgrading as being either very important or extremely important.
Dike Aesthetics / Recreational Use	Many comments received noting the importance of maintaining pedestrian-friendly, multi-use trails. Suggestions relating to recreational use include paved pathways, distance markers, additional lighting, benches, and establishing a continuous perimeter trail. Two commenters like the opportunity to upgrade infrastructure and trails in the Hamilton area. One comment about improving trails around Crown Packaging.
Development / Property Value	Several commenters like the Plans with respect to protection of properties and future development. A commenter suggested research into riverside expansion of the dike. One commenter suggested residential construction standards. One commenter does not support superdikes (development on the dike).

Topic	Summary of Comments
Thoroughness/Consultation	Several comments appreciating the thoroughness of the report; the phasing methodology and clear concepts made the Plan easy to understand. One suggestion to further consult utility stakeholders who may cross the dike.
Priority Areas / Safety	Many commenters like that the City is taking action with regards to community safety. Single commenters noted priority areas which include: Phase 3, Steveston, Terra Nova. A single comment on the west dike as a priority location and for barrier islands to be built. A single comment questioning how Britannia will be protected and concern for houses along Dyke Road.
Environment / Habitat	A few comments and questions on the importance of maintaining habitat and the environment. One comment on using free fill material for the dike rather than other forms of disposal. One commenter is concerned about removal shrubs, trees, logs, and habitat along the dike.
Climate Change / Sea Level Rise	Several questions were received relating to level of protection, climate change, and sea level rise science. A couple of comments suggested that raising the dikes are premature and that sea level rise may not happen.
Cost	Several questions on cost to taxpayers and Provincial/Federal involvement in paying for flood protection upgrades. One question relating to evaluating the cost of managed retreats from certain areas.
General	One comment on providing more information on social media. One question about elevation of areas adjacent to dikes. One commenter requesting additional signage in project areas.



Infographic 3-1: Summary of Pubic Responses

It is expected that there will be opportunity for more engagement with stakeholders during detailed design of dike upgrades.

3.6 Options Evaluation and Selection

The options described in Section 3.4 have been evaluated based on the design considerations and feedback from the stakeholder meetings. Recommended options have been identified and are described below. As noted previously, the recommended options are intended to provide a basis for dike upgrades and planning, with the immediate goal is to raise the dikes to allow for 1 m of sea level rise, and to allow for further upgrading in the future. Environmental impacts, drainage impacts, and geotechnical considerations associated with the recommended options are also summarized below.

It is understood that the recommended options will be confirmed through Council review.

The recommended options are summarized in Table 3-10 and Figure 3-14, and further described in the following sub-sections.

Table 3-10: Recommended Dike Upgrading Options (Phase 5)

Reach # and Name	Recommended Options
1 – Mitchell Island	• Option 2C: Raise roadways with required land raising on private property
2 – Sea Island	• Option 1A: Raise standard river dike and extend land-side *Site specific options in constrained locations (northern end of the BCIT building, at Cessna Drive, and at Lysander Lane):* • Option 1B: Raise standard river dike and extend river-side • Option 1C: Raise dike with land-side retaining wall *Site specific interim option at hotel and marina:* • Option 1G: Raise dike with river-side sheetpile wall and land-side retaining wall
3 – Richmond Island	• Option 4: No flood protection works

Recommended Option: Reach 1 - Mitchell Island

Mitchell Island has no existing flood protection works other than private bank protection works (riprap and sheetpiles) around most of the island. Due to this, the City may consider diking or other alternatives. There are many locations around the perimeter of the island that are well below the current design dike crest elevation of 3.5 m CGVD28 (in some locations as low as approximately 2.5 m). The island is densely developed with industrial and commercial operations, many of which actively access the Fraser River for their businesses.

As a result, a perimeter dike would be highly disruptive to business and would require significant right-of-way or land acquisition. Alternatively, progressive land raising by redevelopment would provide the benefit of flood protection at a timeline that is not disruptive to business. By raising roadways and providing driveways, the City can provide emergency egress and access for properties as they are gradually raised. This would also reduce cost to the City by requiring developments to cover the cost of raising the majority of the land. The drawback to this approach is that in the short term, low properties below the current dike elevation will continue to be at risk of flooding and related environmental contamination. This may warrant short-term collaboration with owners to reduce these risks. Raising roads in advance of property raising would also require trade-offs between reduced road size and amenities, or infringement onto private properties. To partially address this, road raising could initially be

conducted to 4.1 m CGVD28 (dike elevation less freeboard) or a lower elevation selected by the City. Land raising should also consider impacts to drainage servicing, including potential alteration of rainwater overland flow routes on a site-specific basis. This could be further investigated through a land raising and drainage assessment study.

The following option is recommended for Mitchell Island.

- **Raise Roadways with Required Land Raising on Private Property (Option 2C):**
  - Raise all roadways to dike elevation by the City to provide emergency egress (considering partial raises in low areas to reduce impacts to operations).
  - Require owners to raise parcels to dike elevation during redevelopment.
  - Acquire rights-of-way and access during redevelopment along the riverbank for a future dike to 5.5 m CGVD28 and bank protection works.
  - Work with low elevation (below current dike crest elevation of 3.5 m CGVD28) property owners in the short term to mitigate flood and related environmental contamination risks.

The recommended approach, and properties below the current dike elevation of 3.5 m CGVD28, are shown in Figures 3-10, 3-11, and 3-12. Appendix A shows potential right-of-way acquisition around the perimeter of the island.

Recommended Option: Reach 2 - Sea Island

Responsibility for flood protection on Sea Island is shared by YVR and the City. Jurisdictional boundaries and land ownership along the dike are unclear in some locations, including several spots where the City either owns land or has a road dedication along a section of the dike that YVR has assumed responsibility for. The City's portion of the Sea Island dike is generally agreed to be along the eastern portion of the island from BCIT to the north edge of the Miller Road right-of-way.

The dike within this reach can be upgraded to a standard dike, with the exception of a few locations where space is constrained by existing buildings or roadways. In these locations, moving the dike alignment towards the river, or using retaining walls can be considered. This would limit infrastructure impacts and cost. In particular, the dike between the hotel and marina is below the current dike crest elevation of 3.5 m CGVD28, and there is not enough space to raise any standard form of dike to 4.7 m or 5.5 m CGVD28. As a result, an interim solution would be required for this location until the site redevelops. This could include either a setback dike around the building or a narrower dike with retaining walls.

The following option is recommended for the majority of City's portion of the Sea Island dike.

- **Raise Standard River Dike and Extend Land-Side (Option 1A):**
  - Continue to work with YVR to formalize jurisdiction boundaries for the dike.
  - Raise the existing dike along the current alignment with a standard dike wide enough to accommodate a raise to 5.5 m CGVD28 (except in the short-term along the hotel and marina). At the northern end of the BCIT building, at Cessna Drive, and at Lysander Lane, this would require either moving the dike towards the river (Option 1B), building retaining walls (Option 1C), and/or raising the road for short sections.

- When the Miller Road Drainage Pump Station is upgraded (planned for 10 to 15 years in the future), provide structural capacity for loading due to the dike raise and ensure there is sufficient space for the dike raise.
- Consult with MOTI to have the Moray Channel Bridge replaced with a higher structure that is above 5.5 m CGVD28 (when it is at the end of its design life) and raise the land between the two bridges.
- Acquire and widen existing rights-of-way for City access to the dike.

The following option is recommended as an interim solution at the hotel and marina.

- **Raise Dike with River-Side Sheetpile Wall and Land-Side Retaining Wall (Options 1G):**
  - At the hotel and marina, raise the dike to 4.7 m CGVD 28 with a sheetpile wall embedded along the river-side and a land-side retaining wall.
  - When the hotel area is redeveloped, establish a standard dike in accordance with the remainder of the reach.

The recommended options are shown in Figures 3-2, 3-3, 3-4, and 3-8. Appendix A contains plans and sections of the long-term upgrading recommendation.

A general recommendation for flood protection on Sea Island is to target land raising of the areas behind the dike. For areas where City property is located on the YVR portion of the dike, it is recommended that the City works with YVR to raise the dike at Richmond road crossings.

Recommended Option: Reach 3 - Richmond Island

The majority of Richmond Island is currently above the 5.5 m CGVD28 future dike crest elevation. Richmond Island is a single lot owned by North Fraser Terminals Inc., and leased to Milltown Marina & Boatyard Ltd. The development is connected to the City of Vancouver and its utility network and does not pay the City of Richmond Drainage Utility tax.

A restrictive covenant[6] was registered against the land title in November 27, 2012 (between North Fraser Terminals Inc., the Milltown Marina & Boatyard Ltd., and the City of Richmond) that:

- acknowledges the risk of flooding and erosion on Richmond Island;
- notes that the City has no plans to protect the island from flood and erosion; and
- releases the City from any damage or losses caused by flooding or erosion.

The following option is recommended for Richmond Island.

- **No Structural Flood Protection Works (Option 4)**
  - The covenant appropriately addresses the existing situation. In the event of future redevelopment, flood protection on Richmond Island could be reconsidered.

The City may wish to inform/consult with the owners regarding scour in the North Arm.

[6] CA2885848. RCVD: 2012-11-27.

Drainage Impact Assessment

Mitchell Island

The Mitchell Road South and Tipping Road South Drainage Pump Stations may be impacted by the road upgrades. Considerations for these two pump stations may include structural review and upgrade of the inlet bays and piping, as well as the outfall elevations of the pumps relative to projected sea level rise.

The drainage system within Mitchell Island would also be affected by the proposed road upgrades. Drainage services for the properties on Mitchell Island would need to be maintained, which would require further assessment and consideration during design of road raising. Road raising design should also consider future drainage servicing needs for parcels to be raised through redevelopment. The increase in road surface elevations would require adjustments to catch basin inlets and manholes on all roads where the surface would be raised. Some roads currently have drainage in roadside ditches with culverts at driveway crossings. These ditches would likely be required to be either replaced with storm sewer pipes beneath the roadway and additional catch basin inlets to collect runoff or be filled in and moved to be outside the new toe of the raised roadway.

Sea Island

The drainage system on Sea Island is not complete in the City's GIS database and the full range of potential impacts from proposed dike upgrading are not known at this time. The Miller Road Drainage Pump Station will be impacted by dike upgrades, where structural changes may be required to accommodate the increased dike section. In addition, extension of the pump station outlet and review of outfall elevations relative to projected sea level rise should be completed. There may also be impacts to the drainage system where the dike is constrained by Cessna Drive between chainage 0+400 and 0+450, but there is no drainage shown for the road in this location.

Richmond Island

On Richmond Island, no changes are proposed and there is therefore no impact on drainage.

Habitat Impact Assessment

Initial habitat impact assessments based on desktop review are summarized in Table 3-11 and described below.

Mitchell Island

Based on initial desktop review, road raising on Mitchell Island is not anticipated to result in impacts to riparian or aquatic habitat. Future raising of land parcels by landowners will need to consider environmental impacts including impacts to riparian and aquatic habitat, and the need for offsetting.

Sea Island

The recommended option for Sea Island will result in an estimated impact of 1,000 m^2 of high-quality Fraser River intertidal habitat and 2,000 m^2 of high-quality Fraser River riparian habitat. These areas represent an estimate based on FREMP habitat mapping (2007), and City of Richmond orthoimagery interpretation (2017). 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, would also be required in calculations for determining offsetting requirements. A more precise calculation of the area of impact would require an aquatic habitat survey, and an aquatic effects assessment.

The estimated area of overlap of proposed dike improvements with the city's ESA's is 300 m^2 of Intertidal ESA and 13,100 m^2 of Shoreline ESA. ESAs often overlap with high quality habitat (i.e. high quality Fraser River intertidal, high quality Fraser River riparian) but they can also include modified habitat (i.e. dikes), low quality habitat (e.g. areas infested with invasive plant species) and developed areas (e.g. buildings and roads) which do not provide habitat value. If ESAs are to be disturbed due to dike upgrades, mitigation and compensation may be required. In order to properly assess the environment values that may be disturbed by dike improvements in ESAs, and thus the amount of compensation that is required, detailed site specific assessments are recommended.

Richmond Island

As no structural flood protection works are proposed for Richmond Island, no associated impacts to riparian and aquatic habitat will occur.

Table 3-11: Reach-by-Reach Summary of Potential Habitat Impacts and ESA Overlap

Reach # and Name	High-Quality Fraser River Intertidal (m^2)	High Quality Fraser River Riparian (m^2)	Overlap with ESA Types (m^2)
1 – Mitchell Island	0	0	Shoreline: 1400
2 – Sea Island	1,000	2,000	Intertidal: 300 Shoreline: 13,100
3 – Richmond Island	No flood mitigation works recommended (no impacts)		

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 2 sample river dike cross-sections (one for Sea Island and one for Mitchell Island) to estimate the potential deformation resulting from seismic events. The cross-sections were provided by KWL based on a standard river dike cross-section at what was judged to be the most susceptible areas for deformation. Soil conditions were determined by cone penetration tests conducted by Thurber. The analysis included seismic events representing 100, 475 and 2475-year return period events. Seismic performance was assessed using 2 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 B.

The key results of the geotechnical analysis are summarized below.

- Proposed dike cross-sections will not meet the performance requirements of the BC Seismic Design Guidelines for Dikes based on numerical deformation analysis, without ground improvement or alternative approaches.
- 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 2475-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, are provided below.

- **Densification** – The typical approach to densification is to install stone columns beneath a dike. To be effective against the liquefaction expected to follow the 2475-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. Such 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 just results in added deformation, so it is 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 dike side slopes improve seismic stability. However, to prevent large deformations in the 2475-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. several hundred metres) 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. The minimum distance for each fill area should be based on a geotechnical evaluation of the setback required for the superdike to retain its hydraulic integrity under seismic design performance criteria (seismic stability and flowslide). Raising the land 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 in some waterfront areas. Buildings in this zone should be built above the dike crest elevation and have densified foundations capable of withstanding liquefaction.
- **Dike Relocation** – Place the dike inland of the liquefaction lateral spreading zone (a setback dike 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 dike inland would be a form of retreat and would leave property and buildings exposed outside the dike.

Additionally, the City may wish to use alternative seismic performance criteria, as is considered in the pending update to the Flood Protection Management Strategy

Considerations to manage the seismic risk are provided below.

- Consider alternative seismic performance criteria as considered in the pending Flood Protection Management Strategy. Review the criteria if/when the Province issues updated guidelines for seismic performance of dikes.
- Fill a wide swath of land (several hundred metres) inland of the dike to the design dike crest elevation. Buildings in this zone should be built above the dike crest elevation and have densified foudations capable of withstanding liquefaction. The required distance requires some additional evaluation and may be addressed in the pending update 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 items 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 estimated for each island. They were also broken down into the main features that coincide with options that the City may wish to consider further. The cost estimate for the recommended option includes construction from existing condition to recommended option, without considering any potential interim works. Cost estimates for interim works are provided, and it is expected that there would be some cost saving associated with upgrading the interim dike to the long-term option, which are not accounted for. These features are described below.

- **Dike Raising** – this is the core element required to provide flood protection. It includes a 10 m crest width that can be raised while still achieving a 4 m crest width. This includes site preparation, fill, hydroseeding, minor drainage changes, and erosion protection.
- **Road Structure and Utilities** – this includes stripping, subgrade preparation, pavement structure, drainage and utilities.
- **Road Raising** – this includes the additional fill required to raise the road to the dike crest elevation (4.1 m CGVD28 road raising initially).
- **Other** – features such as landscaping, multi-use paths, driveway ramps and other amenities typically have a combined impact of less that 10%, so are lumped together for conciseness. This category was used to capture utilities if the option did not include road construction.
- **Contingency** – A 40% contingency is provided because the costs are based on concept plans only.

Table 3-12 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 5.

Table 3-12: Summary of Construction Costs ($ in Millions)

Item	Mitchell Island[b]	Sea Island[c]	Sea Island Interim Works[d]	Richmond Island 4	Total
Dike Raising	-	$3.6 M	$.8 M	No Flood Protection Works	$4.4 M
Road Structure and Utilities	$15. M	$0.1 M	-		$15.1 M
Road Raising	$36.5 M	$0.2 M	-		$36.7 M
Other[a]	$8.3 M	$0.8 M	$.1 M		$9.1 M
Contingency (40%)	$23.9 M	$1.9 M	$.3 M		$26.1 M
TOTAL	**$83.6 M**	**$6.5 M**	**$1.2 M**		**$91.4 M**

a. Driveway ramps and pathways
b. Includes approximately 5.3 kilometres of road raising, reconstruction, and industrial driveway ramps.
c. Includes approximately 0.9 km of dike raising and road raising at McDonald and Shannon Roads.
d. Interim works refer to 150 m long sheetpile and retaining wall dike along the Pacific Gateway Hotel with access to the marina and hotel land.

Costs that are not included are noted below:

- Land acquisition is not included. Rights-of-way either exist or will be acquired during redevelopment. Similarly, there may be opportunities to have dike improvements tied to adjacent development.
- Seismic performance measures are not included. Raising land to inside the dike is likely a preferred strategy to deal with liquefaction. If the road and land behind the dike is not raised, then densification may be appropriate. Current techniques such as stone columns would cost approximately $9,000 to $18,000 per metre of dike.
- Habitat enhancement and off-site habitat compensation projects 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.
- 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.
- Shoreline protection works and land raising on industrials sites on Mitchell Island are not included. Similarly, raising the land behind the dike is not included on Sea Island. These costs are proposed to be a condition of development behind the dike, with the cost and benefit attributed to property owners.
- Contaminated site remediation on Mitchell Island is not included. To ensure land raising keeps pace with increasing flood risk and sea level rise, the City may consider acquiring, raising, and reselling select properties. Based on historical land use on Mitchell Island, land acquisition is expected to involve site investigation for contamination. Contaminated sites investigations include the following, with approximate average cost estimates provided by City staff[7]:
    - Phase 1 Site Investigation (desktop) - $1,500 per property;
    - Phase 2 Site Investigation (sampling) - $25,000 per property; and
    - additional investigation and remediation for a Certificate of Compliance - $250,000 per property.

