Richmond

Lulu Island Dike Master Plan
PHASE 1 DIKE MASTER PLAN REPORT

March 2013
EB3763

Submitted By:

Delcan

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Executive Summary

The purpose of the Lulu Island Dike Master Plan (LIDMP) is to identify preferred methods for implementing the objectives of the City of Richmond's 2008 – 2031 Flood Protection Strategy.

Phase 1 of the LIDMP focusses on the Steveston area and the southern West Dike. To mitigate the overall flood risk profile, which includes climate change induced sea level rise, an alignment and concept design is recommended for dike improvements. This plan recommends a significant change from the existing Steveston dike to an outer dike along Steveston (Shady) Island that will enclose Steveston Harbour. The plan also proposes breakwater options along the adjacent West Dike.

Steveston Dike

The Steveston area dike protects the City of Richmond from ocean storm surges as part of the overall Lulu Island Ring Dike. This 3km long section of dike that stretches between Garry Point Park and London Farm will require raising and strengthening over the long term to address the changes in flood risk posed by climate change induced sea level rise.

Numerous dike alignments and design concepts for raising and strengthening were evaluated by the consulting team, City staff, and with stakeholders. Two distinct alignment concepts emerged:

- Primary Dike Alignment 1 - Raise the dike along the current alignment with some local variations.
- Primary Dike Alignment 2 - Re-align the dike along Steveston Island to close the harbour.

Figure 1 shows the two primary dike alignments. The main challenges associated with the Lulu Island alignment are the numerous building, road, park, and heritage structure conflicts. Along the Steveston Island alignment, the greatest change is to the marine environment and the access to the harbour. **Figure 2** provides a rendered image of the

Steveston Island dike option to better illustrate proposed changes.

Based on the evaluation and stakeholder consultation, the Steveston Island alignment emerged as the preferred option for the following reasons:

- It is less disruptive to the community, including to business accesses and heritage structures.
- It is easier to construct with few infrastructure conflicts and easy access to bulk material (dredging operations and barges).
- It is more adaptable to future height increases.
- It is compatible with other plans for the area such as the Steveston Harbour Authority's Steveston Community Fishing Harbour plan illustrated in **Figure 3**.
- It received generally positive feedback from stakeholders and the public.

Construction cost estimates for the two primary alignments are similar, and both alignments have environmental compensation requirements and opportunities.

Although the consulted agencies have been agreeable with the concept, there are additional steps required to establish ownership and rights of access over Steveston Island. The Provincial Land Tenure Department advised that the City should apply to the Ministry of Forests Land and Natural Resource Operations (MFLNRO) for an Investigative license to identify land management jurisdictions on Steveston Island. This is recommended to be among the next steps to further develop the Steveston Island Dike concept.

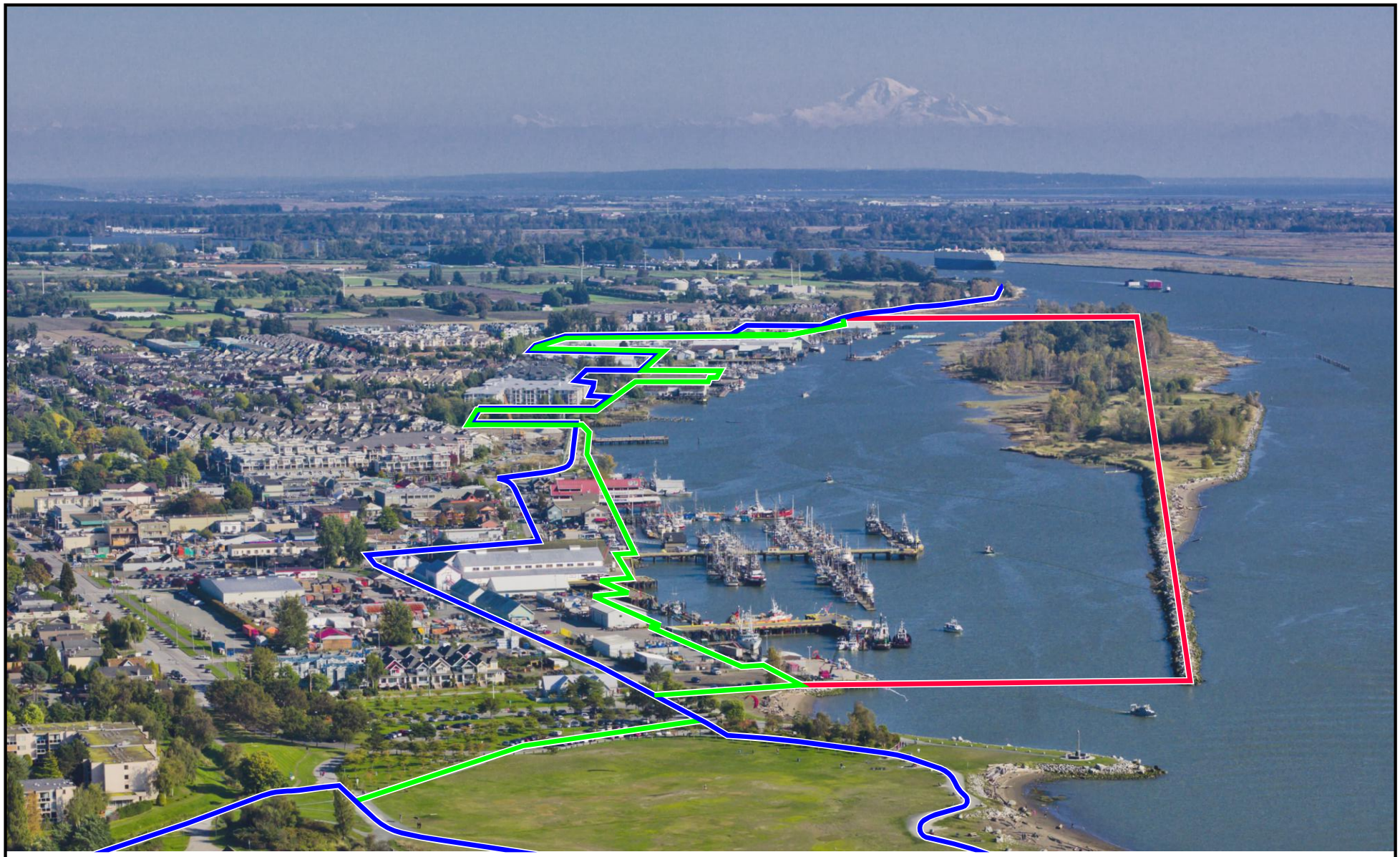
Assuming that there are no significant jurisdictional issues, the City will need to resolve a number of environmental, operational and maintenance issues prior to gaining acceptance from key stakeholders.

West Dike

The West Dike stretches from Garry Point Park in Steveston to the Middle Arm of the Fraser River. The primary option for flood protection in this area will be to raise and strengthen the existing West Dike in its current alignment over the long term.

Presently, the Sturgeon Bank helps protect the West Dike form wind generated waves. With sea level rise, the Sturgeon Bank may become submerged and their breakwater effects diminished. In parallel with increasing the West Dike's crest height to counter future wave run-up, options to maintain or enhance the breakwater effects of the Sturgeon Banks are proposed. **Figure 4** provides a rendered image of barrier islands that could be used to mitigate increased wave height caused by sea level rise.

The environmental habitat value of the Sturgeon Banks may be reduced with sea level rise. However, as the sea rises and reduces intertidal habitats, the placement of barrier islands may offset some of this loss and be considered an environmental asset. Further monitoring and evaluation of sea levels and habitat loss is proposed.