  City staff estimate that all properties on Mitchell Island will require Phase 1 investigations, approximately 75% of properties may require Phase 2 investigations, and approximately 40% of properties may require additional investigation and remediation.

[7] City Hall Transmittal #5905343 Mitchell Island Pollution Prevention and Known Contamination

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City of Richmond

Richmond Dike Master Plan - Phase 5

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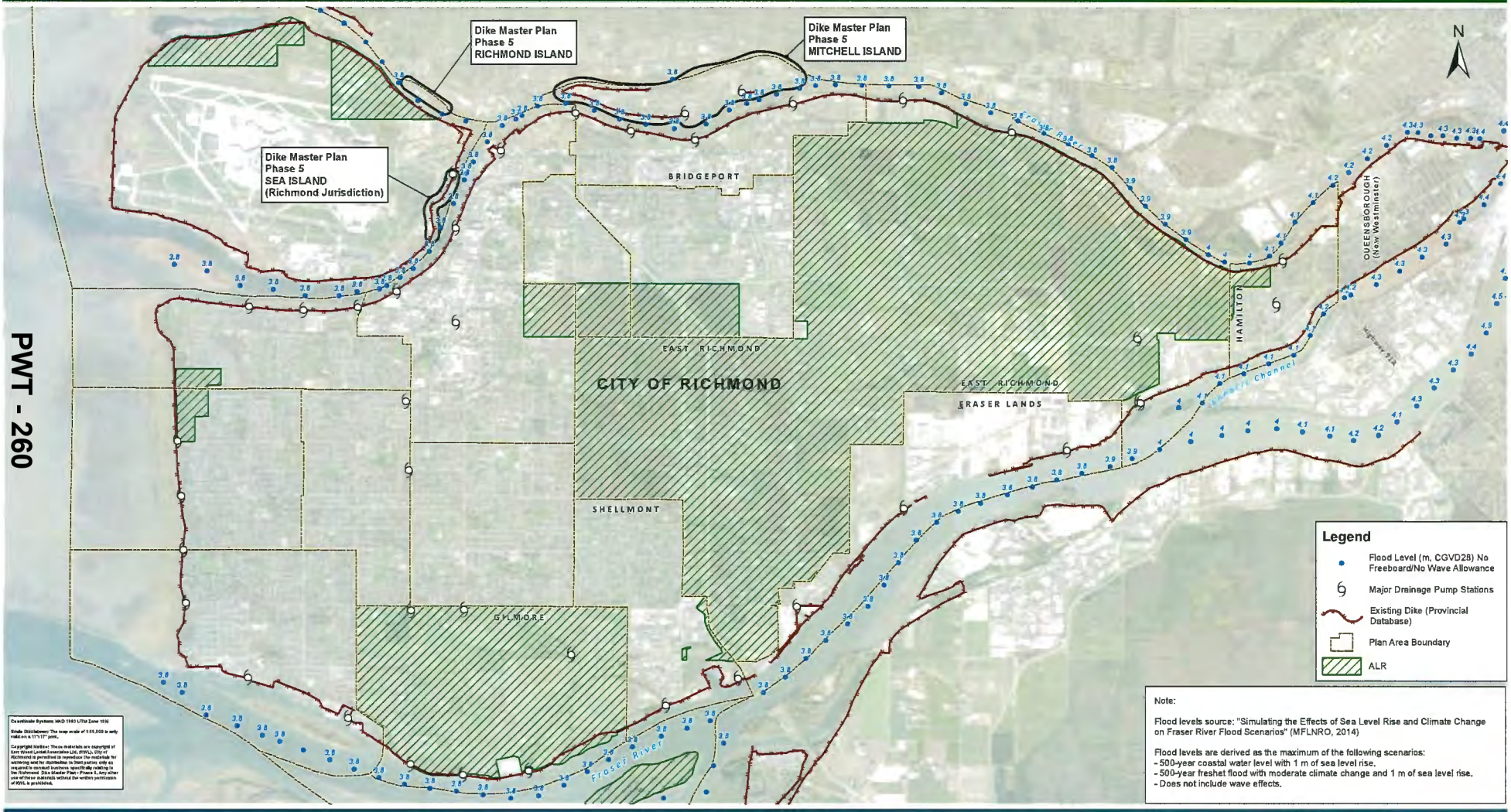

PWT - 260

Note:

Flood levels source: "Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios" (MFLNRO, 2014)

Flood levels are derived as the maximum of the following scenarios:
- 500-year coastal water level with 1 m of sea level rise.
- 500-year freshet flood with moderate climate change and 1 m of sea level rise.
- Does not include wave effects.

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:55,000 is only valid on a 11"x17" print.

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Project No. 651.129

Date February 2019

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1,000 500 0 1,000 m

Fraser River Flood Elevations

Figure 3-1

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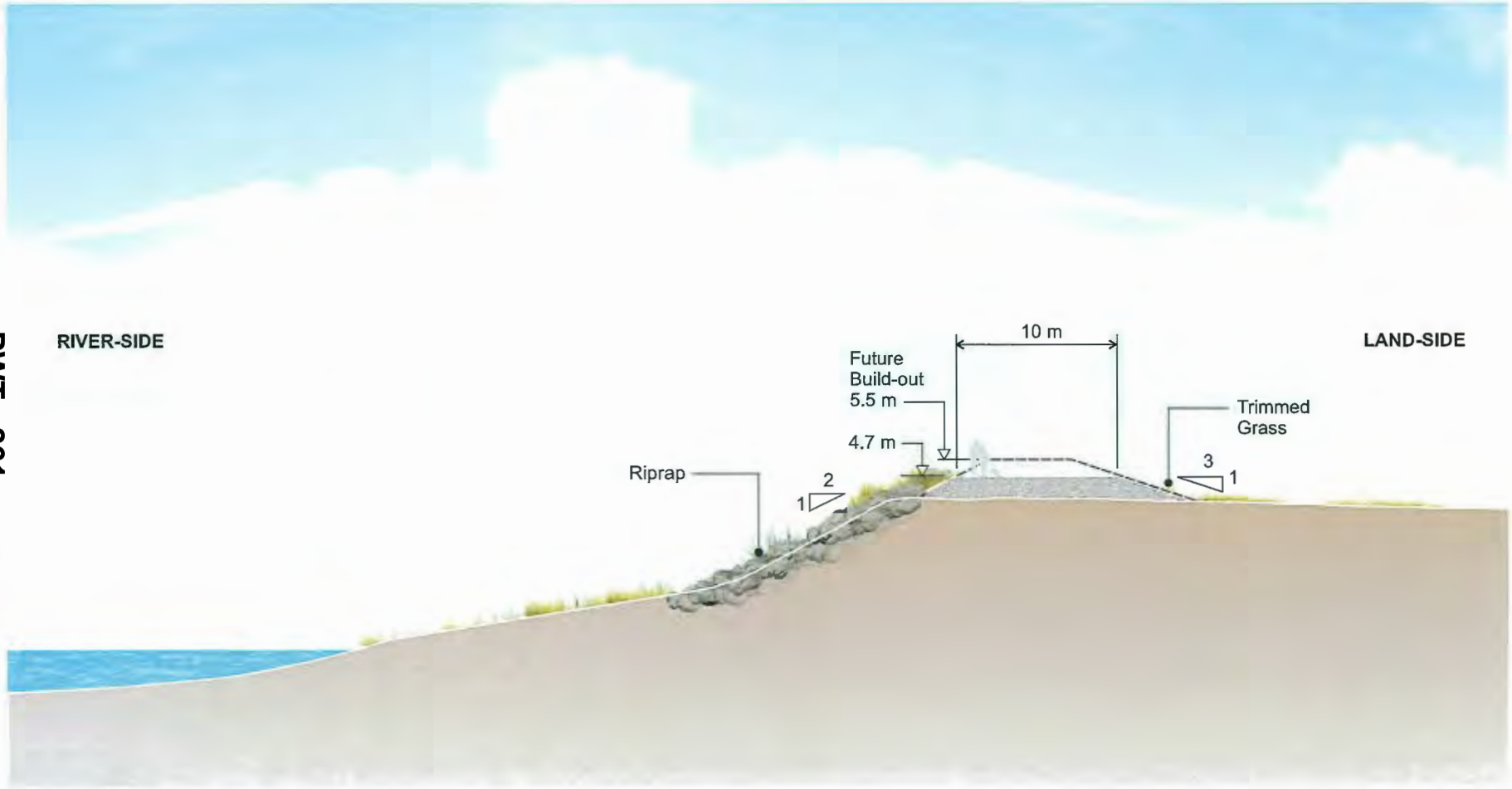

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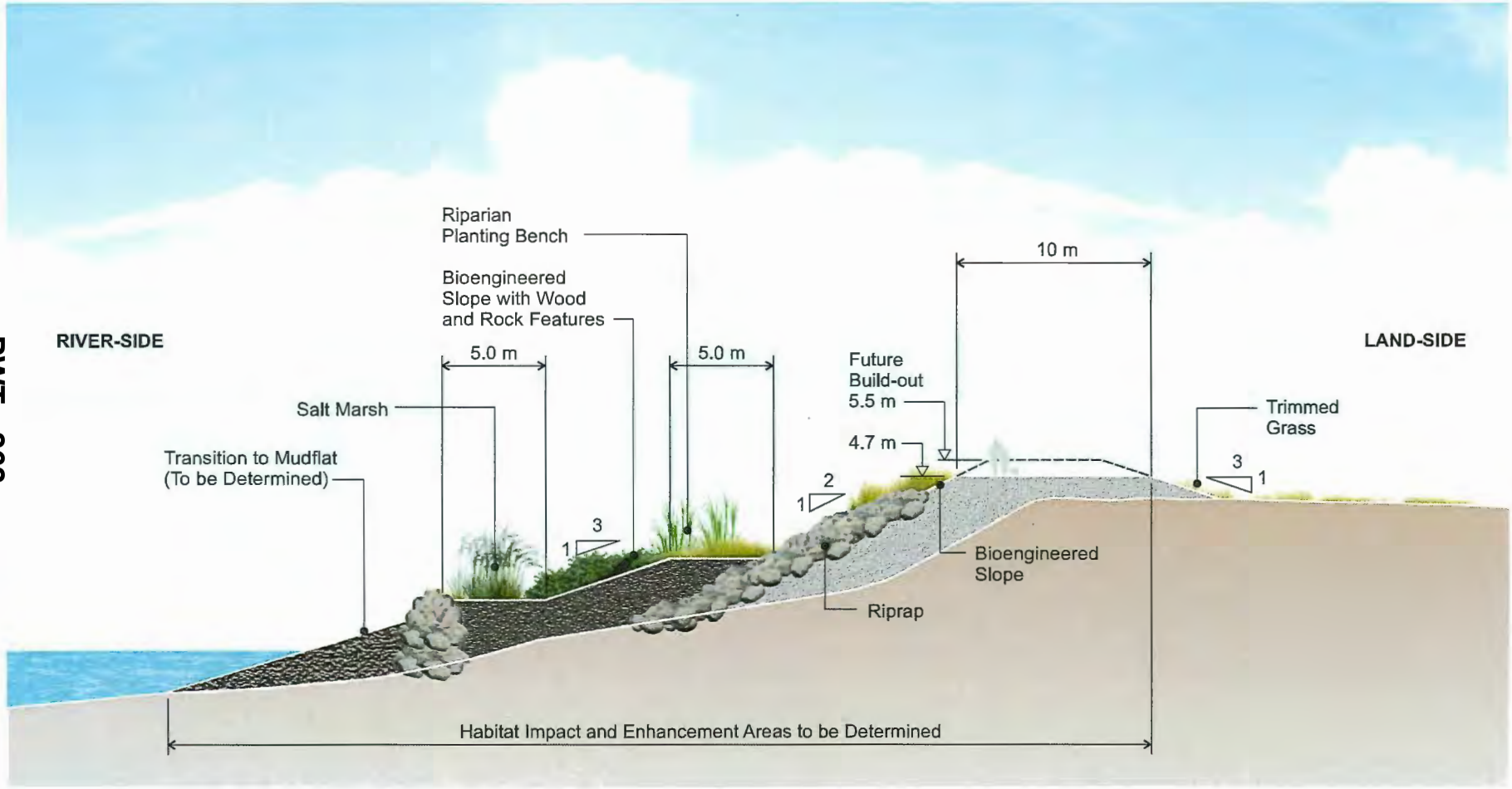
Option 1A: Build/Raise Standard River Dike and Extend Land-Side

Figure 3-2



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Option 1B: Build/Raise Standard River Dike and Extend River-Side

Figure 3-3

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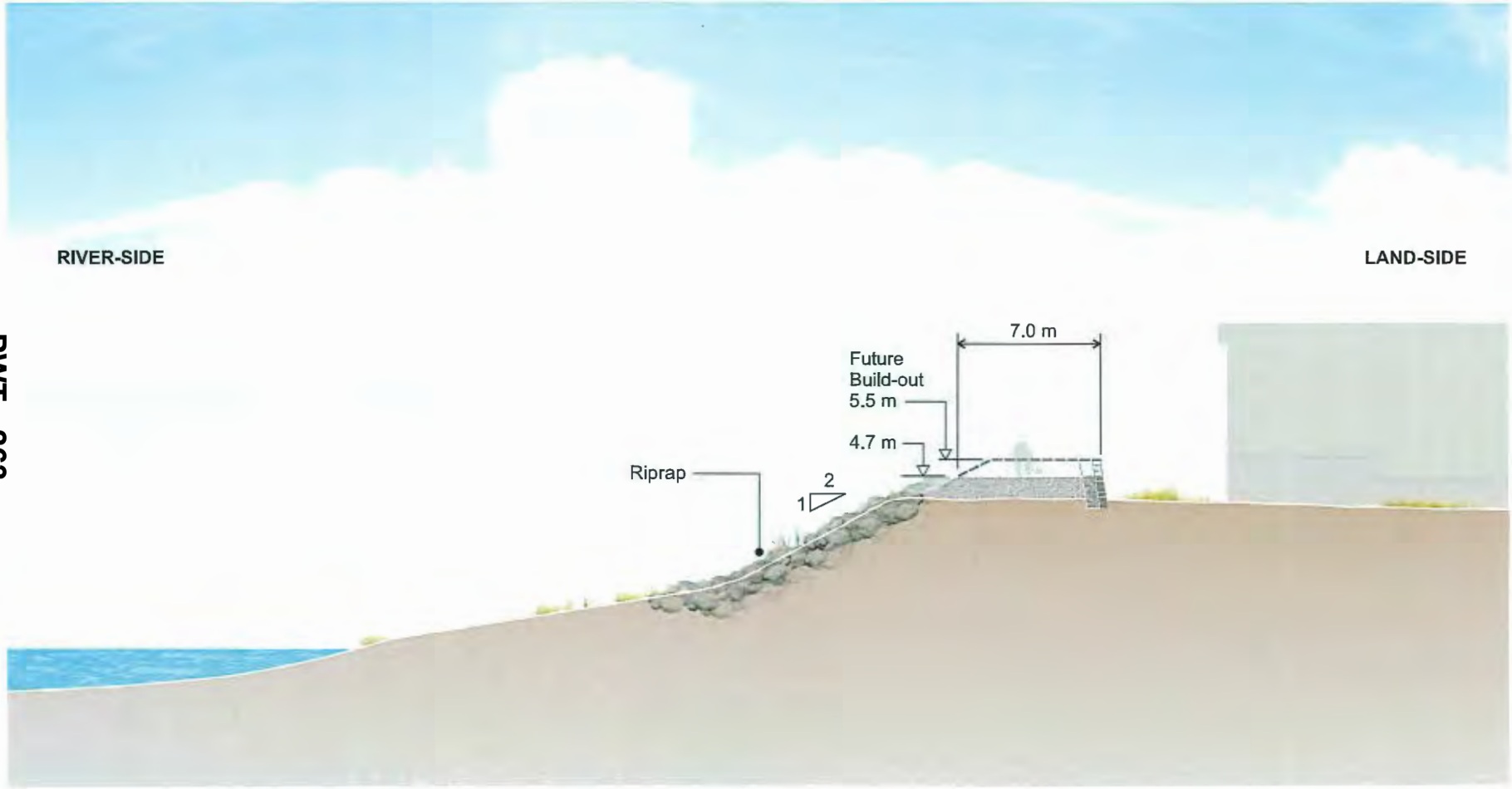

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Project No.	651.129
Date	February 2019
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Option 1C: Build/Raise Dike with Land-Side Retaining Wall

Figure 3-4

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Richmond Dike Master Plan - Phase 5

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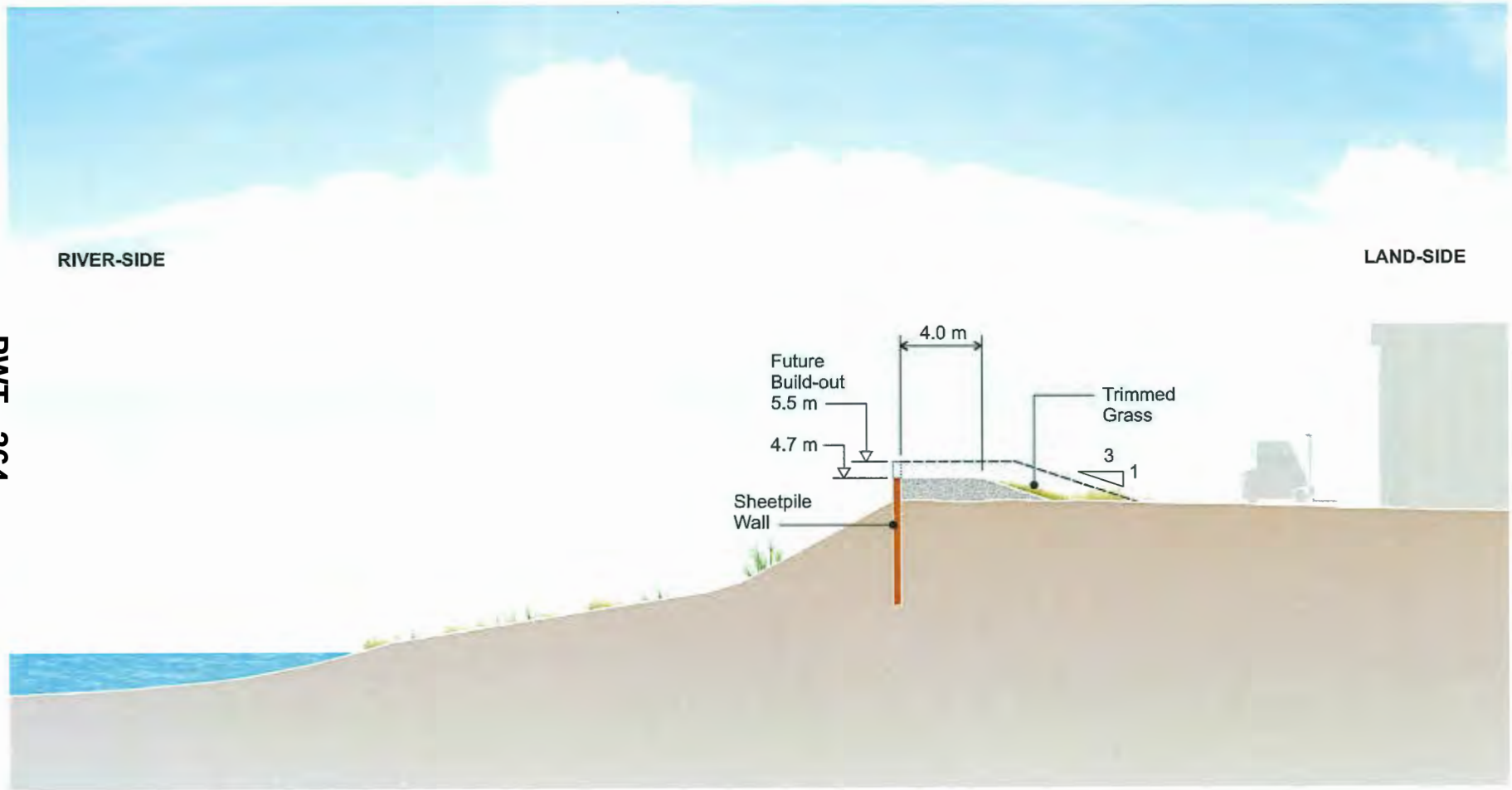

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Project No.	651.129
Date	February 2019
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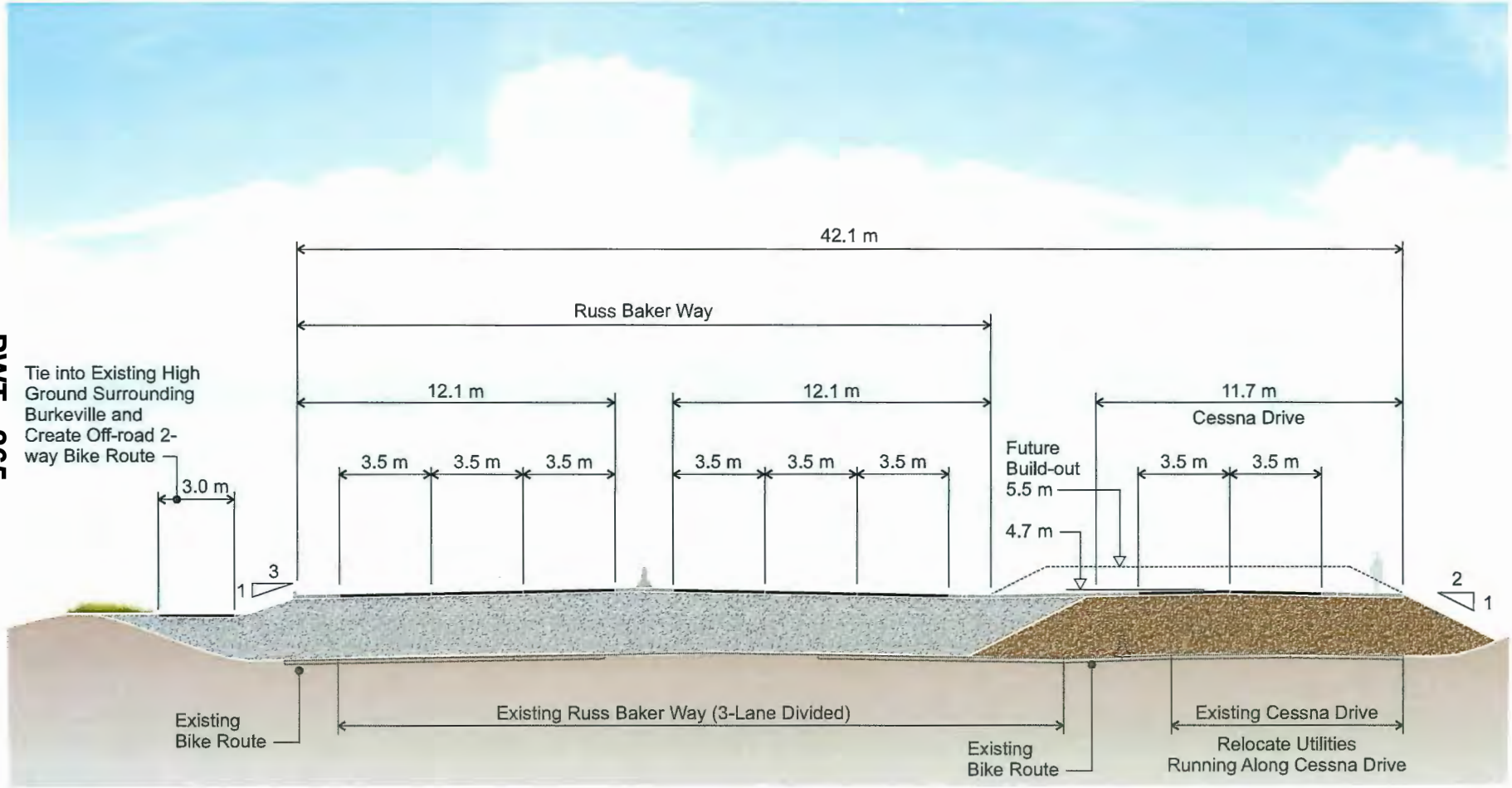
Option 1D: Build/Raise Dike with Sheetpile Wall on River-Side

Figure 3-5



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Project No.	651.129
Date	February 2019
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Option 1E: Build Setback Dike along Cessna Dr. North of BCIT

Figure 3-6

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Option 1E and 1F: Build Setback Dike Along Cessna Drive

Figure 3-7

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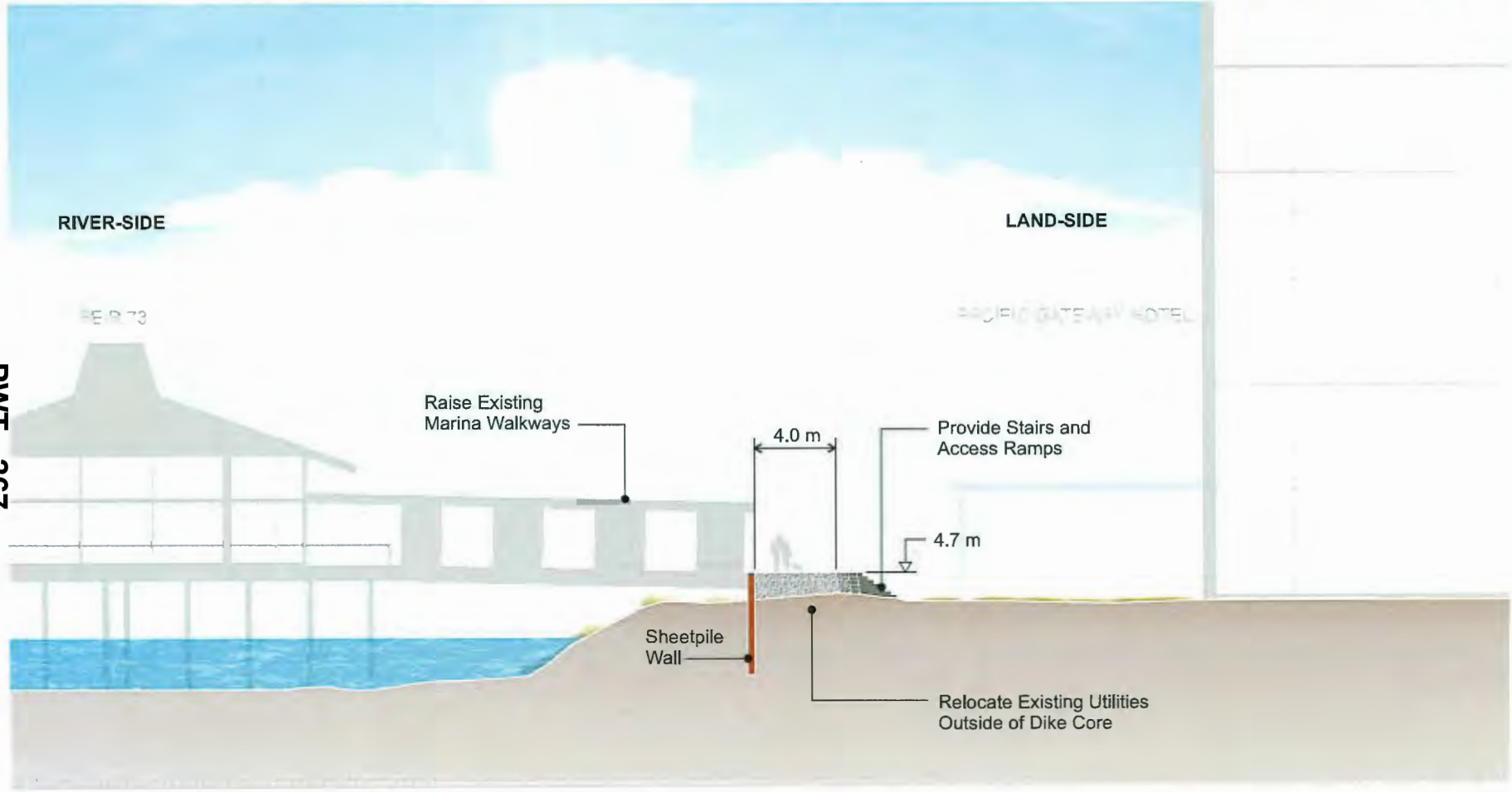

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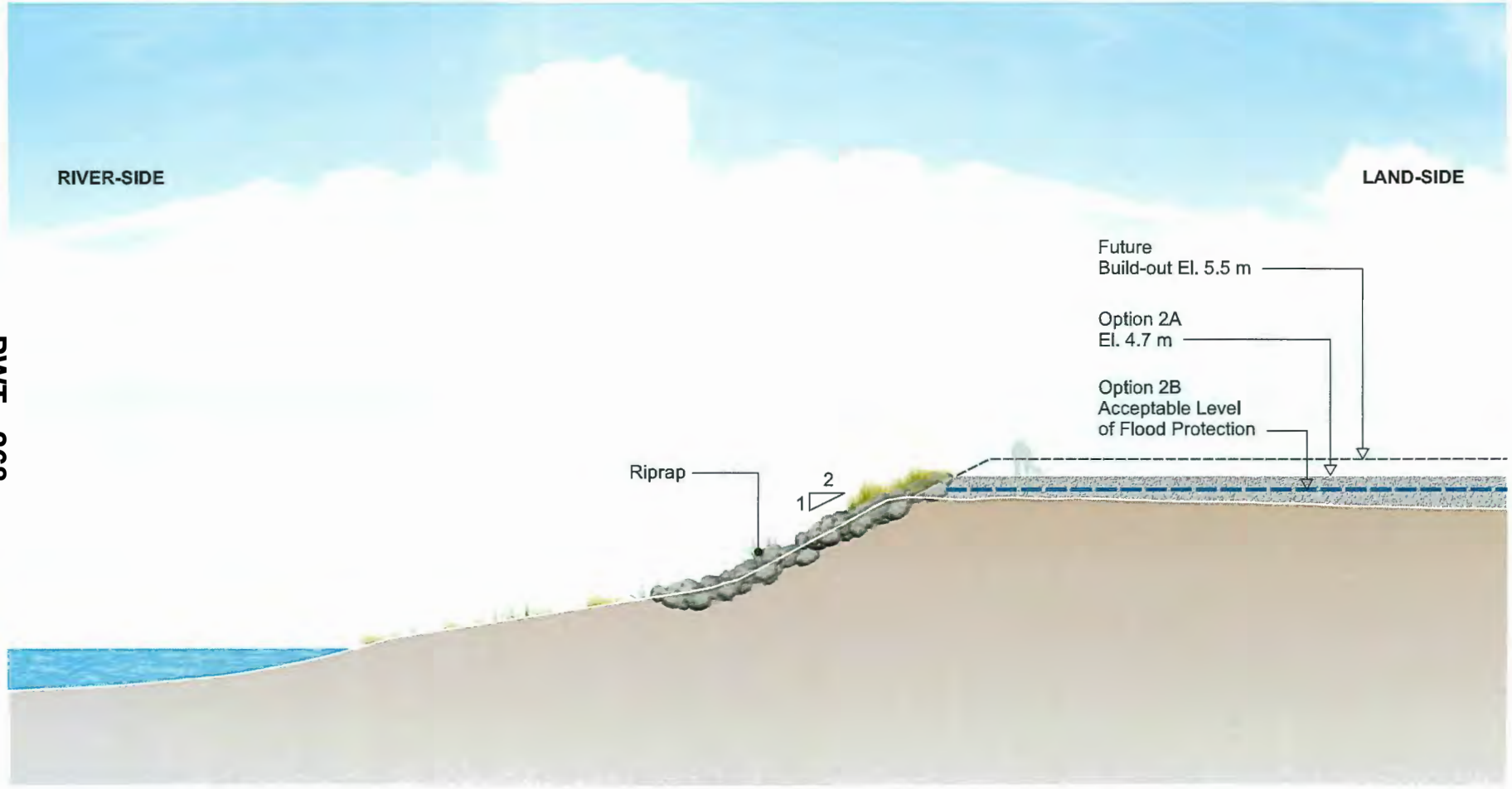
Option 1G: Raise Dike with River-Side Sheetpile Wall and Land-Side Retaining Wall (Interim Option)

Figure 3-8



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Project No.	651.129
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Option 2A and 2B: Raise Land

Figure 3-9

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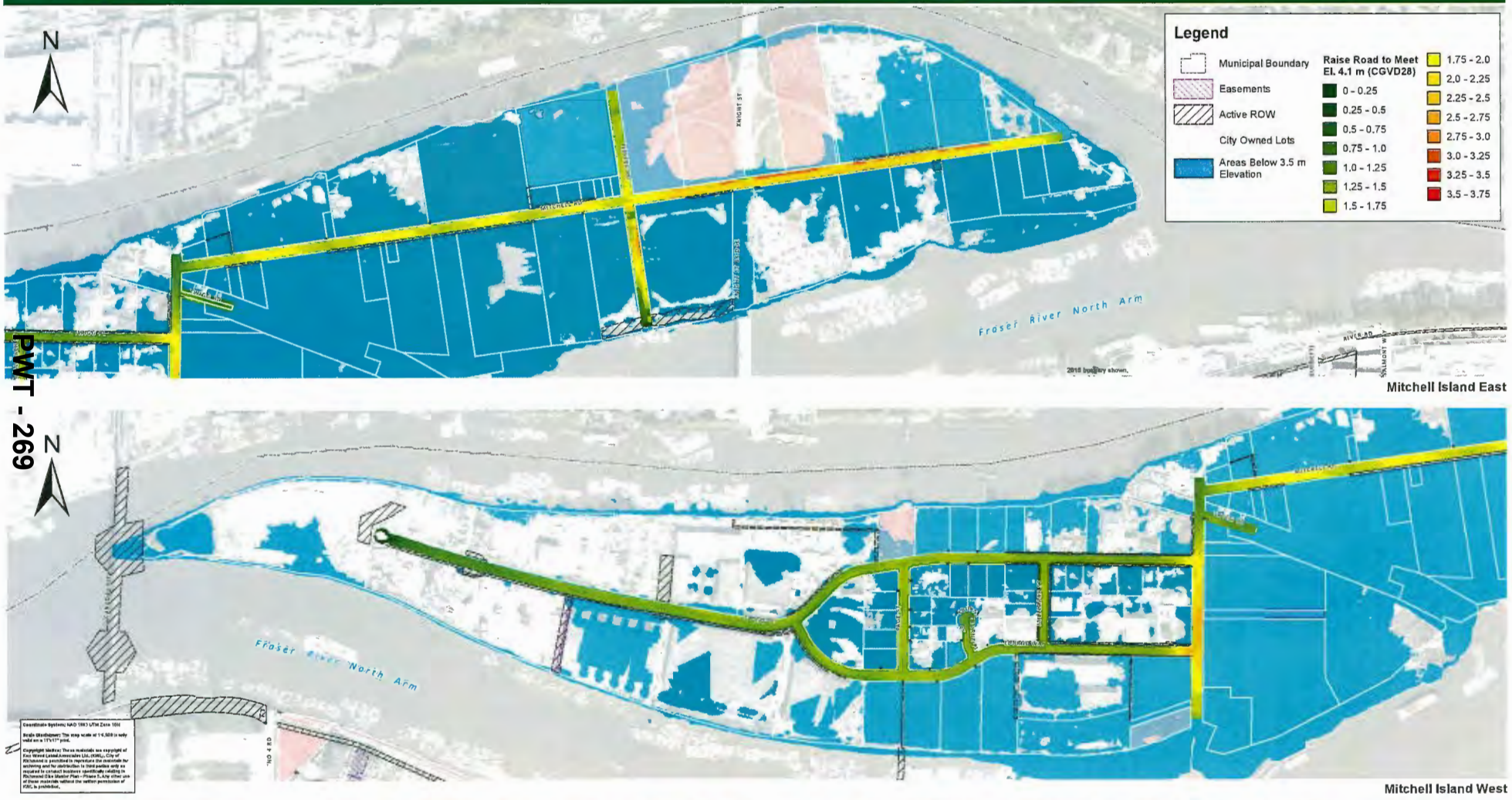