LEGEND:

CURRENT DIKE ALIGNMENT

PRIMARY ALIGNMENT 1 - LULU ISLAND ALIGNMENTS

PRIMARY ALIGNMENT 2 - STEVESTON ISLAND

City of Richmond Dike Master Plan
Primary Alignment Alternatives
Figure 1

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City of Richmond Dike Master Plan
Steveston Island Concept
Figure 2

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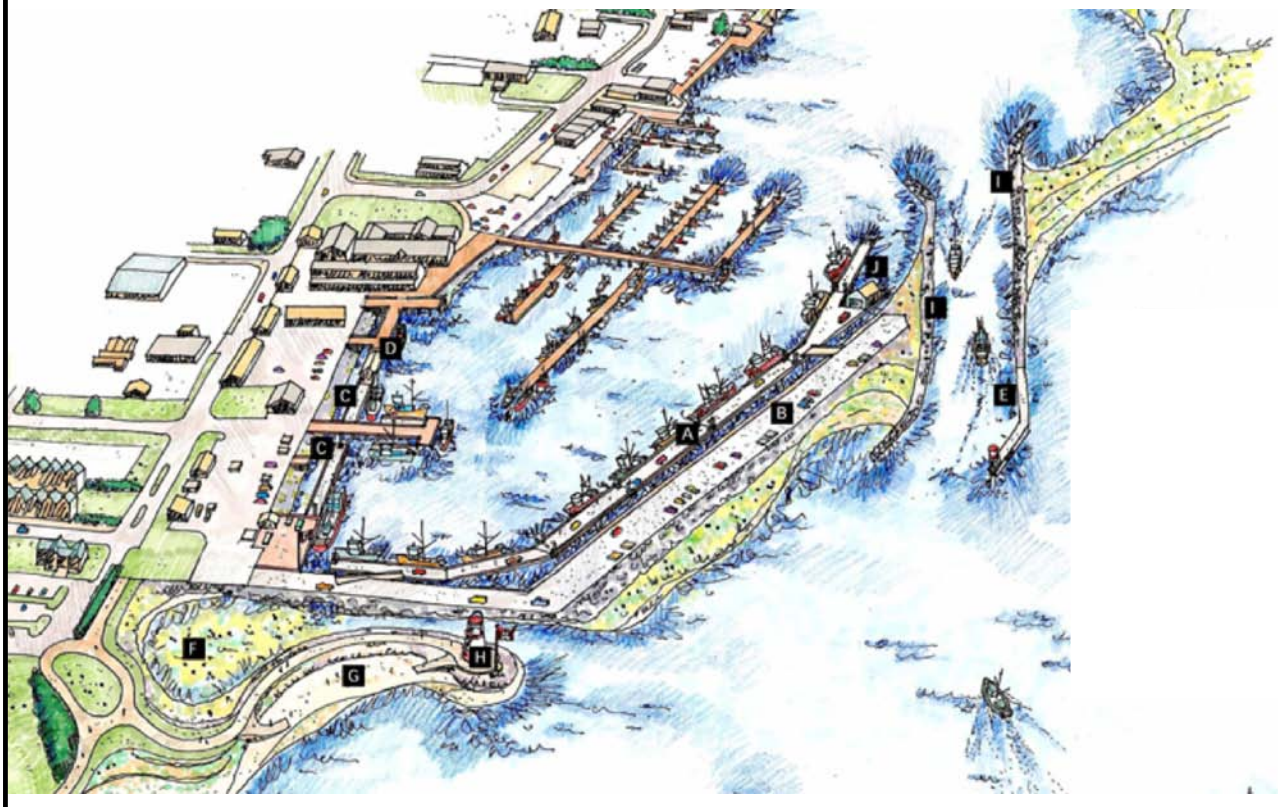

City of Richmond Dike Master Plan
Compatibility with Steveston Harbour Authority Plans
Figure 3

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City of Richmond Dike Master Plan
West Dike Breakwater Concept
Figure 4

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1 Introduction

"Flood prevention approaches are to be socially, economically, environmentally sound and sustainable, and able to achieve the City's long term planning, growth and development objectives."

2008 – 2031 Flood Protection Strategy - City of Richmond

1.1 PURPOSE

The purpose of the Lulu Island Dike Master Plan (LIDMP) is to identify preferred methods for implementing the objectives of the City of Richmond's 2008 – 2031 Flood Protection Strategy. The LIDMP will provide guidance on mitigating increases to the flood risk profile to the City resulting from anticipated climate change related increases to flood levels during freshet and storm surge events.

Due to land development and related issues, creating a long-term dike master plan for the Steveston area was identified as a priority. The southern West Dike was also considered in this study because of its proximity to Steveston and because it has similar storm surge and wave characteristics.

This report is the first phase of the LIDMP and focusses on how to adapt flood protection in the Steveston area and the West Dike to meet the challenges of anticipated increasing flood levels associated with climate change induced sea level rise.

This report establishes a recommended long term flood protection concept for the Steveston area. It also identifies a recommended approach to flood protection for the adjacent West Dike. Additional reports will be generated to recommend flood protection upgrades throughout the City.

1.2 DOCUMENT STRUCTURE

Section 1 of this report provides a summary of the overall scope of, and approach to, the project. **Section 2** presents the design considerations for the development of flood protection strategies. **Section 3** presents the flood protection strategies and primary alignments for Steveston. **Section 4** presents flood protection strategies for the West Dike. **Section 5** presents recommendations.

1.3 SCOPE & APPROACH

The LIDMP is intended to be a planning guide to upgrading the City's flood protection infrastructure to:

- Adequately protect Richmond from flood risks resulting from ocean storm surges and Fraser River freshet events.
- Adapt to sea level rise as identified and updated through the City's 2008-2031 Flood Protection Strategy.
- Meet appropriate seismic and other design standards.
- Follow the five strategic directions of the City's 2009 Waterfront Strategy.
- Prioritize dike improvement phasing to efficiently use resources.

The primary goal of this project is to establish concept plans for flood protection works to protect the Steveston area and West Dike from future flood risks associated with long-term sea level rise.

The five strategic directions from the City's 2009 Waterfront Strategy have been considered throughout this study. Directions and means of addressing them are summarized below.

1 - Working Together

Stakeholder consultation played a key role in establishing concept plans for the LIDMP Phase 1.

2 - Amenities and Legacy

The concepts consider how to connect people with the waterfront rather than separating them with large barriers.

3 - Thriving Ecosystems

The concepts consider an ***Eco-Plus+*** approach to maximize environmental returns and consider opportunities for habitat creation.

4 - Economic Vitality

The concepts align with the Steveston Harbour Authority's operating vision.

5 - Responding to Climate Change and Natural Hazards

The LIDMP Phase 1 will ultimately be the road map for the Steveston area on how to plan for and respond to flood risks.

1.4 STUDY AREA

The primary study areas for the LIDMP Phase 1 project include:

- The Steveston neighbourhood between Garry Point in the west to London Farm in the east.
- Steveston Island.
- The southern West Dike of Richmond.
- Sturgeon Bank.

Steveston Neighbourhood

Steveston is a historic site. Originally settled as a multi-ethnic fishing village, Steveston has sustained a fishing industry and link to the waterfront for over 100 years. It has a mosaic of historic amenities, high density residences, commercial and tourist waterfront development, and a range of parks and green space. Many valuable properties and assets are located on or adjacent to the dike.