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100 50 0 100 m

Option 2C: Raise Roadways with Required Land Raising on Private Property (Plan)

Figure 3-10

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Richmond Dike Master Plan - Phase 5

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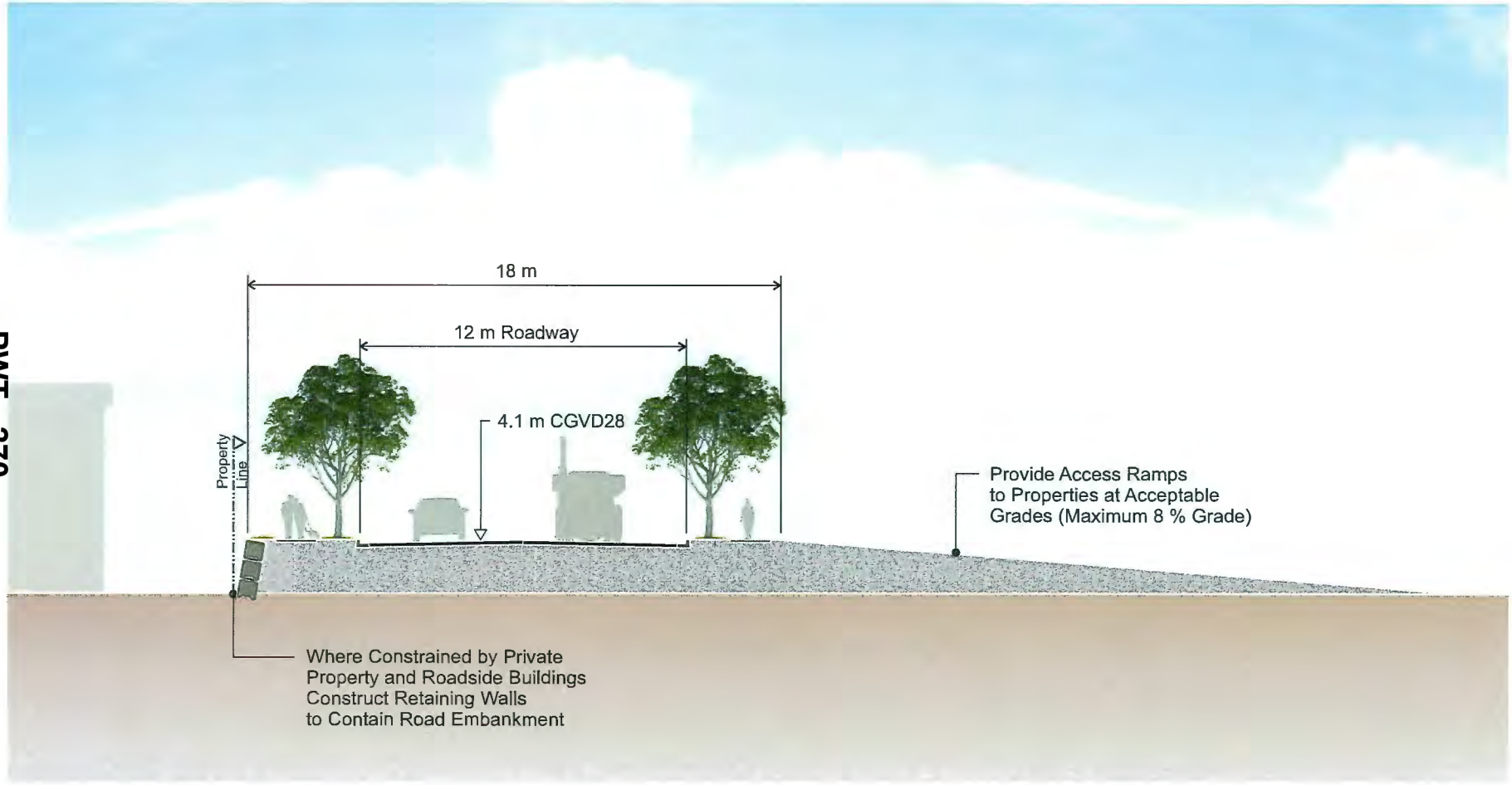

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Project No.	651.129
Date	February 2019
Scale	Not to Scale

Option 2C: Raise Roadways with Required Land Raising on Private Property (Road Typical Section)

Figure 3-11

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Richmond Dike Master Plan - Phase 5

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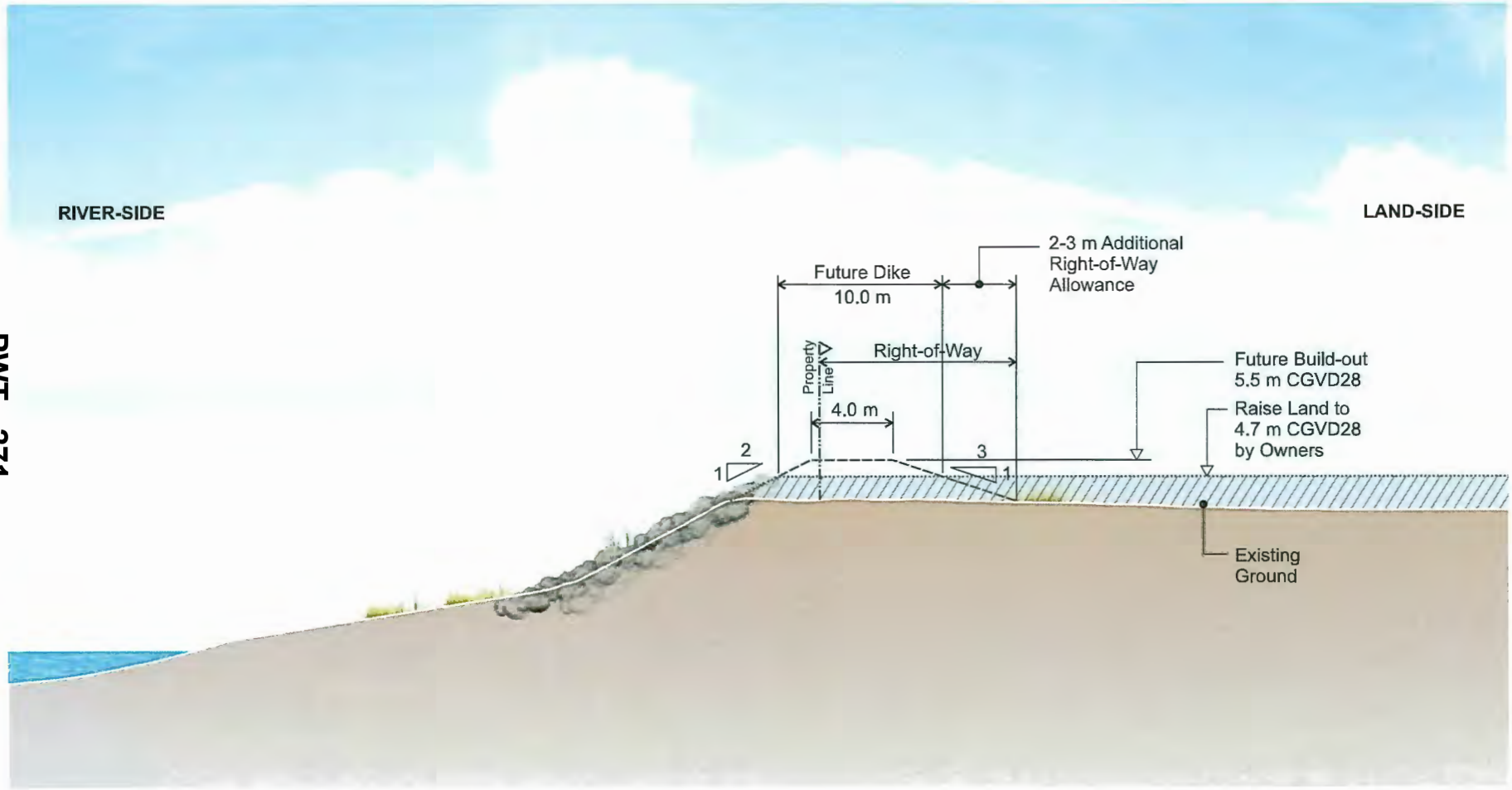

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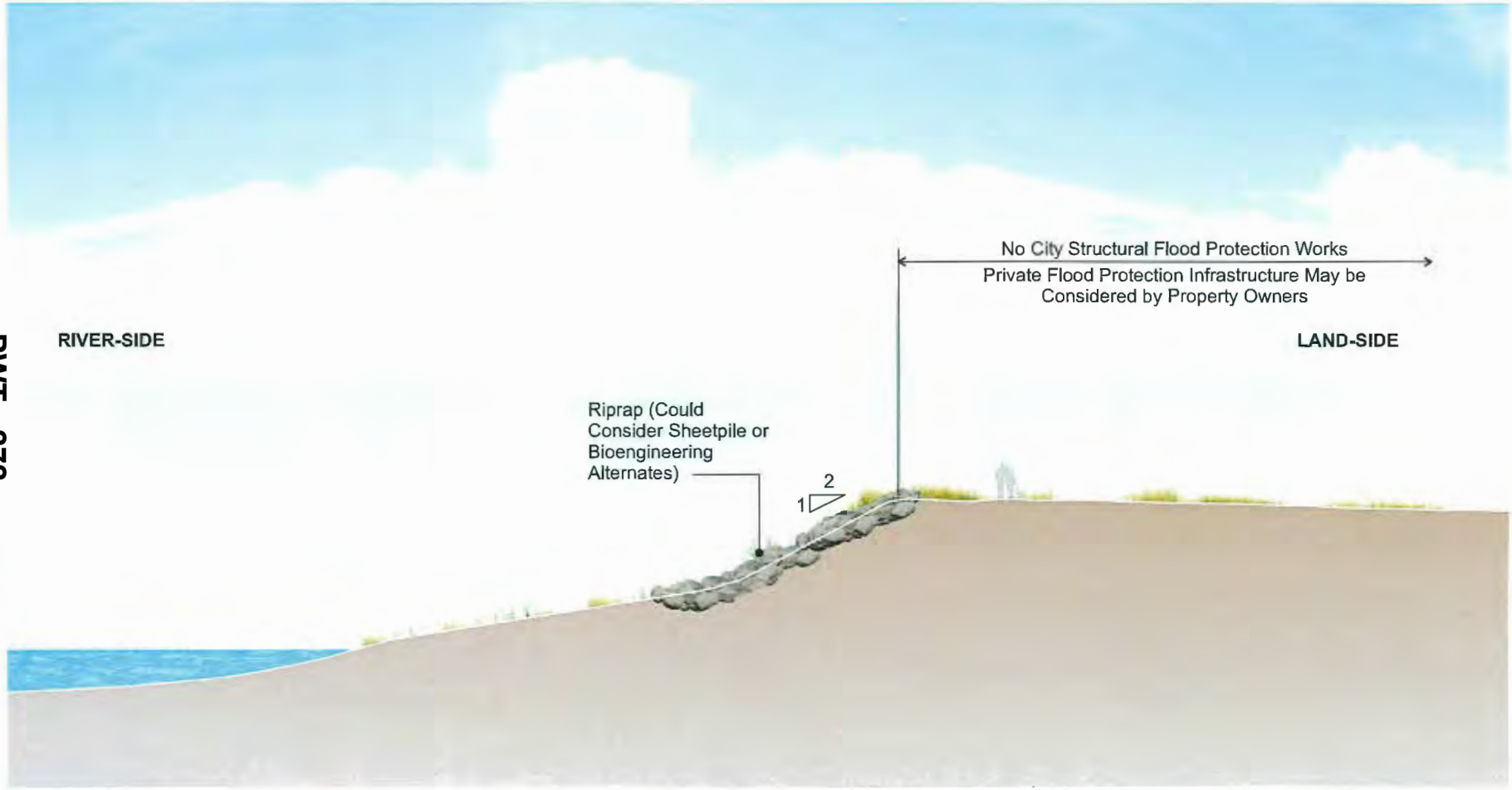
Project No.	651.129
Date	February 2019
Scale	Not to Scale

Option 2C: Raise Roadways with Required Land Raising on Private Property (Riverbank Section)

Figure 3-12



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Project No.	651.129
Date	February 2019
Scale	Not to Scale

Option 3: Install/Maintain Bank Protection Works Only

Figure 3-13

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City of Richmond
Richmond Dike Master Plan - Phase 5

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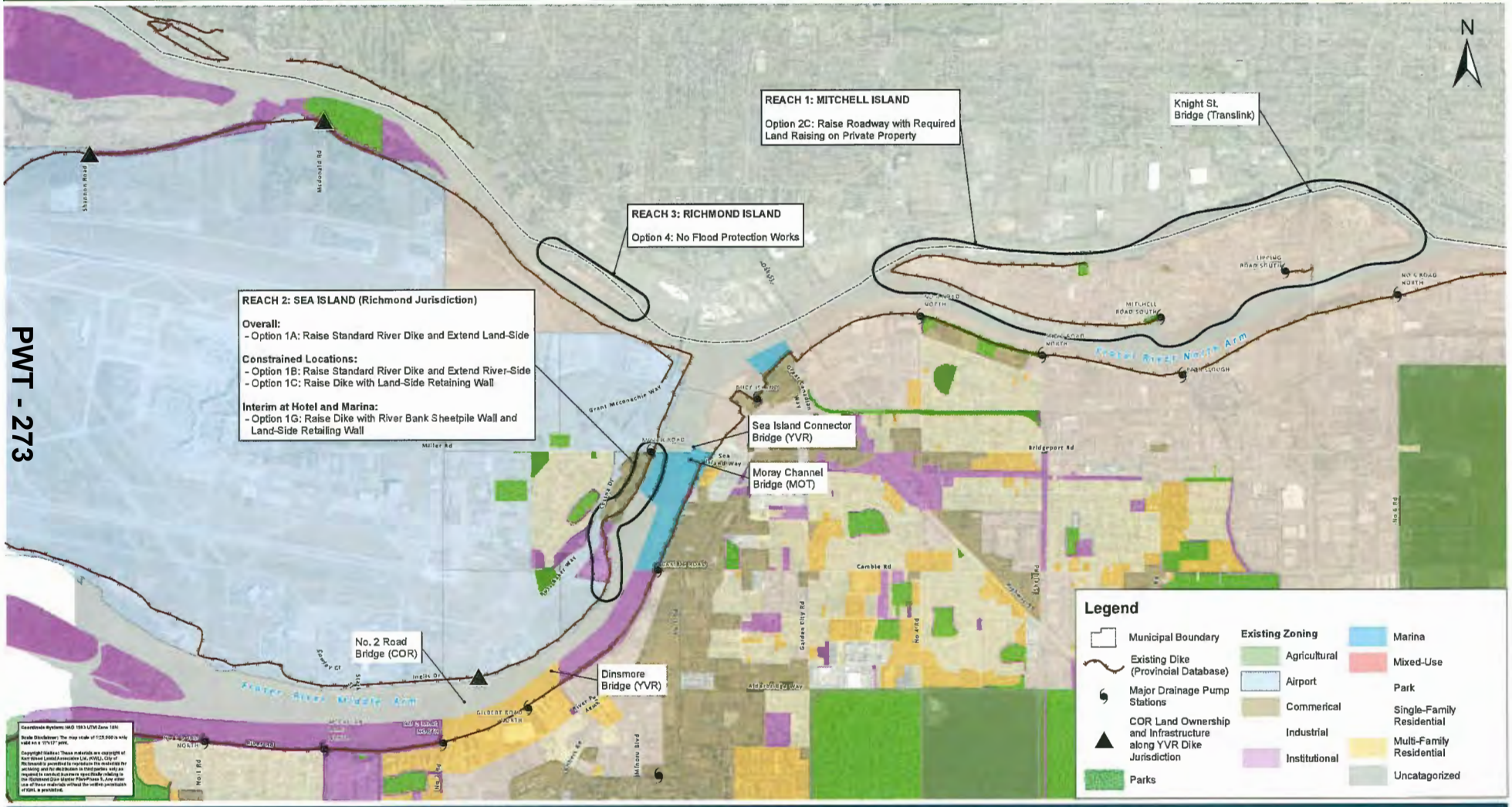

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Project No. 651-129
Date February 2019
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Phase 5 Dike Master Plan Recommended Upgrade Options

Figure 3-14

4. Implementation Strategy

The implementation strategy is intended to guide the City in progressing the Dike Master Plan from an engineering planning document to constructed works. It suggests priority within Phase 5, key considerations moving forwards, coordination with other parties, and it addresses potential challenges. The implementation strategy for Phase 5 is described below by Island, given the unique recommendations for each area.