The City developed a Steveston Area Plan in 2009 to set a vision for future development in the area. This plan states that in the year 2021 the community will:

- Support a "homeport" for the commercial fishing fleet;
- Actively conserve its heritage;
- Ensure public access along the waterfront;
- Provide a place where people can live, work and play; and,
- Enable residents and visitors to shop and enjoy the heritage, recreation, commercial fishing fleet, private moorage, natural amenities and waterfront activities.

This vision for the Steveston neighbourhood has been integrated into the LIDMP Phase 1.

West Dike

The West Dike is located on the west side of Richmond and extends from Garry Point Park in the South to Terra Nova Park in the north. The dike is primarily bordered by residential property on the inland side. The Sturgeon Bank extends from the West Dike up to 6 km into the Strait of Georgia.

2 Design Considerations

2.1 EXISTING INFRASTRUCTURE

Steveston Area

The Steveston area is currently protected from flooding by a dike and foreshore structures including Steveston Island (also known as Shady Island), the South Jetty, the Albion Dikes, and Roberts Bank. These features are identified on an exerpt from a Canadian Hydrographic Services Chart in **Figure 2.1**.

Steveston Island, the South Jetty, the Albion Dikes, and Roberts Bank play integral roles with the Steveston dikes. The dikes in Steveston receive partial protection from waves from these features. These structures may also need to be raised to adapt to sea level rise so that they continue to provide the same level of protection to Steveston.

The South Jetty and Albion Dikes were constructed in the 1920s and 1930s to control the main channel of the Fraser River. The Albion Dikes consist of timber pile breakwaters while the South Jetty was constructed with rip rap.

Steveston Island grew from a minor sand bar. Large riprap and timber pile breakwaters and training structures were placed in 1953 to create the protected harbour and island that exists today. This included a riprap “bridge” along the east end that connected it to Lulu Island. This was later lowered to increase flow through the Harbour and improve water quality, but is still exposed at low tide.

West Dike

The West Dike protects the City from high tides and storm surges originating in the Strait of Georgia. Sturgeon Bank, a mudflat and marshland, extends up to 6 km into the Strait of Georgia from the toe of the dike. The dike forms part of the trail network along Sturgeon Bank, connecting Terra Nova Rural Park to Garry Point Park. The dike’s water side has a relatively flat face with grass cover, followed by the marsh and mudflats of the Sturgeon Bank. The crest is a gravel path, and the inland slope is typically a grass revetment with a ditch or swale separating it from residential uses.

Sturgeon Bank currently provides some protection from wave run-up to the West Dike. Sea level rise will reduce this level of protection unless Sturgeon Bank rose in

conjunction with the sea level.

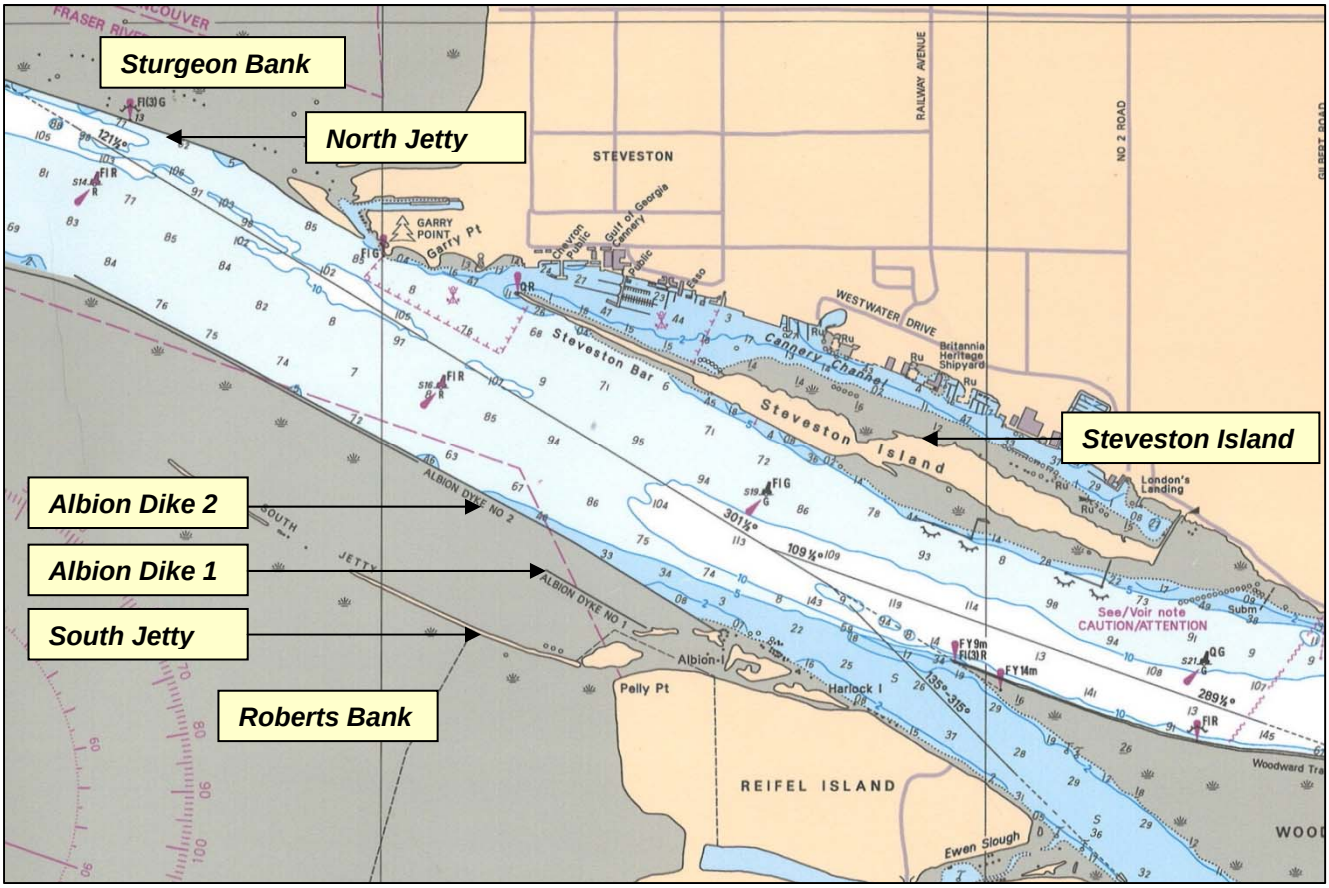
The design team conducted a cursory review of the morphology of Sturgeon Bank. Based on this review it is considered that the mudflats are slowly eroding.

Key reasons are identified as follows:

- The existing Lulu Island dikes and Fraser River jetties block sediment transport onto the Sturgeon Bank. As a result, sand transport from the Fraser River goes to deep water zones and Sturgeon Bank is not nourished.
- Large portions of river sediment is dredged and used for construction (taken out of the system).

Reversing the erosion of Sturgeon Bank is challenging. Removing the Lulu Island dike is not on option. Removing the jetty to allow nourishment of the mudflats would cause slumping of the mudflat into the navigation channel, uncontrolled migration of the river requiring intensive dredging to sustain required depth, and possibly undesired formation of dendritic channels on the mudflat. Artificial nourishment using sediment from dredging may slow down or reverse the degradation process, but would be costly.