4.1 General

1. 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.
2. Prioritize implementation in areas below the current design dike elevations of 3.5 m CGVD28.
    a. This includes low-lying properties on Mitchell Island, and the dike on Sea Island from Lysander Lane northwards.
3. In conjunction with other Dike Master Plan phases, develop habitat compensation opportunities in Richmond. By considering all Dike Master Plan phase impacts together, habitat compensation work could be completed at a larger scale and provide more significant habitat, as opposed to small site-by-site compensation.
    a. Consult and coordinate this work with MFLNRO to develop compensation opportunities amenable to the Province, to streamline and reduce uncertainty during the approvals process.
4. Develop an overall phasing strategy and timeline for dike upgrades for all of Richmond, considering other phases of the Dike Master Plan.
5. 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 Mitchell Island

1. Work with low elevation (below current dike crest elevation of 3.5 m CGVD28) property owners in the short term to mitigate flood and related environmental contamination risks. This could include consultation, development of emergency policies, and short-term private flood protection measures. Consultation with low properties may also inform the sequencing of road raising.
2. Establish development policies on Mitchell Island that require the following at redevelopment:
    a. right-of-way acquisition along the riverbank to provide a 12 m wide band of access for the City along the entire perimeter of Mitchell Island, and
    b. land raising to 4.7 m on all properties (including considerations for excavation of contaminated soil and fill quality to reduce environmental contamination).
3. Consult with IOD regarding removal of listed flood protection infrastructure on Mitchell Island from the provincial inventory.

4. Progressively raise all roadways to dike elevation. Newer developments on Mitchell Island are relatively high, given the current Mitchell Island FCL of 4.35 m CGVD28, and as a result, raising the roads in these areas may improve access. Conversely, low lying areas (as low as 2 to 2.5 m CGVD28) would require access ramps to allow for continued operations and retaining walls or narrower roads to avoid impacts to private property. To address access challenges in low areas, the City could consider progressive raising or raising in conjunction with redevelopment. A road elevation of 4.1 m CGVD28 (dike elevation less freeboard) would be appropriate as an initial target, with refinement for specific areas. As part of road raising, assess and modify drainage system infrastructure to maintain drainage services for lots before and after land raising. Consider the impacts to existing utilities and the needs for modifications as part of the design of raised roads.
5. As rights-of-way are acquired around the perimeter of the island, assess the need for additional bank protection works. Consider whether bank protection works should be the responsibility of the City or private land owners.
6. In the long term, if low-lying sites are not redeveloping or raising land and may be putting other property at risk as sea levels rise, consider purchasing and raising the land to be resold.
7. To achieve the future scenario dike elevation of 5.5 m CGVD28, consider further land raising or establish a perimeter dike.

4.3 Sea Island

1. Continue to work with YVR to resolve long-standing dike jurisdiction and land ownership uncertainties as they relate to the dike on Sea Island.
2. Work with YVR to raise the dike at Richmond road crossings. This includes the jurisdiction boundaries of the City's dike and agreements for locations where City land is located along a portion of the dike that is operated by YVR (such as at McDonald Beach Park).
3. Raise the existing dike along the current alignment, prioritizing dike upgrades from Lysander Lane northwards first, to target low areas below the current dike design elevation of 3.5 m CGVD28.
4. Consult with YVR regarding opportunities to raise the dike at Cessna Drive to 4.7 m CGVD28 in conjunction with planned bike path improvements.
5. Consult with the Pacific Gateway Hotel and marina to develop an interim design to raise the dike to 4.7 m CGVD28 along the current alignment, while allowing for access for each business. When the site eventually redevelops, establish a standard dike in accordance with the remainder of the reach.
6. At Lysander Lane, consider either raising the road or constructing a retaining wall to avoid moving the dike towards the river.
7. When the Miller Road drainage pump station is upgraded (planned for 10 to 15 years in the future), provide structural capacity for loading due to the dike raise and ensure there is sufficient space for the dike raise. To reduce overall construction costs, consider designing and constructing pump station and floodbox upgrades in conjunction with dike raising.
8. When the Moray Channel Bridge is at the end of its design life, replace it with a higher structure that is above 5.5 m CGVD28 and raise the land between the two bridges.
9. The current dike along BCIT limits the recommended dike upgrade option and would require moving the dike towards the river or retaining walls. Consider raising dike with a landside retaining wall, moving towards the river, or raising with a narrower crest initially until the site redevelops in the long term.

10. Consider establishing development policies on Sea Island that require land raising to dike elevation during site redevelopment.

4.4 Richmond Island

1. No flood protection works are recommended as the island is predominantly above 5.5 m CGVD28.
2. Consider informing the owner of Richmond Island of the scour risk that has been identified in the North Arm of the Fraser River adjacent to the Richmond Island.

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 5. The second sheet summarizes 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.

Mitchell Island

Existing Conditions

The island is heavily developed with industrial and commercial operations, including sawmills, cement manufacturing, recycling, mechanics, warehouses, and more. Water oriented lots often have sheeptile walls along the river bank that allow for easier access and riprap bank protection works along the bank in adjacent areas.

An unmaintained private dike is located on the western perimeter of the island. There is no existing dike on Mitchell Island that meets current standards. Private bank protection works installed on the majority of the river bank, with sheetpile walls in several locations.

Unique Features

- Complex patchwork of properties with full occupancy of the lot right up to the river bank.
- Drainage pump stations at Tipping Road South and Mitchell Road South.
- No access to the riverbank for dikes except at a few isolated locations.
- Industrial operations that use the river to conduct their work, with sheetpile walls and barge facilities.
- Twigg Island sanitary forcemain crosses from Vancouver.
- Watermain below Page Street.
- Limited riparian habitat around the island.
- Two small existing Richmond parks.
- Log boom storage along the river bank.
- Two sawmills located directly on the water.

Considerations

Flood Protection

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

Industrial

- Water access for industrial sites along the Fraser River
- Land acquisition or rights-of-way required to build and maintain flood protection works
- Road design and driveway grade to accommodate large trucks

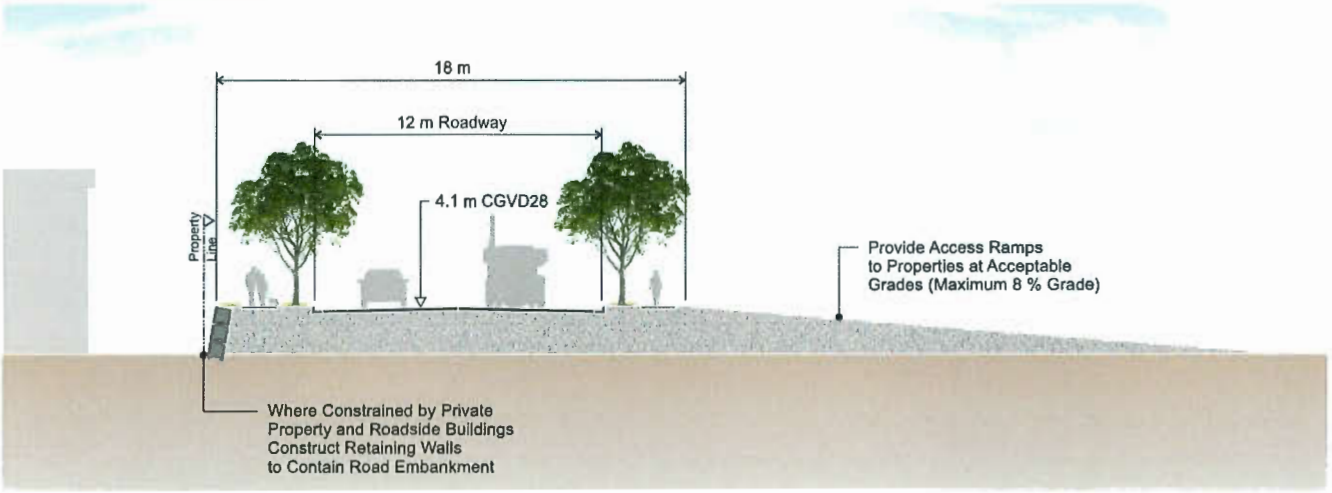
Social

- Mitchell Island Pier
- Park at south end of Mitchell Road
- Align with 2009 Waterfront Strategy
- Connect to existing and planned trails and public amenities
- Wayfinding and public information signs

Environmental

- High quality intertidal habitat in many locations
- Limited riparian habitat
- Log boom storage along the foreshore in many locations
- Several large habitat compensation projects completed around Mitchell Island
- Shoreline and Intertidal ESAs present around perimeter of island

Mitchell Island - Recommended Improvements



Master Plan Features

Flood Protection

Raise roads to dike elevation to provide emergency egress

Require landowners to raise land to dike elevation at redevelopment

Acquire rights-of-way around the island perimeter for future bank protection works or perimeter dike

Industrial

Work with low industrial properties to mitigate short term flood and environmental contamination risks

Provide access driveways to properties during road raising

Social

No plans for additional parks or trails around Mitchell Island

Raise land at current parks and trails and reconstruct as needed

Environmental

No anticipated impacts to riparian or aquatic habitat caused by road raising

Landowner management of environmental impacts during raising

Excavation and fill standards to consider historical contamination risks

Mitigation and compensation for disturbance to ESAs may be required

Priority

Priority is secondary to Sea Island as the majority of Mitchell Island is higher than Sea Island. Implementation priority on Mitchell Island is described below.

1. Work with low properties to mitigate flood and related environmental contamination risks.
2. Establish redevelopment policies on Mitchell Island that require right-of-way acquisition along the riverbank and land raising to 4.7 m on all properties.
3. Progressively raise roads to dike elevation, considering interim raises in low areas to reduce impacts to access and operations.
4. As rights-of-way are acquired around the perimeter of the island, assess the condition and presence of existing bank protection and consider the need for City-owned and maintained bank protection works.
5. In the long term, if low-lying sites are not redeveloping or raising land, consider purchasing and raising the land to be resold.

Construction Cost

Dike works are proposed to be fully funded as part of site raising with redevelopment over long term. 5.3 km of road costs for are expected to be borne by the City that would include driveway access ramps for private properties.

Item	Cost per metre	Cost
Road Structure	$2,900	$15,000,000
Raise Road to Dike Height	$6,900	$36,500,000
Other (Driveways)	$1,600	$8,300,000
Contingency (40%)	$4,500	$23,900,000
Total	**$15,900**	**$83,600,000**

Cost opinions are in 2018 Canadian Dollars.

Sea Island

Existing Conditions

The City of Richmond reach of the Sea Island dike stretches from BCIT north to the Miller Road Pump Station. The remainder of the dike is YVR responsibility.

This reach has a gravel/paved walking path along the crest and is bordered by four large commercial lots including BCIT, the Pacific Autism Family Centre, and the Pacific Gateway Hotel.

The Moray Channel Bridge located at the north end of the reach is lower than the proposed future dike elevation.

The dike is tightly hemmed in by the hotel and adjacent marina with private utilities installed along it. There is little to no bank protection works along the dike.

Unique Features

- Dike tie in at the Moray Channel and YVR Connector Bridges
- Miller Road drainage pump station
- Sanitary forcemain crossing
- Lack of right of way north of BCIT with low spot in the dike near Cessna Drive
- One section of the dike has already been raised to 4.7 m CGVD28 (design elevation)
- Evidence of old timber crib wall

Considerations

Flood Protection

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

Industrial

Commercial and institutional space
Russ Baker Way borders the existing dike
Access and use of the marina

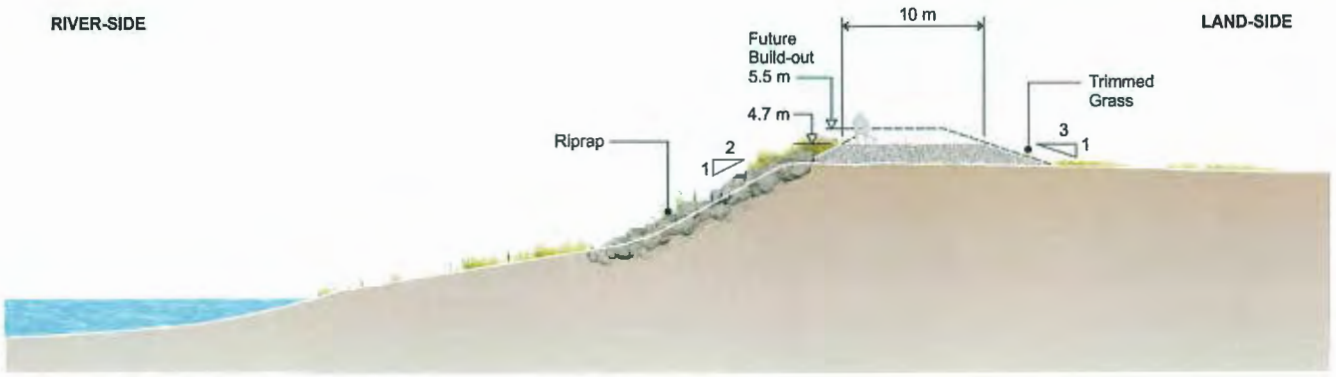
Social

Align with 2009 Waterfront Strategy
Connect to existing and planned trails and public amenities (consideration for YVR trails)
Wayfinding and public information signs

Environmental

High quality intertidal habitat for majority of the reach
High quality riparian habitat for majority of the reach
FREMP habitat mapping did not include the area in front of the hotel and marina. Further investigation would be required to characterize this area.
One existing habitat compensation site near the Miller Road Drainage Pump Station
Shoreline and Intertidal ESAs present in existing dike footprint

Sea Island - Recommended Improvements



Master Plan Features

Flood Protection

Raise dike along existing alignment wide enough to accommodate future raise

Consider moving dike towards river-side or building retaining walls in constrained locations

Along the hotel and marina, raise the dike with sheetpile and retaining wall in the interim

At end of life, replace the Moray Channel Bridge with a higher structure

Acquire and widen rights-of-way

Industrial

Short Term

Reduce impacts to infrastructure along hotel with interim non-standard dike raise.

Raise access ramps at Marina during dike raise.

Long Term

Upgrade the dike along the hotel in accordance with the overall recommended option for a 10 m wide dike.

Social

Provide landside pedestrian access to the dike along the hotel

Maintain existing multi-use path on the dike crest

Environmental

Dike raise towards the landside where feasible to reduce habitat impacts

The proposed footprint would impact an estimated 1,100 m^2 of high quality Fraser River intertidal habitat and 1,900 m^2 high quality Fraser River riparian habitat

An aquatic habitat survey and aquatic effects assessment would need to be completed to confirm impacts during design

Mitigation and compensation for disturbance to ESAs may be required

Sea Island - Recommended Improvements

Priority

Sea Island is the first priority reach in Phase 5. Implementation priority on Sea Island is described below.

1. Continue to work with YVR to resolve dike jurisdiction and land ownership uncertainties.
2. Raise the existing dike along the current alignment, prioritizing dike upgrades from Lysander Lane northwards first (below 3.5 m CGVD28).
3. Consult with the Pacific Gateway Hotel and marina to develop an interim design to raise the dike to 4.7 m CGVD28 along the current alignment.
4. At the Miller Road drainage pump station, consider designing and constructing pump station and floodbox upgrades in conjunction with dike raising.
5. Work with MOT to have the Moray Channel Bridge replaced with a higher structure that is above 5.5 m CGVD28 and raise the land between the two bridges.
6. Establish development policies that require land raising to dike elevation for river bank properties.

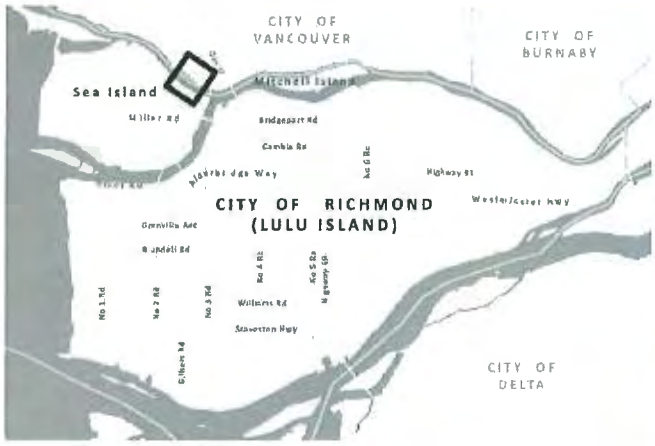
Cost

1.1 km of dike works may be funded as part of site raising with redevelopment or by the City, with 200 m that has already been raised to 4.7 m CGVD28. 40 m of dikes in City road rights-of-way may be covered as part of YVR dike improvements (Shannon and McDonald Roads). 150 m of interim works along the hotel.

Item	Cost per metre	Cost
Interim Dike Raising at Pacific Gateway Hotel	$6,000	$900,000
Dike Raising	$4,500	$3,600,000
Road End Improvements (McDonald Beach, Shannon Road)	$7,200	$300,000
Other (Pathway and access)	$1,000	$800,000
Contingency (40%)	$2,100	$2,200,000
Total	**$7,100**	**$7,800,000**

Cost opinions are in 2018 Canadian Dollars.

Richmond Island



Existing Conditions

Richmond Island is connected to the City of Vancouver via a small causeway. There is no existing dike on Richmond Island. The majority of the island is above both the dike upgrade elevation of 4.7 m CGVD28 and the future allowance to 5.5 m CGVD28, with the exception of the causeway. The entire Island is one private lot.

In 2012, a covenant was established that acknowledges that the City has not plans to protect the island from flooding and releases the City from any damage or losses covered by flooding or erosion.

The Fraser River North Arm is deep, and bathymetry indicates scour along this section. Riprap bank protection is in place around the island.

Utilities are provided by the City of Vancouver.

Unique Features

- Richmond Island is one private lot with a restaurant and marina that is serviced by the City of Vancouver.
- Covenant in place that acknowledges Richmond has no plans to protect the island from flooding or erosion.
- Fraser River north arm along this reach is deep due to scour.
- The majority of the island is above the dike elevation of 4.7 m CGVD28.