Figure 2.1: Steveston Area Flood Protection Infrastructure



Prepare:
"strengthen corporate and community capacity to adapt to unavoidable impacts"

3rd Pillar of the Climate Change Response Agenda

-City of Richmond

2.2 PROTECTION NEEDS

Richmond is a large city with considerable assets. Sea and river dikes form the backbone of Richmond's flood protection infrastructure. The current dikes provide flood protection from winter storm surge and Fraser River freshet events. In the medium to long term, dike crest elevations will need to be raised to adapt to changing flood risks including anticipated increases to flood levels during freshet and storm surge events resulting from climate change.

This report presents recommendations for future flood protection works that are required to address long-term sea level rise and associated flood risks. The implementation of flood protection infrastructure proposed by the LIDMP is recommended to occur over many decades as sea level rise materializes.

Crest Elevation Assumptions

In 2006, the Provincial Government increased sea dike crest elevations from 3.35 to 3.5 m. The City's current dike design crest target elevation is 4.7 m. This elevation aims to address predicted sea level rise that would accumulate over the next 50 to 100 years. This crest elevation was used as the design basis for each flood protection concept. All concepts were also assessed for their ability to accommodate additional future sea level rise.

2.3 STRATEGY CONSIDERATIONS

Other factors that influence the selection and evaluation of flood protection strategies and alignments include social, environmental, geotechnical, and regulatory considerations.

Social Considerations

Improvements to the Steveston area's existing dike would significantly impact the community and character of Steveston Village.

To quantify and address potential social impacts, key stakeholders were engaged and public open houses were held to solicit feedback from the general public.

Key social impacts of raising Steveston's existing dike included the disruption of roads, buildings, harbour functionality, park space, trails, festivals, market, restaurants, and the Steveston Conservation Plan.

Key social impacts of raising the West Dike include impacts to view corridors, park space, and accessibility.

Environmental Considerations

Environmental impact is a significant consideration in dike upgrade projects. Many improvement options impact fish habitat both inside and/or outside of the existing dike footprint. Addressing environmental values need not consist solely of avoiding changes to the marine or riparian environments. Work on the water side of dikes can be coupled with habitat enhancements that provide a net environmental benefit and lower costs than alternate options.

"Flood prevention approaches are to be socially, economically, environmentally sound and sustainable, and able to achieve the City's long term planning, growth and development objectives."

2008 – 2031 Flood Protection Strategy

-City of Richmond

The study area is predominantly red-coded habitat, except in the areas currently being used for commercial marine purposes. The habitat coding is shown in **Figure 2.2**. The red–coded areas have high habitat value. Alternations are strongly discouraged with high associated compensation costs. Sturgeon Bank is all red-coded and considered to have high environmental habitat value. The river, below low water, is not coded. Raising some portions of the river bottom to increase the amount of inter-tidal areas is considered beneficial.

Figure 2.2: Habitat Coding for Study Area

Various types of breakwaters including engineered sand banks, rip-rap breakwaters, and artificial reefs can perform a wave mitigation function and create new habitat. Such improvements have been considered and incorporated into the assessment of alternative flood protection strategies. Strategies have been reviewed in terms of potential environmental impacts; opportunities for implementing environmentally beneficial changes; and potential for regulatory issues.

Geotechnical Considerations

The BC Ministry of Forests Lands and Natural Resource Operations (MFLNRO) implemented Draft Seismic Design Guidelines for Dikes in 2011. These guidelines describe factors that should be considered in the seismic design of *High Consequence* dikes located in Southwestern British Columbia. High Consequence dikes are defined in the Seismic Design Guidelines as: *flood protection dikes where the consequences of failure during a major flood are very high*. All of the City's dikes are considered *High Consequence.*

During an earthquake, liquefiable soils may lose cohesion leading to lateral spread of the dike and vertical slumping. The Seismic Design Guidelines recommend maximum vertical and horizontal deformations that are allowable after a seismic event. These allowable deformations are small and as a result they can require a significant amount of subsurface soil improvement to achieve.

The potential construction cost of such soil improvements vary significantly depending on the type of soil. Traditional solutions fall into three main categories.

1. Rapid vibratory compaction. This can be sufficient in the best cases.
2. Stone columns or similar techniques. This can be used to compact and strengthen the ground in less favourable soils.
3. Soil injection or mixing techniques. This involves using additives to combine with the soil to create a much denser and stronger base which is tied into the non-liquefiable soil layers. This would be used in the most severe cases.

Rather than designing infrastructure to meet the Province recommended post-seismic deformation requirements, there may be the potential to establish alternate post-seismic dyke performance criteria. For example, overbuilding the flood protection infrastructure such that the post-seismic crest elevation meets the intent of the guidelines may be an acceptable practice. An additional alternative may be to create a very wide and stable dike zone that would extend inland. This is consistent with the City's Flood Protection Strategy which calls for the raising of the overall land base over the long term.

Wave Action

Design water levels have historically been established based on a frequency analysis of maximum annual water levels plus freeboard. More recently, it has been the standard practise to determine the potential storm surge and wave run-up levels, and add these to the maximum high tide level to establish coastal dike design elevations.

Wind speed, water depth, and fetch length determine the size of a wave. Presently, the West Dike has some protection from waves provided by the shallow waters of the Sturgeon Banks. The Steveston area has some protection from waves provided by Steveston Island, the Albion Dikes, and the South Jetty.

Wave action is anticipated to increase with sea level rise. Offshore wave height predictions remain the same pre and post sea level rise; however, the level of protection provided by Sturgeon Bank will be reduced as the water depth increases closer to shore. The increased wave height attributed to this increase in water depth could require additional increases in dike crest elevation, or some other form of wave attenuation in front of the dike. Further study is required to confirm if Sturgeon Bank will grow or erode with sea level rise.

If Steveston Island, the Albion Dikes, and the South Jetty were not raised to follow sea level rise, wave heights in the Steveston area could also increase.

Regulatory Requirements

Depending on the preferred alternatives for dike improvements, regulatory approvals may be required from a number of agencies including, but not limited to: Fisheries and Oceans Canada; MFLNRO; Ministry of Environment, Transport Canada; Port Metro Vancouver; and First Nations.

2.4 ADAPTATION OPTIONS

There are two main elements to determining options for adapting to evolving design flood conditions:

1. understanding the constraints and boundary conditions for a specific reach of dike; and,
2. understanding the available solutions to manage flood risk that work within those limits.

There are many options for managing flood risk. The Climate Change Adaptation for Sea Dikes and Coastal Flood Hazard Land Use - Draft Policy Discussion Paper (2011) categorizes the options into four groups: one group of structural options, and three groups of non-structural options. Options for providing structural and non-structural flood protection for the study area are illustrated in **Figure 2.2**.

"To reduce flood vulnerability by continuing to review and implement a high standard of dike design in priority areas as Richmond's primary protection strategy."

Key Objective from 2009 Waterfront Strategy

-City of Richmond

Figure 2.3: Grouping of Flood Protection Options

Structural							***Non-Structural***				
Protect							**Accommodate**			**Retreat**	**Avoid**
Dikes			Floodwalls		Foreshore						
Widen footprint to land side	Widen footprint to water side	Special Structures	Permanent	Demountable	Breakwater / Barrier Islands	Coastal wetlands	Flood proofing	Secondary Dikes	Emergency preparedness and response	Managed Retreat	Planning and Development Controls

The options and how they relate to the Steveston area, are described in detail on the following pages.

PROTECT

To protect against flooding is to construct protective works that form a barrier between the flood hazard and the at risk property behind the hazard. Flood protection works can be 'hard', such as dikes and floodwalls, or 'soft', such as dunes or tidal marshes. The Steveston area has a variety of existing flood protection infrastructure including dikes, floodwalls, and foreshore structures.