Considerations

Flood Protection

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

Industrial

- Private marina on north side of the island.
- Road design and driveway grade

Social

- Align with 2009 Waterfront Strategy
- Connect to existing and planned trails and public amenities
- Wayfinding and public information signs

Environmental

- High quality intertidal habitat around the island
- FREMP mapping did not include riparian area, though based on orthimagery interpretation, riparian habitat is present
- Large habitat compensation project is located at the western tip of the island
- Shoreline and Intertidal ESAs present around perimeter of island

Richmond Island - Recommended Improvements

No Works Proposed

Master Plan Features

Flood Protection

No flood or erosion protection works by the City

Inform property owner of scour risk in the North Arm

Industrial

No impacts to business or industry

Social

No impacts to public infrastructure

Environmental

No impacts to existing habitat

Priority

1. Consider informing the property owner on Richmond Island of the scour risk that has been identified in the North Arm of the Fraser River adjacent to the Richmond Island.

Cost

No works are proposed. Flood protection to remain the responsibility of this single lot.

6. Recommendations

It is recommended that the City adopt the Phase 5 Dike Master Plan as documented in this report, including the main features described below.

Mitchell Island

- During redevelopment, require private properties to be raised to dike elevation and acquire rights-of-way along the river bank. Rights-of-way allow for a future dike and bank protection works.
- As rights-of-way are acquired around the perimeter of Mitchell island, assess the condition of existing bank protection works and consider whether the works should be the responsibility of the City or private land owners.
- Raise roadways to dike elevation to provide emergency egress (consider partial raises in low areas to reduce impacts to operations). Assess and modify drainage system infrastructure to maintain drainage services for lots before and after land raising.
- Work with low elevation properties to mitigate flood and associated contamination risks.

Sea Island

- Raise the dike crest to 4.7 m CGVD28 to allow for 1 m of sea level rise. Widen the dike on the land side rather than into the Fraser River Middle Arm. Retaining walls or extending the dike towards the riparian area may be considered in site-specific constrained areas. Recent raises have been completed on some sections of the dike, including up to 4.7 m CGVD28 in one location.
- Establish development policies on Sea Island that require land raising to dike elevation during site redevelopment.
- Coordinate dike upgrades with upgrades to the Miller Road Drainage Pump Station and the Moray Channel Bridge (MOTI).
- As an interim measure along the Pacific Gateway Hotel, raise the dike to 4.7 m CGVD 28 with a sheetpile wall embedded along the river-side and a land-side retaining wall.
- Coordinate dike improvements with YVR and establish agreed upon dike jurisdictions.

Richmond Island

- No changes by the City are proposed as the island is predominantly above 5.5 m CGVD28. Flood protection responsibility is recommended to remain with the property owner.
- Inform the property owner on Richmond Island of the scour risk that has been identified in the North Arm of the Fraser River adjacent to the Richmond Island.

For all phases of the Dike Master Plan, the City should continue to research alternative densification strategies for seismic stability, consider alternative seismic performance criteria, and consider filling a wide swath of land (several hundred metres) inside the dike. The latter two points (seismic criteria and fill inside the dike) are considerations in the pending Flood Protection Management Strategy update.

It is also recommended that the City prepare a comprehensive implementation plan for dike upgrading that incorporates the elements of Phase 5 and 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.

Allison Matfin, EIT
Project Engineer

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
A. TALEGHANI
45901
2019-02-21

Amir Taleghani, M.Eng., P.Eng.
Water Resources Engineer

Reviewed by:

Mike V. Currie, M.Eng., P.Eng., FEC
Project Director and Technical Reviewer

Colin Kristiansen, MBA, P.Eng.
Project Manager

This document is a copy of the sealed and signed hard copy original retained on file. The content of the electronically transmitted document can be confirmed by referring to the filed original.

Patrick Lilley, M.Sc., R.P.Bio., BC-CESCL
Senior Biologist

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Revision History

Revision #	Date	Status	Revision	Author
0	February 21, 2019	FINAL	Issued to client as final	ARM

IQQM CERTIFIED

References

BC Ministry of Environment (MoE). 2013. Guidelines for Raptor Conservation During Urban and Rural Land Development in British Columbia (2013). Available: http://www.env.gov.bc.ca/wld/documents/bmp/raptor_conservation_guidelines_2013.pdf. Accessed Nov. 8, 2017.

City of Richmond. 2012. Official Community Plan (OCP) – Schedule 1 of Bylaw 9000. 2041 OCP – Moving Towards Sustainability. Richmond, BC. Available: https://www.richmond.ca/__shared/assets/OCP_9000_consolidation34181.pdf. Accessed on November 3, 2017.

City of Richmond. 2008. City of Richmond Engineering Design Specifications – Section 7: Roadworks. Richmond, BC. Available: https://www.richmond.ca/__shared/assets/Roadworks20127.pdf. Accessed on July 28, 2018.

City of Richmond. 2017. Riparian Management Area Info-23 Bulletin. Available: https://www.richmond.ca/__shared/assets/info_2332212.pdf. Accessed on November 8, 2017.

iMapBC. 2017. British Columbia iMapBC. Web application. Available: http://maps.gov.bc.ca/ess/sv/imapbc/. Accessed November 2, 2017.

Fraser River Estuary Management Program (FREMP). 2007. FREMP Habitat Inventory (2007 edition). Spatial Data. Available for viewing: http://cmnmaps.ca/FREMP/map.php?agree=0#. Accessed November 10, 2017.

FREMP. 2012. Colour Code Segments. Spatial Data. Available for viewing: http://cmnmaps.ca/FREMP/map.php?agree=0#. Accessed November 10, 2017.

Province of British Columbia: Ministry of Water, Land and Air Protection. 2003. Dike Design and Construction Guide: Best Management Practices for British Columbia. Available: http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/dike_des_cons_guide_july-2011.pdf. Accessed June 1, 2018.

Richmond Interactive Map (RIM). 2017. Richmond interactive map – Aerial Photos 2016. Available: http://map2.richmond.ca/Html5Viewer_2_0/Index.html?viewer=RIM. Accessed November 3, 2017.

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Appendix A

Plans and Sections for Richmond Dike Master Plan – Phase 5

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City of Richmond
Richmond Dike Master Plan - Phase 5

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Legend

- Easements
- Active ROW
- City Owned Lots
- Parcels (from BC Open Data Catalogue -Parcel Fabric)
- Existing Dike (Provincial Database)

Water Network
- Water Service Lateral
- Watermain
- Alternate Node
- Blow Off
- Cap
- Hydrant
- PRV Chamber
- Valve
- Valve Chamber

Storm Network
- Storm Main
- Service Lateral
- Culvert
- Perimeter Drain
- Drainage Ditch
- Chamber
- Catch Basin
- Storm Manhole
- Headwall
- Rain Gauge
- Drainage Pump

Sanitary Network
- Service Lateral
- Forcemain
- Sanitary Main
- Trunk Sewer
- Alternate Node
- Cap
- Chamber
- Sanitary Manhole
- Sanitary Pump

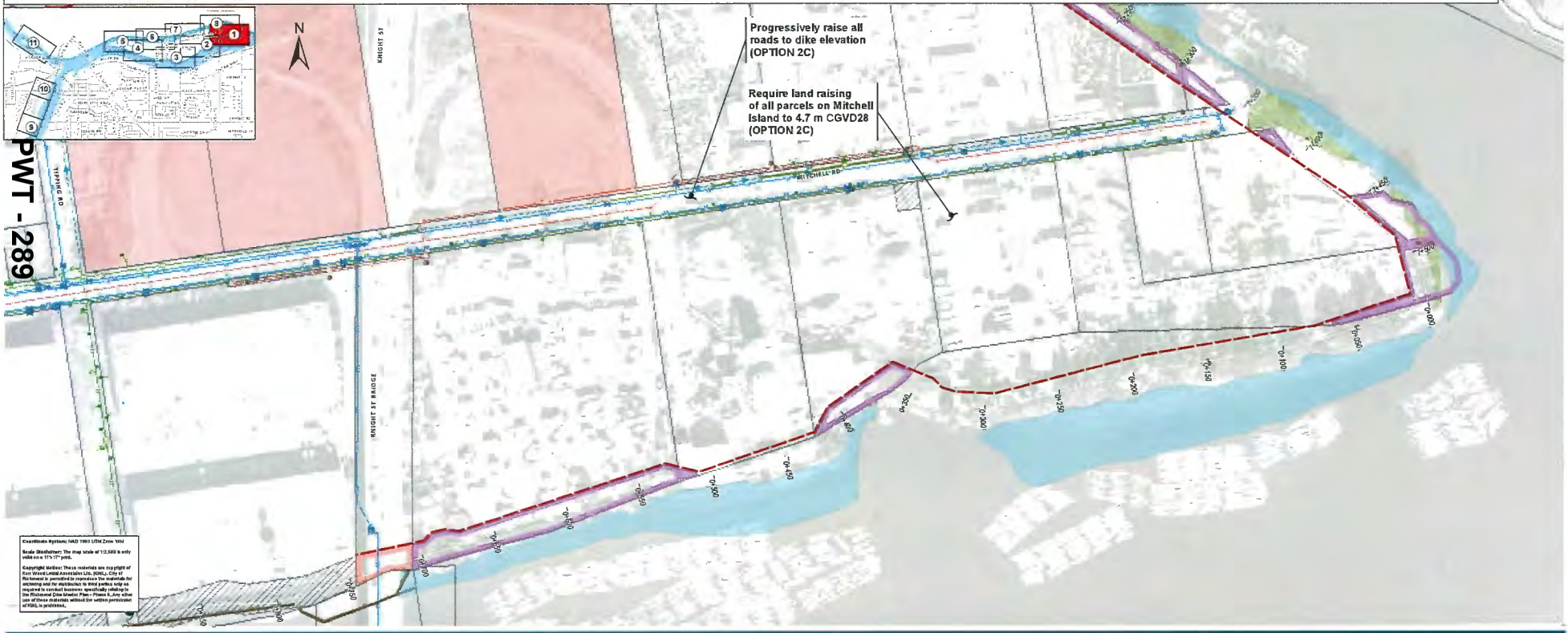
- Fish Habitat Compensation Sites

Habitat Quality & Type
- High Quality Intertidal
- High Quality Riparian

- Possible ROW Limit to be Acquired for Dike Option

Possible Parcel Area to Acquire for ROW (Owner Type)
- Municipal
- Private

Note: 2016 Imagery Shown.



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Richmond Dike Master Plan - Phase 5
Mitchell Island

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City of Richmond
Richmond Dike Master Plan - Phase 5

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Legend

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- PRV Chamber
- Valve
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- Service Lateral
- Culvert
- Perimeter Drain
- Drainage Ditch
- Chamber
- Catch Basin
- Storm Manhole
- Headwall
- Rain Gauge
- Drainage Pump

Sanitary Network
- Service Lateral
- Forcemain
- Sanitary Main
- Trunk Sewer
- Alternate Node
- Cap
- Chamber
- Sanitary Manhole
- Sanitary Pump

- Fish Habitat Compensation Sites

Habitat Quality & Type
- High Quality Intertidal
- High Quality Riparian

- Possible ROW Limit to be Acquired for Dike Option

Possible Parcel Area to Acquire for ROW (Owner Type)
- Municipal
- None
- Private

Note: 2016 Imagery Shown.

PWT - 290

Project No. 651.129
Date February 2019
Scale 1:2,500

50 25 0 50 m

Richmond Dike Master Plan - Phase 5
Mitchell Island

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City of Richmond
Richmond Dike Master Plan - Phase 5

KERR WOOD LEIDAL consulting engineers

Legend

- Easements
- Active ROW
- City Owned Lots
- Parcels (from BC Open Data Catalogue -Parcel Fabric)
- Existing Dike (Provincial Database)

Water Network
- Water Service Lateral
- Watermain
- Alternate Node
- Blow Off
- Cap
- Hydrant
- PRV Chamber
- Valve
- Valve Chamber

Storm Network
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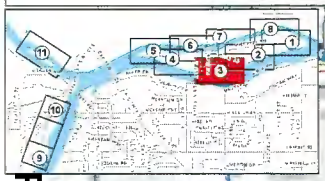

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Project No. 651.129
Date February 2019
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Richmond Dike Master Plan - Phase 5
Mitchell Island

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City of Richmond
Richmond Dike Master Plan - Phase 5

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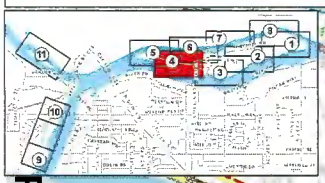

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Project No. 651.129
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 5
Mitchell Island

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City of Richmond
Richmond Dike Master Plan - Phase 5

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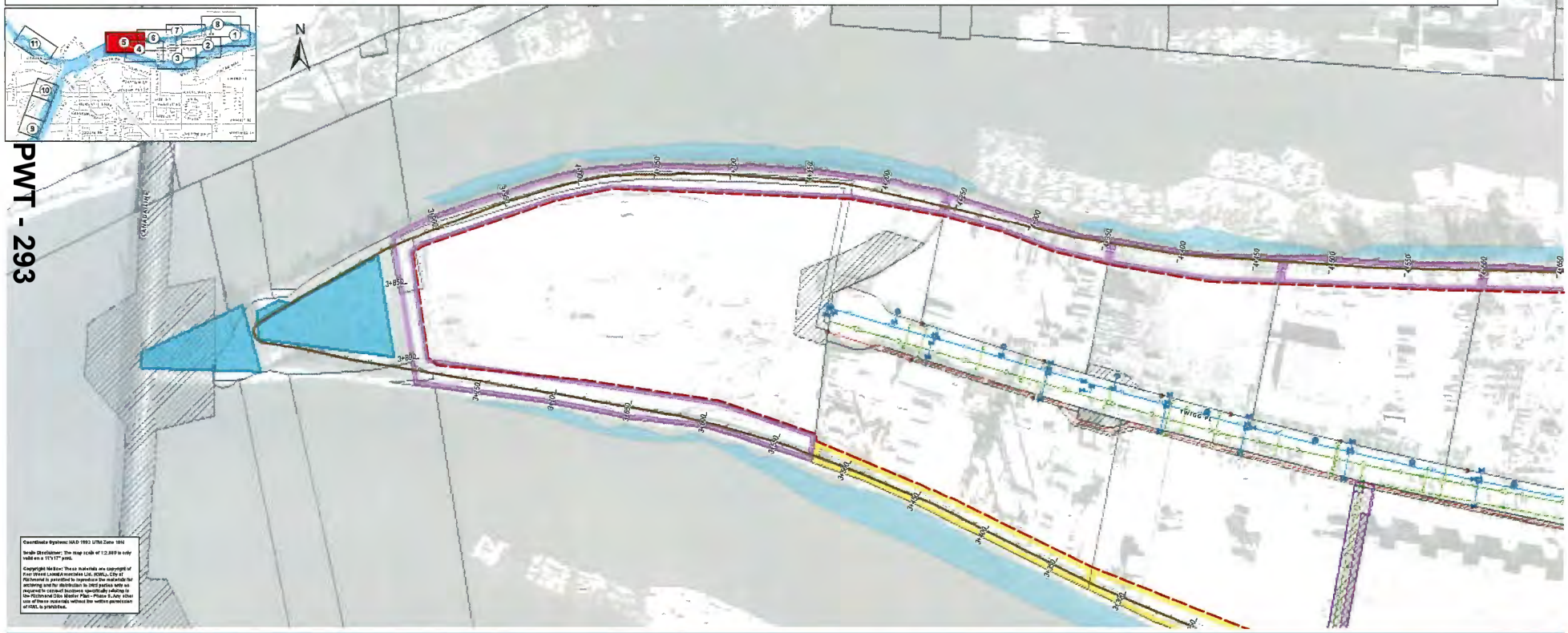

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Richmond Dike Master Plan - Phase 5
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City of Richmond
Richmond Dike Master Plan - Phase 5

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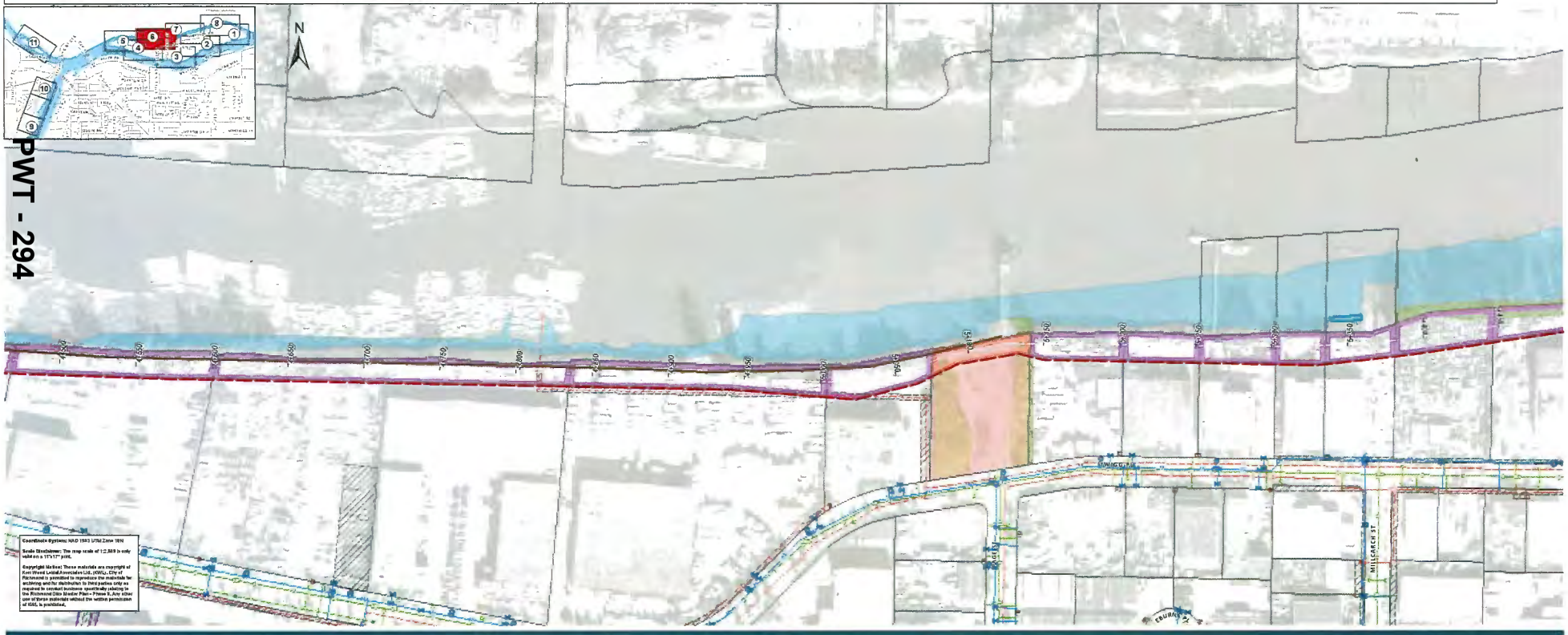

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Richmond Dike Master Plan - Phase 5
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City of Richmond

Richmond Dike Master Plan - Phase 5

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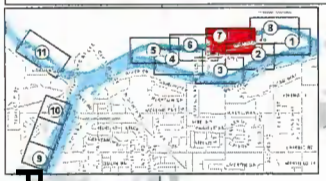
Note: 2016 Imagery Shown.