Dikes

A dike is an embankment constructed on dry ground along a riverbank or shoreline to prevent overflow of water into the lowlands behind. Dikes have a long history of use within Richmond and are the most common form of structural flood protection. Many dikes in Richmond, including most of the dikes within Steveston, were constructed or upgraded during the Fraser River Flood Control Program. Upgrades to the dikes in Steveston took place in the late 1970's. At that time, the dikes were generally upgraded with expansions to the land side and increases to crest height and width.

Typically dike crest elevation increases are obtained by expanding to the land side to minimize environmental concerns and construction costs. However, there are many potential options, which are dictated by local conditions. Dikes can also be upgraded with expansion to the water side; steepening side slopes to construct dikes within the same footprint; or by the installation of special structures such as flood gates or locks.

Floodwalls

A floodwall is a constructed barrier designed to hold back flood waters. Floodwalls are typically used at locations where space is limited and a dike would interfere with other land uses or structures, such as existing buildings and historical areas. Flood walls are also required where access to the water is required for economic activity such as fishing or shipping. A floodwall can be constructed from a number of different materials including concrete, steel or plastic. Some floodwalls can be designed to be demountable and are only erected prior to a flood. There are some existing examples of sheet pile floodwalls in the Steveston Area.

Foreshore Structures

In areas where raising shoreline dikes to full heights to withstand wave run-up is impractical, foreshore structures can be constructed. These structures dissipate wave energy and reduce the burden on the dike allowing for lower crest levels. Steveston Island and the jetties at the mouth of the Fraser River are examples of these structures in the Steveston area.

ACCOMODATE

The accommodate approach to flood risk management is planning for development in an area with the expectation that the area may occasionally be flooded. There are a number of tools in the accommodation approach that can be used including: flood proofing individual buildings; secondary dikes; and, emergency preparedness and response.

Flood Proofing

"Generally, as an overall long term objective, the City will seek to raise the average grade of land within the urbanized areas of the City"

2008-2031 Flood Protection Strategy

Flood proofing can be achieved, fully or in part, by enacting bylaws that regulate the use of building space below a set flood construction level (FCL). In 2008, the City established the Flood Plain Designation and Protection Bylaw No. 8204 that sets minimum flood construction levels throughout the City. For the Steveston area, this level is at or above the adjacent sidewalk elevation. While this elevation is lower than the preferred elevation of 2.9 m, it provides a level of flood protection, and over time may be increased.

Secondary Dikes

Secondary dikes work in conjunction with primary dikes and can reduce the impact of a flood if a primary dike is breached. Due to the built-up nature of the Steveston area, a secondary set-back dike is not a feasible option.

Emergency Preparedness and Response

An essential strategy for reducing flood risk is to be emergency prepared. The City has established an Emergency Operations Centre that coordinates with various departments to establish and implement the City's Emergency Preparedness Flood Management Plan.

RETREAT

In some cases an approach for flood protection is to move back from the flood hazard over time such that development would no longer be located in flood prone areas. This is not a feasible option for the Steveston area.

Managed Retreat

In this approach, the 'retreated' properties are essentially decommissioned and the land is returned to a coastal land form that periodically would be flooded. This approach could be used for Garry Point Park. Future dike improvements could be constructed along the east boundary of the park to tie the West Dike to the Steveston Dike. Future park improvements could be planned to accommodate periodic flooding.

AVOID

The general principle of this approach is to provide room for the river and keep development out of the flood plain. The avoid approach is most suitable for new development and is not applicable for the Steveston area. However, this approach is currently being applied to the properties that lie on Sturgeon Bank outside of the West Dike, where no development is permitted.

3 Steveston Dike

"Strategic Directive #5: To have excellent civic infrastructure and services that protect and reduce the vulnerability of the community to natural hazards and climate change impacts while protecting the environmental health of the foreshore and river."

2009 Waterfront Strategy

- City of Richmond

3.1 FLOOD PROTECTION STRATEGIES

The study assessed a number of approaches to flood protection for the Steveston area as outlined in **Section 2**. Two flood protection strategies were identified for evaluation to determine the preferred approach for the Steveston area.

Strategy 1: Modfication of the Existing Lulu Island Dike

The first strategy is to upgrade the existing dikes. Tweaks and adjustments to the alignment would be made as required. The existing dikes would require crest level increases of up to 1.5m to meet the proposed 4.7m crest elevation. Improvements could be made to the Steveston Island breakwater to provide harbour protection and reduce wave run-up on the existing dike.

Strategy 2: Realignment to Steveston Island

The second strategy is to construct a new dike along Steveston Island with a crest level to meet the proposed 4.7m crest elevation. Flood gates would be installed at the harbour entrances that would be closed during major storm surge events. The existing dike through Steveston would be secondary and could be raised at a much slower pace to account for sea level rise.

For each of these strategies, a primary alignment was established for evaluation:

- Primary Dike Alignment 1: Raise dikes in their current alignment or a close parallel alignment on Lulu Island
- Primary Dike Alignment 2: Raise a dike on Steveston Island and install gate structures to enclose the harbor

Detailed descriptions of both strategies used for evaluation are outlined on the following page. The alignments are presented on **Figure 3.1**.

Primary Dike Alignment 1: Raise Dikes in their Current Alignment or a Close Parallel Alignment

Primary Dike Alignment 1 is based on improving the existing dikes in their current alignment, or a close parallel alternative.

To establish an alignment to be used for evaluation, the Steveston dike was broken into seven different reaches with similar characteristics and constraints. Conceptual alignment alternatives were developed for these reaches considering various issues and challenges.

Raising dikes in their current location presents a number of challenges that include limited space, utility conflict, development conflict and construction scheduling. Leaving dikes in their existing alignment also excludes a number of properties from current and future flood protection.

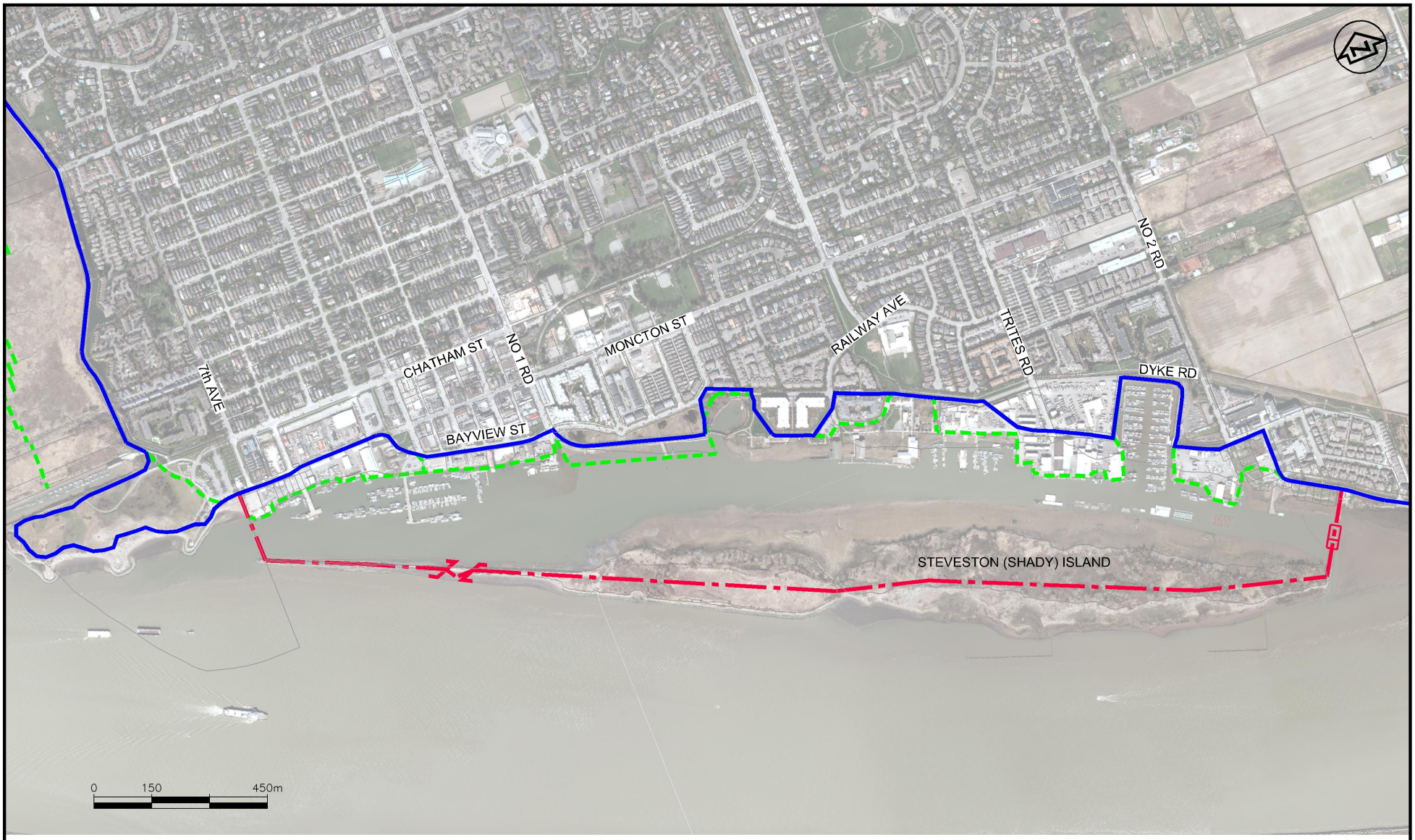
Moving the dike closer to the water's edge presents challenges, significantly changes the look and feel of the existing harbour, and may disrupt sensitive shoreline ecology. In some areas sheet pile walls with backfilled dike material will likely be required to create a seismically stable dike that is capable of meeting today's dike crest planning elevation (4.7 m geodetic) and those required further into the future.

Primary Dike Alignment 2: Raise a Dike on Steveston Island and Install Gate Structures

Primary Dike Alignment 2 would begin west of 7th Avenue where a new structure would be built heading south into the Steveston Harbour that would intersect the west end of Steveston Island. At this point, Steveston Island would be modified along its entire length to form a dike. Additional structures or embankments would then be needed to enclose the Harbour approximately 250 m east of No. 2 Road. At its west end, a gate structure would be built to close off the Harbour during periods of combined storm surge and high tide.

A gate structure meets the needs of the current planning requirements; however, continued sea level rise may ultimately mean that the harbour can no longer operate at high tide. In this case, a lock structure would be required.

A pump station may also be required to ensure stable water elevations during closure periods.



LEGEND:

CURRENT DIKE ALIGNMENT

PRIMARY ALIGNMENT 1 - LULU ISLAND ALIGNMENTS

PRIMARY ALIGNMENT 2 - STEVESTON ISLAND

Richmond

City of Richmond Dike Master Plan
Lulu Island Dike Master Plan Phase 1
Primary Alignment Alternatives
Figure 3.1

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TRANSPORTATION • INFORMATION TECHNOLOGY • WATER

3.2 EVALUATION OF ALTERNATE ALIGNMENTS

The two primary dike alignments were evaluated to determine the preferred flood protection strategy for the Steveston area. The evaluation is summarized in **Table 3.1**.

Table 3.1: Summary of Evaluation of Alignment Alternatives

Category	Primary Dike Alignment 1 Current or Close Parallel Alignment		Primary Dike Alignment 2 Steveston (Shady) Island with Flood Gate	
	Advantages	Disadvantages	Advantages	Disadvantages
Cost Estimate	Initial cost estimates are similar for both options			
Property & Land Use	City owns land and right of ways for some options	Existing structures must be accommodated High impact on existing village character and heritage assets	Steveston Island is vacant of development Minimizes the impacts to existing buildings and infrastructure	Government jurisdiction issues with land use
Construction	Can build in pieces and use temporary infrastructure for effective flood protection	High community disruption	Low community disruption	Must be built as one project to be effective
Adaptability to Future Raising		Will disturb the community if raised in the future	Relatively easy to raise in the future	
Environmental	Similar constraints and issues for both options			
Geotechnical Implications		Ground improvement may impact existing buildings and infrastructure	Minimises ground improvement impacts to existing buildings and infrastructure	
Operations & Maintenance	Design resembles existing or traditional infrastructure for relatively simple O&M	The replacement cost of sheet pile sections is high. Maintenance may impact the local community	Maintenance can be achieved with little impact to the local community	A harbour gate requires new O&M procedures with additional short and long term costs

A detailed evaluation of each factor used to determine the preferred primary dike alignment is as follows.

COST ESTIMATE

Class 'D' capital cost estimates were produced to predict the approximate magnitude cost of each alignment. Costs include allowances for seismic upgrades to the dike. The initial estimates indicate that both alternatives are in the same order of magnitude and cannot be distinguished by cost alone.

Table 3.2 and **Table 3.3** present the costs for the Preliminary Dike Alignments.

Primary Dike Alignment 1 *(Current or Close Parallel)*

Table 3.2: Estimated Cost of Primary Dike Alignment 1

Reach (Section)	Length (m)	Cost (M$)	Description
London	940	3.9	earthfill with road
Paramount	1040	4.5	sheet pile / earthfill with road
Britannia	260	1.3	earthfill with road, raise historic structures
BC Packers	870	4.7	earthfill with trail, sheet pile
Steveston Village	415	6.8	sheetpile and modify waterfront
Gulf of Georgia	480	3.9	sheetpile, fill behind
Breakwater	2790	11.0	Riprap
	Sub-Total	36.1	
	Contingency (50%)	18.1	
	Total	54.2	

Primary Dike Alignment 2 *(Steveston Island)*

Table 3.3: Estimated Cost of Primary Dike Alignment 2

Reach (Section)	Length (m)	Cost (M$)	Description
London	670	2.8	earthfill with road
Cross to island	240	6.5	earthfill, pump station, flood box
East tip to No. 1 Rd	2000	9.5	earthfill
No. 1 Rd to 7th	800	14.6	earthfill, floodgate
West tip to Moncton & 7th	115	3.2	Earthfill
	Sub-Total	36.6	
	Contingency (50%)	18.3	
	Total	54.9	

PROPERTY AND LAND USE

Existing and future land use can create opportunities and challenges to implementing dike improvements. Property and land use issues relating to the two primary dike alignments are outlined below:

Primary Dike Alignment 1 *(Current or Close Parallel)*

- Most of the current dike sections are on existing City property or rights of way, although there remain a few sections that run through Provincial or Federal land where rights of way are not registered.
- Existing structures and land uses would need to be accommodated in the design of dike improvements.
- Leaving dikes in their existing alignment also excludes a number of properties from current and future flood protection. Property or rights of way acquisition would be required to protect these properties.
- Heritage sites would either be left outside of the flood defenses or require alteration to remain protected as sea levels rise.
- Piecemeal dike improvements may create significant elevation differences between adjacent developments that challenge the development community in many ways.