N

MITCHELL RD

TWIGG RD

PWT - 295

Project No. 651.129

Date February 2019

Scale 1:2,500

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Richmond Dike Master Plan - Phase 5
Mitchell Island

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City of Richmond
Richmond Dike Master Plan - Phase 5

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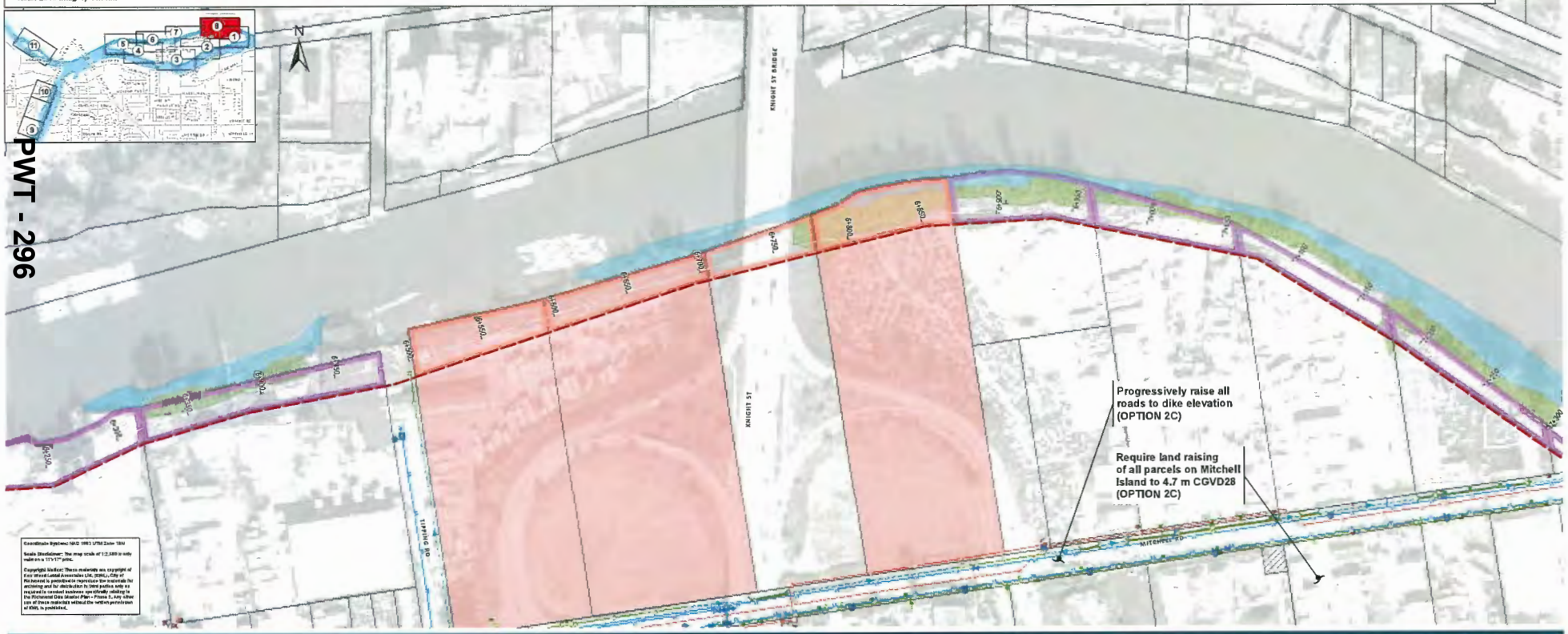

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Project No. 651.129
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 5
Mitchell Island

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City of Richmond
Richmond Dike Master Plan - Phase 5

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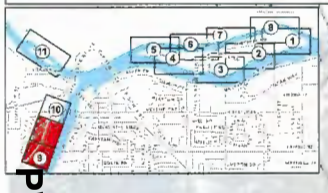
- Fish Habitat Compensation Sites

Habitat Quality & Type
- High Quality Intertidal
- High Quality Riparian

Recommended Upgrade
- Top of Bank /Crest
- Bank Slope
- Dike Fill Extent

Note: 2016 Imagery Shown.



Project No. 651.129
Date February 2019
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Richmond Dike Master Plan - Phase 5
Sea Island

9

PWT - 297

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City of Richmond
Richmond Dike Master Plan - Phase 5

KERR WOOD LEIDAL consulting engineers

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Recommended Upgrade
- Top of Bank /Crest
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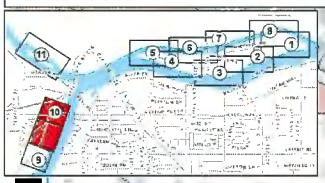

Acquire rights-of-way where none exists along dike and widen existing for future upgrades.

When the Miller Road drainage pump station is upgraded, provide space and structural capacity for loading due to future dike upgrades.

Acquire rights-of-way where none exist along dike and widen existing for future upgrades.

Continue to work with YVR to formalize jurisdiction boundaries for the dike. Boundary shown is based on consultation during the Dike Master Plans's development.

Where constrained at Lysander Lane, either raise Lysander Lane, move the dike towards the river (OPTION 1B), or build a retaining wall (OPTION 1C) to avoid impacting the road. Footprint shows OPTION 1A.

Where constrained at hotel and marina, raise the dike to 4.7 m CGVD28 with a river bank sheetpile wall and land-side retaining wall (OPTION 1G) in the interim, until redevelopment of the site occurs. Footprint shows OPTION 1A.

Consult with MOT to have the Moray Channel Bridge replaced with a structure above 5.5 m CGVD28 and the land raised between the bridges, when the bridge is at the end of its design life.

Coordinate System: NAD 1983 UTM Zone 10N
Scale Disclaimer: The map scale of 13,589 is only valid on a 11"x17" print.
Copyright Notice: These materials are copyright of Kerr Wood Leidal Associates Ltd. (KWL). City of Richmond is permitted to reproduce the materials for archiving and for distribution to third parties only as required to conduct business specifically relating to the Richmond Dike Master Plan - Phase 5. Any other use of these materials without the written permission of KWL is prohibited.

Project No. 651.129
Date February 2019
Scale 1:2,500

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Richmond Dike Master Plan - Phase 5
Sea Island

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City of Richmond
Richmond Dike Master Plan - Phase 5

KERR WOOD LEIDAL consulting engineers

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Habitat Quality & Type
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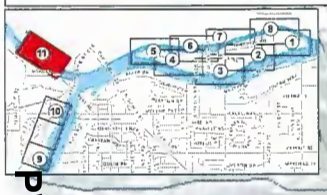

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Project No. 651.129
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Scale 1:2,500

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Richmond Dike Master Plan - Phase 5
Richmond Island

KERR WOOD LEIDAL
consulting engineers

Appendix B

Geotechnical Engineering Analysis Report (Thurber)

THURBER ENGINEERING LTD.

October 16, 2018 File: 17991

Kerr Wood Leidal Associates Ltd.
200 4185A Still Creek Drive
Burnaby, BC V5C 6G9

Attention: Colin Kristiansen, P.Eng.

LULU ISLAND DIKE MASTER PLAN - PHASES 3, 4 AND 5
GEOTECHNICAL SEISMIC ASSESSMENT OF FLOOD CONTROL DIKES
PRELIMINARY REPORT

Dear Colin:

As requested, Thurber Engineering Ltd. (Thurber) has carried out numerical seismic deformation analyses for the above project using the software program Plaxis. This report presents the results of the deformation analysis and a preliminary assessment of the performance of flood control measures in the context of provincial design requirements for high-consequence dikes. It is a condition of this report that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

1. INTRODUCTION

The City of Richmond (the City) requires input to identify dike upgrade options for Phases 3, 4 and 5 of the Lulu Island Dike Master Plan. The purpose of the Dike Master Plan is to address the short, medium and long-term needs of the Lulu Island diking system. Phase 1 of the plan was carried out in 2012 and included input on the Steveston Dike and south section of the West Dike. Phase 2 of the plan included the north section of the West Dike and the North Dike.

Phase 3 comprises about 20 km of the South Dike on the south arm of the Fraser River. Phase 4 includes the North Dike, extending from No. 6 Road to Boundary Rd. Phase 5 includes Mitchell Island, Richmond Island, and the Richmond part of Sea Island (from the southern end of the BCIT campus North to the Moray Rd. Bridge).

These high-consequence dikes are required to consider seismic performance as described in the Ministry of Forests Lands and Natural Resource Operations' (MFLNRO's) 2014 Seismic Design Guidelines for Dikes. (2014 Seismic Guidelines). Additionally, the dikes are anticipated to be raised in the future to address sea level rise.

Accordingly, this report presents the preliminary results of our numerical seismic deformation analyses for eight dike sections: three in each of the Phase 3 and Phase 4 study areas, and two in the Phase 5 study area. The analyses presented below follow the analytical methods described in the 2014 Seismic Guidelines.

THURBER

2. SEISMIC ASSESSMENT BASIS

Seismic assessments were carried out for the eight dike sections at the locations in the table below. The assessments for the Phase 3 dike sections were carried out using cone penetration test (CPT) data provided by the City. Geotechnical investigations were carried out specifically for this project at the five sections in the Phase 4 and 5 study areas. The locations of the dike sections were selected by KWL. Profile drawings showing the section analysed at each location were prepared by KWL and are included in Appendix A. Our analyses followed the analytical methods described in the 2014 Seismic Guidelines.

Section	Phase	Test Hole
53+900	3	Tetra Tech CPT17-02
61+900	3	GeoPacific CPT06-03, CPT 06-06
67+600	3	MEG CPT17-03
11+700	4	CPT 18-03
16+400	4	CPT 18-04
18+750	4	CPT 18-05
1+000	5	CPT 18-01
5+700	5	CPT 18-02

The 2014 Seismic Guidelines recommend designing high-consequence dikes and appurtenant structures to control seismic deformations within prescribed limits. The seismic deformation limits vary depending on the seismic hazard return period as shown in the table below.

Seismic hazard return period (year)	Maximum allowable displacement (mm)	
	Horizontal	Vertical
1 in 100	<30	<30
1 in 475	300	150
1 in 2,475	900	500

The analyses used earthquake time-histories that were developed for the George Massey Tunnel replacement project. The earthquake time-histories were scaled for each dike section location using Natural Resources Canada's on-line seismic hazard calculator. The analyses were carried out for the crustal, inslab, and interface (i.e. Cascadia subduction event) scenario earthquakes. Three earthquake time histories for each scenario earthquake were developed for each of the 1 in 100, 475 and 2,475-year return period seismic hazards.

We carried out 1-dimensional site-specific response analyses (SSRAs) using each of the time histories. The SSRAs were carried out using the software program DEEPSOIL published by the University of Illinois. The SSRAs were completed using three crustal, three in-slab and three interface earthquake time-histories for each of the 1 in 100, 475 and 2,475-year return period

seismic hazards, for a total of 27 SSRAs per dike section. The results of the SSRAs were used in both the liquefaction assessment and numerical deformation analysis. The SSRAs used the shear wave velocity data from the CPTs to estimate the site-specific seismic accelerations and seismically induced shear stresses and strains.

The numerical deformation modelling analyses were completed using one crustal, one inslab and one interface earthquake for each of the slope sections analysed. The time history for each scenario earthquake type (i.e. crustal, inslab and interface/subduction) used in the numerical analyses was selected by choosing the earthquake that had the median maximum shear stress profile obtained from the SSRAs. The soil stiffness and damping parameters used in the numerical deformation analyses were calibrated based on the maximum shear strain profile and ground response obtained from the SSRAs.

The seismic assessment included liquefaction analyses and numerical deformation analyses using the results from the SSRAs and the data from the CPTs. The numerical deformation analyses were based on the dike sections provided by KWL.

3. GEOTECHNICAL INVESTIGATION

3.1 Program of work

The field investigation was carried out July 5 and 6, 2018 and comprised a combination of auger drilling and CPT profiling. The CPTs included two seismic CPTs (i.e. SCPTs), which are CPTs with the addition of shear wave velocity profiling. The CPT profiles, test hole logs and a test hole location plans (Drawings 17991-1 to 17991-5) are attached in Appendix B.

The CPTs were advanced to depths of 30 m. Two CPTs (CPT 18-02 to 18-05) were supplemented with shear wave velocity measurements. The CPT provides a continuous trace of cone tip resistance, sleeve friction and pore pressure. This data was used to interpret the soil stratigraphy and estimate soil properties (e.g. strength and density). The SCPT includes shear wave velocity measurements that were used to estimate the small-strain shear modulus of the soil. The small-strain shear modulus has been used in the SSRAs and numerical deformation analyses. The CPTs were drilled out to depths of nominally 7.5 m with a solid stem auger to confirm the soil profile and obtain disturbed samples.

The soil and groundwater conditions in the test holes were logged in the field by an experienced geotechnical engineer and representative disturbed samples were collected for routine moisture content testing and visual classification in our laboratory. Fines content analyses (% passing 75 µm sieve) and Atterberg limit testing were carried out on select representative samples.

All test holes located on the dike and within the dike right-of-way were grouted in general accordance with B.C. groundwater protection regulations and MFLNRO requirements.

THURBER

3.2 Results

The results of the investigation and laboratory testing are summarized on the attached test hole and CPT logs. The logs provide a complete, detailed description of the conditions encountered and should be used in preference to the generalized descriptions given below. The soil descriptions provided on the CPT logs are Gregg Drilling and Testing Canada's interpretations of the CPT data using generally accepted correlations and should be considered approximate.

At TH/CPTs 18-04 and 18-05, which are at the east end of Lulu Island, the conditions encountered comprised a thick silt layer at the surface underlain by Fraser River sand. The silt layer was about 17 m to 20 m thick and comprised clayey organic silt to sandy silt. The underlying Fraser River Sand was encountered to the maximum depth investigated (30 m).

At TH/CPTs 18-01, 18-02 and 18-03 the subsurface conditions comprised a silt crust that varied from about 4 m to 7 m thick. Below the crust, Fraser River sand was encountered to depths of about 23 m to 24 m. Silt was encountered below this to the maximum depth investigated.

The interpretation of the CPT data provided by the City for the three Phase 3 dike sections indicates the subsurface conditions at these locations are similar to the conditions encountered at TH/CPTs 18-01, 18-02 and 18-03. We expect that conditions in this phase typically comprise a 2 m to 7 m thick clay first overlaying Fraser River sand to depths of about 20 m to 25 m.

The results of the investigation were consistent with the British Columbia Geological Survey's Map 2010-2 "Quaternary Geology of Richmond, British Columbia", which is attached for reference. This map indicates that surficial geology of most of Lulu Island comprises a silt crust at the surface that is typically 2 m to 7 m thick, underlain by Fraser River sand extending to depths of about 25 m. The map shows that the surficial geology on the east end of Lulu Island comprises organic silts and peat up to 12 m thick underlain by Fraser River Sand.

Groundwater levels are anticipated to generally follow water levels in the Fraser River and can be expected to vary with rainfall, drainage and infiltration.

4. SEISMIC PERFORMANCE

4.1 Liquefaction Assessment

Liquefaction assessments using empirical methods were carried out to assess the degree of liquefaction under each of the seismic hazard return periods for each earthquake scenario type and to provide estimates of reconsolidation settlement. These liquefaction assessments were also used to compare the liquefaction predicted using empirical methods against the liquefaction predicted from the 1D numerical models.

Liquefaction assessments were carried out for flat ground (i.e. 1D) conditions for each of the three design earthquake levels using the software program CLiq published by Geologismiki.

These assessments followed the methods described by Idriss and Boulanger (2008 and 2014) to evaluate the resistance to liquefaction (i.e. the cyclic resistance ratio (CRR)). The shear stress triggering liquefaction (i.e. the cyclic stress ratio (CSR)) was calculated by averaging the maximum stress ratio profiles for each scenario earthquake (e.g. the CSR for the 1 in 100-year crustal earthquake was calculated using the average of the maximum stress ratio profiles from the three crustal time-histories).

The results of the liquefaction triggering analyses are presented on the plots generated by CLiq in Appendix C. These plots show layers where liquefaction is anticipated (i.e. where the CSR is greater than the CRR, or the factor of safety is less than one against liquefaction) and also provide estimates of post-liquefaction reconsolidation settlement.