Primary Dike Alignment 2 *(Steveston Island)*

- Steveston Island is vacant of development conflicts.
- This alignment uses a similar layout to the Steveston Harbour Authority's Long Range Plan that is a key initiative of the City's 2009 Waterfront Strategy.
- Land management jurisdictions on Steveston Island are unclear and need to be confirmed.

CONSTRUCTION

Options for construction phasing, as well as potential for construction impacts, are an important consideration for the evaluation. Construction considerations relating to the two primary dike alignments are outlined below:

Primary Dike Alignment 1 *(Current or Close Parallel)*

- The current dike option is already a functional dike. Improvements can be made incrementally over an extended time period.
- Temporary measures can be made available to fill gaps in the dike system until the full project is complete if an emergency warranted it.
- It is anticipated that there will be considerable disruption to the community during the dike upgrade process.

Primary Dike Alignment 2 *(Steveston Island)*

- A Steveston Island dike can be constructed relatively quickly and independently of development concerns.
- Temporary measures may be required on the existing alignment until the full project is complete.
- The Steveston Island dike is more appropriately constructed as one or a series of large projects.
- The Steveston Island dike will provide little added protection until the entire length is complete.

ADAPTABILITY TO FUTURE RAISING

Design crest elevations are expected to continually rise due to sea level rise, land subsidence, and higher standards to protect the ever increasing value of property and economic activity behind the dikes. The ability to raise the dikes in the future is an important design feature. The adaptability of the two primary dike alignments to future raising is outlined as follows:

Primary Dike Alignment 1 *(Current or Close Parallel)*

- The current dike is constructed in a highly urbanized environment with many conflicting property accesses, utilities and road structures. Every improvement, current or future, must confront these challenges.

Primary Dike Alignment 2 *(Steveston Island)*

- The Steveston Island alignment is expected to include a more conventional earth fill structure and gravel surface. Future improvements would have fewer challenges than Primary Dike Alignment 1 because of property access, and a lack of road, and utility conflicts.
- In the event of continued sea level rise, the proposed flood gate structure on the Steveston Island Dike could be modified to a Lock to protect from flooding against daily high tides.

ENVIRONMENTAL

To different extents, both options require environmental permitting and work within the water. Shoreline areas of the Fraser River are important to fish and are especially important to juvenile salmon as nursery, rearing, feeding and migration areas.

The environmental issues related to the two primary dike alignments are outlined as follows:

Primary Dike Alignment 1 *(Current or Close Parallel)*

- Raising dikes on the current alignment often minimizes impacts to fish habitat if expansion is to the inland.
- In some reaches, expansion may be required to the water's edge with sheet pile to accommodate existing developments.

Primary Dike Alignment 2 *(Steveston Island)*

- The Steveston Island option is expected to include more major alterations to Fraser River fish and wildlife habitats, but also includes opportunities for environmental enhancements.

GEOTECHNICAL

Geotechnical considerations are essential when selecting a dike alignment and considerably impact dike construction costs. A preliminary geotechnical assessment suggests that both alignments will require significant densification works for seismic stability. Along the waterfront banks, this typically includes stone column densification under the full width to the toes of the dike, driven to approximately 20% deeper than the adjacent channel depth. Set-back dikes, including the one proposed for the middle of the wide section of Steveston Island, were assumed to include some additional height for settlement, but no densification. These assumed improvements were included in the cost estimates and accounted for 12-16% of the total cost.

Primary Dike Alignment 1 *(Current or Close Parallel)*

- High density residential or commercial development behind the dike typically includes soil densification and raising of the ground to Flood Construction Levels, both which improve the geotechnical stability of the dikes.
- Densification under the dike footprint is expected to be required to meet seismic design guidelines.
- Some sections include vertical walls or steep banks which require deep densification.
- Constructing additional height to compensate for vertical displacements is less likely in built up areas where the challenges to match existing property accesses are already problematic.

Primary Dike Alignment 2 *(Steveston Island)*

- Constructing additional height to compensate for vertical displacements is a viable option on the island as an alternative to densification.
- Most of Steveston Island is wide and relatively flat, which minimizes the need for densification.
- The portion of the channel to be filled and the gate structure are expected to required deep densification.

OPERATIONS AND MAINTENANCE

Operations and maintenance of dikes requires conducting regular inspections and carrying out repairs. The requirements for the two primary dike alignments are considerably different from each other and are outlined below:

Primary Dike Alignment 1 *(Current or Close Parallel)*

- The existing alignment option is not significantly different from the status quo thereby requiring annual inspections and maintenance similar to that conducted for the remainder of Lulu Island.
- Some additional sheet piles are proposed instead of the riprap revetment slopes, but both are passive structures with similar maintenance regimes.
- The upgrade of the existing dike would require little additional operation and maintenance resources and budget.
- Access, repairs, and improvements are difficult due to conflicting road, property access, and commercial activity on and adjacent to the dike.

Primary Dike Alignment 2 *(Steveston Island)*

- Access for maintenance is readily available with no traffic business conflicts.
- Repairs and improvements are easily achieved with basic earthfill and armoured revetment slopes and without conflicting road, utility, and property access conflicts.
- The Steveston Island option includes new gate and pump station structures that would require operation during storm surge events. New operations and maintenance procedures would need to be developed.
- Additional maintenance throughout the year would also be necessary.

3.3 STAKEHOLDER FEEDBACK

The two primary dike alignments were presented to key stakeholders and the general public. Although concerns were raised, the public and key stakeholder groups generally favoured creating a new dike alignment on Steveston Island opposed to using existing or new dikes in their current alignment. The main reasons for this were concerns that upgrading existing dikes will be more disruptive to the community than creating a new Steveston Island dike, and that a Steveston Island dike will simplify long-term future upgrades. The main concerns with building a Steveston Island dike relate to harbour water quality, possible increased dredging needs, and the disruption it may cause to wildlife and their habitats.

Public Open Houses

Two public open houses were held to present the two flood protection concepts for the Steveston area. The sessions were well attended with a combined attendance of over 120 people. To maximise public participation, all public house advertisements referenced the City's community engagement website address, Letstalkrichmond.ca. This website presented the same material provided at the open house. 392 people viewed the project on this website, seven of whom also provided feedback.

A summary of the open house and website feedback is presented in **Table 3.4**.

Table 3.4: Summary of Open House and Website Feedback

Topic	Summary of Comments
Dike Raising	Concerns were expressed that dikes are not being raised quickly enough. This feeling seemed to be driven by general media reports suggesting that the rate of sea level rise may be increasing. However, people seemed happy that the City is taking a proactive approach to flood protection planning.
Flood Protection	Some people liked that in the long-term a dike built on Steveston Island would be easier to upgrade that one on Lulu Island. Also, creating a Steveston Island dike provides two lines of defence, as the current dike would act as backup to the new one. Many people feel that the Steveston Island option would provide the best protection for both Steveston Village and Steveston harbour.
Construction	There were many concerns that dike construction on Lulu Island will disrupt the Steveston community, its businesses, and residents while a new dike on Steveston Island will help to avoid this.
The Environment	There were many concerns that a new dike on Steveston Island will disrupt wildlife habitats, and studies were requested to identify any potential ecosystem impacts of this proposed alignment. Some concerns arose that enclosing the harbour and its wetlands would create water quality issues as well as health issues for the Steveston population.
Dredging	There was a concern that if the harbour is enclosed increased dredging will be necessary.
Seismic	One concern was expressed about the high cost of upgrading dikes to a 1:2475 level.
Harbour Vitality	One resident did not believe that the water flow through the harbour could be controlled to the extent necessary in order to keep the enclosed harbour viable.
Property Value	Some residents were concerned about how each option would affect their property value.
General	One resident noted that dike upgrades have created better walking and cycling paths in the Steveston area and that new Lulu Island dikes could further improve this.