The liquefaction triggering assessment shows that liquefaction is anticipated to be insignificant under all of the scenario earthquakes for the 1 in 100-year return period seismic hazard. This corresponds to "No liquefaction (L0)" per the 2014 Seismic Guidelines. The assessment also indicates that the sand encountered is generally liquefiable under all of the scenario earthquakes for the 1 in 475 and 2,475-year return period seismic hazards. We have inferred that the extent of liquefaction of the sand layers under the 1 in 475-year return period earthquakes is "Mild liquefaction (L1)" to "Moderate liquefaction (L2). The extent of liquefaction under the 1 in 2,475-year return period seismic hazards is inferred be "High liquefaction (L3)".

The reconsolidation settlements under the 1 in 475 and 2475-year return period seismic hazards are anticipated to be typically between about 400 mm to 1000 mm. The exception to this is at the sections at the east end of Lulu Island where a thick layer of surficial silt was encountered. At these locations, reconsolidation settlements are anticipated to be about 50 to 400 mm under the 1 in 475 and 2475-year return period seismic hazards. For the 1 in 100-year return period seismic hazard, reconsolidation settlements are anticipated to be less than 100 mm at all of the dike sections analysed for all earthquake scenario types. The reconsolidation settlements typically nominally meet or exceed the performance requirements of the 2014 Seismic Guidelines.

For reference we have attached the British Columbia Geological Survey's Map 2010-3 "Liquefaction Hazard Map of Richmond, British Columbia" which shows a qualitative assessment of the liquefaction risk. The results of our liquefaction assessment are consistent with the information shown on the map.

4.2 Numerical Deformation Analysis

We carried out seismic numerical deformation analyses using the software program Plaxis 2D. Plaxis 2D is an advanced finite element modelling program that allows for complex modelling of cyclic soil behaviour, similar to the software program FLAC, but with a user-friendly interface that allows for more rapid model construction and a faster computation routine. The deformation analyses incorporated complex cyclic soil behaviour using the UBCSand soil model, which is the same model used in FLAC for similar numerical deformation analysis.

The numerical deformation analysis used the site-specific earthquake acceleration time histories output from the SSRAs. The numerical deformation analyses were carried out for the 1 in 100, 475 and 2,475-year return period seismic hazards for each of the earthquake scenario types.

One time-history was run for each of the scenario earthquakes for each return period seismic hazard. The time histories were selected by taking the scenario earthquake time-histories that had the median CSRs for each scenario earthquake type.

In keeping with the intent of the concept that the dikes must perform under a uniform hazard framework consistent with the NRC's probabilistic seismic hazard assessment, we have taken the performance under each earthquake return period as the largest displacements of the scenario earthquakes. The largest displacements for all of the sections analysed was the crustal scenario earthquake for the 1 in 100-year return period seismic hazards. For the 1 in 475 and 2,475-year return period seismic hazards, the subduction scenario earthquake resulted in the largest displacements for all of the dike sections.

The output from the Plaxis analyses provided in Appendix D presents the results from the earthquake scenario type that had the largest seismic displacements. The output includes plots of vertical and horizontal displacements for comparison with the performance requirements of the 2014 Seismic Guidelines. We have also included plots showing total displacement as this provides a clearer interpretation of the pattern of displacements.

The numerical deformation analyses indicate that the dikes will not meet the performance requirements of the 2014 Seismic Guidelines for any of the return period seismic hazards. The analyses indicate that typically the required dike setback will be about 50 m to 100 m. The actual setback will depend on the dike height and configuration and site-specific conditions.

5. DISCUSSION

We understand that the intent of the 2014 Seismic Guidelines is for construction of conventional dikes using alignments or reasonable design features to meet the required seismic performance criteria. However, extensive ground improvement is not necessarily required if the seismic performance criteria are not met. The 2014 Seismic Guidelines acknowledge that ground improvement methods are "costly and may only be practical for short sections or at appurtenant structures", such as pump stations or flood gates. Accordingly, if cost-prohibitive ground improvement is the only way to conform to the guidelines, alternatives should be considered.

The 2014 Seismic Guidelines suggest alternatives such as: 1) realigning dikes to less seismically vulnerable areas, 2) overbuilding dikes to accommodate seismic displacements, 3) building very wide "superdikes", and 4) developing comprehensive flood risk and flood protection strategies, including post-earthquake dike repair plans.

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The analysis indicates that ground improvement or other remedial measures will be required to meet the performance requirements of the 2014 Seismic Guidelines for dikes near riverbanks.. The critical location for ground improvement is under the waterside toes/slopes of the dikes, where the shear stress bias is the highest. In some situations, such as where the dikes are high, ground improvement may also be required under the landside toes/slopes of the dikes. Sufficient deformation control could probably be achieved using ground improvement with an aspect ratio of between 0.75H:1V and 1H:1V extending to the bottom of the deepest liquefiable layer (i.e. in profile view, the width of the ground improvement should be 75% to 100% of the depth of liquefaction).

It is our opinion that ground improvement using stone columns is probably the most suitable ground improvement method for the contemplated dike upgrade. Stone columns typically cost about $\$15/m^3$ on a treated volume basis. Compaction piles, soil mixing and jet grouting are other alternatives to increase the strength of the sand to limit liquefaction. These alternatives typically cost more and could be more difficult to adapt to changing or unexpected subsurface conditions than stone columns.

Compaction piles would also probably need to be straight (i.e. without taper) displacement piles. Although timber piles are commonly used as compaction piles, because they are tapered they may not be able to densify the soil at depth. Accordingly, they are not recommended. Compaction piles comprising precast concrete or steel pipe piles are expected to cost about 20 times stone columns on a volume basis.

Soil mixing methods include deep soil mixing (DSM) and cutter soil mixing (CSM). These methods are typically about five times the cost of stone columns per treated soil volume. Jet grouting also costs more, at about seven times the cost of stone columns.

As a potential alternative to ground improvement, the dikes could be set back from the river bank. Based on the results of the Plaxis deformation analyses, the required distance could be in the order of 50 m to 100 m. Setback dikes could either require flat slopes or some ground improvement to mitigate seismic deformations (i.e. lateral spreading of the dike embankment).

6. CLOSURE

We trust that this letter provides sufficient information for your needs at this time. Should you require clarification of any item or additional information, please do not hesitate to contact us.

Yours truly,

Thurber Engineering Ltd.
David Regehr, P.Eng.
Review Principal

Steven Coulter, P.Eng.
Project Engineer

Attachments

- Statement of Limitations and Conditions (1 page)
- Appendix A – KWL Dike Sections (9 pages)
- Appendix B – Geotechnical Investigation (15 pages)
- Appendix C – Liquefaction assessment CLiq output (72 pages)
- Appendix D – Numerical deformation analyses Plaxis output (72 pages)
- British Columbia Geological Survey Map 2010-2 "Quaternary Geology of Richmond, British Columbia"
- British Columbia Geological Survey Map 2010-3 "Liquefaction Hazard Map of Richmond, British Columbia"

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STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

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All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report, which is of a summary nature and is not intended to stand alone without reference to the instructions given to Thurber by the Client, communications between Thurber and the Client, and any other reports, proposals or documents prepared by Thurber for the Client relative to the specific site described herein, all of which together constitute the Report.

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a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and the Report is delivered subject to the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. If special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

c) Design Services: The Report may form part of design and construction documents for information purposes even though it may have been issued prior to final design being completed. Thurber should be retained to review final design, project plans and related documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the Report's recommendations and the final design detailed in the contract documents should be reported to Thurber immediately so that Thurber can address potential conflicts.

d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause the escape, release or dispersal of those substances. Thurber shall have no liability to the Client under any circumstances, for the escape, release or dispersal of pollutants or hazardous substances, unless such pollutants or hazardous substances have been specifically and accurately identified to Thurber by the Client prior to the commencement of Thurber's professional services.

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The information, interpretations and conclusions in the Report are based on Thurber's interpretation of conditions revealed through limited investigation conducted within a defined scope of services. Thurber does not accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.

British Columbia Geological Survey
Geoscience Map 2010-2

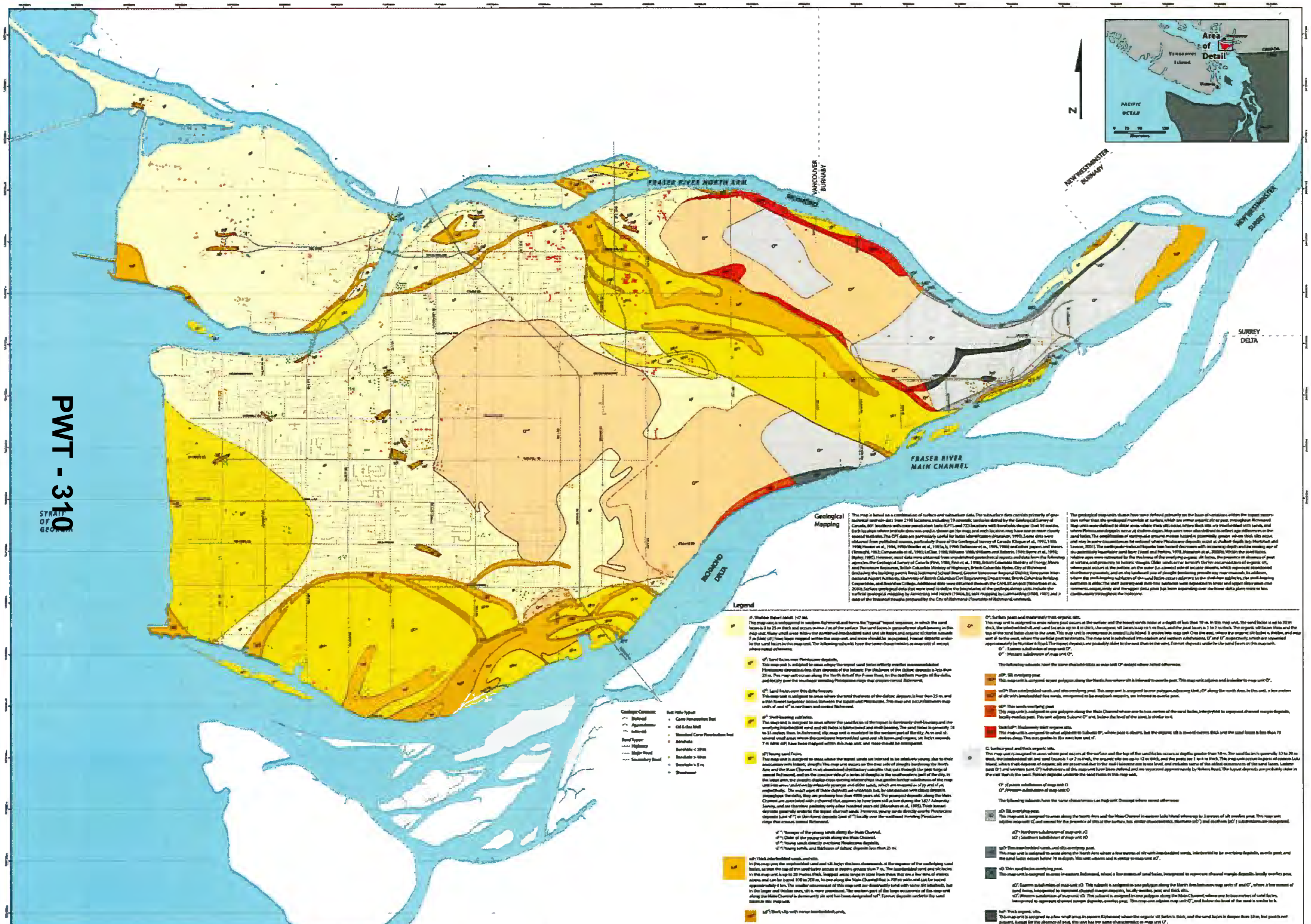
QUATERNARY GEOLOGY OF RICHMOND, BRITISH COLUMBIA

Patrick A. Monahan, Victor M. Levson and Ben Kerr

This map shows geological variation in the Quaternary deposits underlying the City of Richmond, British Columbia, and has been prepared as part of an earthquake hazard mapping project in the city. Richmond is located in one of the most seismically active regions in Canada (Rogers, 1998), and the deltaic sediments on which the city is built can amplify ground motions and are susceptible to earthquake induced liquefaction (e.g. Byrne, 1978; Finn et al., 1989; Byrne and Anderson, 1991; Clague et al., 1992, 1997, 1998b; Watts et al., 1992; Rogers et al., 1998; Harris et al., 1995, 1998; Cassidy et al., 1997; Cassidy and Rogers, 1999; Levson and Monahan, 2004). Because the variation in earthquake hazards is most affected by geological conditions in the upper 20 to 30 metres, this map primarily reflects geological variation in the upper 20 to 30 metres of the Quaternary sequence.

Quaternary Geology Framework

Fraser Delta Topset Deposits



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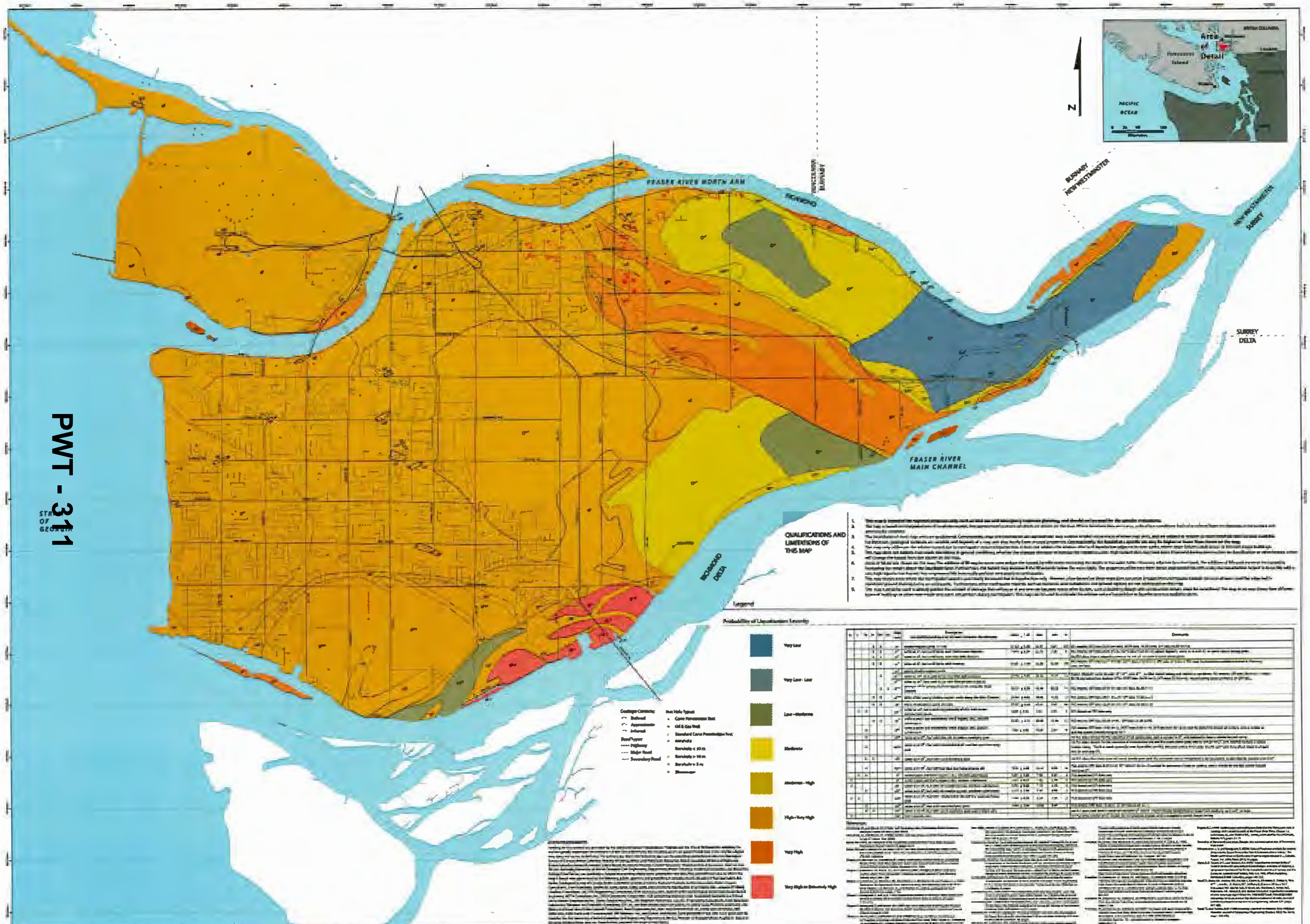

PWT - 311

British Columbia Geological Survey

Geoscience Map 2010-3

LIQUEFACTION HAZARD MAP OF RICHMOND, BRITISH COLUMBIA

Patrick A. Monahan, Victor M. Levson and Ben Kerr

The City of Richmond, British Columbia, is located in one of the most seismically active regions in Canada (Rogers, 1998). The effects of earthquakes are not only dependent upon the magnitude of the earthquake and the distance from the source, but can vary considerably due to local geological conditions. These conditions can be mapped using existing geological and geotechnical data. This map shows the variation in the earthquake-induced liquefaction hazard in City of Richmond, British Columbia. The city is located entirely within the modern Fraser River delta, and the deltaic sediments on which the city is built are particularly susceptible to earthquake induced liquefaction (e.g. Byrne, 1978; Finn et al., 1989; Byrne and Anderson, 1991; Clague et al., 1992, 1997, 1998b; Watts et al., 1992). This map has been prepared as part of an earthquake hazard mapping project in the city. An accompanying map shows the Quaternary geology of the Richmond area.

This map is intended for regional purposes only, such as land use and emergency response planning, and should not be used for site-specific evaluations. This map can be used with other criteria to help planners select potential areas for development, avoid geologically vulnerable areas, and prioritize seismic upgrading programs. *However, this map does not replace the need for site-specific geotechnical evaluations* prior to new construction or upgrading of buildings and other facilities. The qualifications and limitations of this map are discussed in more detail below.

Liquefaction Hazard Mapping