In addition to the two public open houses that were held, the City hosted a number of individual key stakeholder meetings. Key points from these meetings are summarized below.

Provincial Inspector of Dikes

Preferred Option
Primary Dike Alignment 2: Steveston Island

The Provincial Inspector of Dikes, MFLNRO, generally prefers Primary Dike Alignment 2 for the following reasons:

- It is relatively free of land use requirements that conflict with diking such as access across the dike, service crossings and future pressures to develop areas adjacent to the dike.
- It allows for relatively unlimited future expansion of the diking system.
- It provides flood protection for areas that would otherwise be on the water side of the dike.

Richmond Heritage Commission

Preferred Option
Primary Dike Alignment 2: Steveston Island

The Heritage Commission generally prefers Primary Dike Alignment 2 for the following reason:

- It is the opinion of the Heritage Commission that diking system improvements which do not alter the existing road grade of Bayview Street or the immediate foreshore of the Steveston Harbour are the most supportive of on-going heritage conservation efforts in the Steveston Village core.

Steveston Harbour Authority

Preferred Option
Primary Dike Alignment 2: Steveston Island

The Steveston Harbour Authority generally prefers Primary Dike Alignment 2 for the following reasons:

- It uses a similar layout as the Steveston Community Fishing Harbour development plan.
- Raising the dike in its current location raises a multitude of challenges and costs.

Fisheries and Oceans Canada

Preferred Option
none

The Fisheries and Oceans Canada does not have a preferred alignment. They provided comment on both Primary Dike Alignment 1 and Primary Dike Alignment 2.

Comments for Primary Dike Alignment 1 are as follows:

- Shoreline areas of the Fraser River are important to fish and are especially important to juvenile salmon as nursery, rearing, feeding and migration areas.
- The raising of dikes should avoid or minimize the placement of fill below the higher high water elevation into the Fraser River. Of particular concern is the dike alignment immediately east of the south end of No. 1 Rd where the dike alignment clearly extends into the river.

Any proposed design for Primary Dike Alignment 2 should ensure that:

- Fish access into and out of Steveston Harbour is maintained.
- Water quality suitable for fish in Steveston Harbour is maintained.
- Adverse impacts to fish habitat are minimized and that fish habitat be increased.

Port Metro Vancouver

Preferred Option
none

Port Metro Vancouver (PMV) does not have a preferred alignment. They provided the following comments with respect to Primary Dike Alignment 2:

- PMV would like a hydraulic modeling analysis or study completed to check the effects of enclosing the Steveston Harbour Channel upon the main shipping channel and how changed sedimentation patterns will impact dredging requirements.
- Jurisdiction in the area is very complicated and requires further investigation.
- Steveston Island has changed over the years and requires a new survey to confirm boundaries and jurisdiction.
- PMV wish to be kept informed of environmental compensation and land reclamation opportunities as related to Steveston Channel/Harbour/Dike realignment

Provincial Land Tenure Department

Preferred Option
none

The Provincial Land Tenure Department, MFLNRO, does not have a preferred alignment. They provided the following comments:

- No land title is needed for the Province to issue a Statutory Right of Way (or interim License of Occupation) for diking purposes over Crown Land.
- To identify land management jurisdictions on Steveston Island the City should apply to MFLNRO for an Investigative license. This license would allow for drilling and other stability testing if required.
- MFLNRO would liaise with Federal Government Agencies (e.g. Port Metro Vancouver, Fisheries and Oceans Canada/Small Craft Harbors, and Public Works Canada) to process a Statutory Right of Way application.
- The province must consult with the First Nations and the depth of the consultation will depend on the strength of claim and the potential for conflict identified by the First Nation. The Province will make every attempt to ensure that the consultation would stand up to a court challenge.
- If the City has good relations with First Nations groups they should liaise with them prior to any MFLNRO investigations.

Richmond's Advisory Committee for the Environment

Preferred Option
None

The Advisory Committee for the Environment does not have a preferred alignment but would like to see the utilization of the existing diking system where possible. Key concerns identified included: confirmation of land ownership of Steveston Island; and, ensuring that an environmental impact assessment is conducted prior to finalizing a preferred alignment for the LIDMP.

Urban Development Institute

The Urban Development Institute had no group comment on the project.

3.4 RECOMMENDED STEVESTON AREA FLOOD PROTECTION STRATEGY

Based on the evaluation of the two identified primary dike alignments for the Steveston area, it is recommended that the City adopt the Steveston Island Dike (Primary Dike Alignment 2) as the preferred future dike alignment, subject to securing land tenure. This route includes raising a new dike on Steveston Island and installing structures and gates to enclose Steveston Harbour.

When compared to raising the dike in its current alignment, the Steveston Island Dike alignment is anticipated to:

- cause lower community disruption,
- facilitate future dike raising,
- provide flood protection to more land area, and,
- provide additional storm protection for harbour users.

The alignment is preferred by numerous key stakeholders including the Provincial Inspector of Dikes, the Richmond Heritage Commission, and the Steveston Harbour Authority.

4 West Dike

4.1 FLOOD PROTECTION STRATEGIES

To adapt the West Dike to predictions of sea level rise the dikes must be designed to withstand a designate flood level consisting of the reference tide (high high water level), a storm surge, and local wind set up. Furthermore, as sea level rises, it is anticipated that this will impact the future conditions of the Sturgeon Banks and their ability to dissipate waves and assist with flood protection of the City. The dike must therefore have additional protection against wave run-up. The current predictions and assumptions used in the BC Sea Dike Guidelines for the year 2100 suggest wave run-up may account for up to 2.7 m of the future dike crest elevation. The full extent of future crest height increases will require detailed observation and study of observed sea level rise.

Presently, the City has established 4.7 m as the crest elevation for the West Dike. Additional protection for wave run-up, when required, could be provided in the form of wave attenuation structures, or by providing additional crest height.

Three adaptation strategies have been identified. These include:

1) Raise the existing dike crest height to the full requirement.
2) Construct a toe berm on the dike to reduce wave run-up.
3) Construct offshore barrier or breakwater islands to reduce wave run-up.

Strategies are described below.

Strategy 1: Raise the Existing Dike

Without wave protection, the West Dike's future required crest elevation could be considerably higher than today. A 4.7 m high dike will likely have a shorter effective life span than that of a less exposed dike, such as in the Steveston Area. One option to address this is to raise the dike crest to accommodate predicted wave run-up. Increases to the crest height would require the footprint of the dike to be expanded. Expansion to the inland side would require relocation of the existing drainage ditch on the land side slope, and potential property acquisition. Expansion to the water side would require compensation for lost environmental habitat. As crest heights increase by 1 m increments, a minimum additional 4.5 m in dike footprint is required.

Strategy 2: Construct a Toe Berm

As an alternate to large crest elevation increases, structures can be constructed in front of the dike to dissipate wave energy and reduce wave run-up. One option for this would be to construct a toe berm (**Figure 4.1**). The toe berm would resemble a low, wide dike that would extend from the toe of the West Dike onto Sturgeon Bank.

Strategy 3: Construct Barrier / Breakwater Islands

Similarly to Strategy 2, Strategy 3 aims to dissipate wave energy by constructing a breakwater or barrier islands on Sturgeon Bank (**Figure 4.2**).

Breakwaters are most effective when constructed close to the shore, as broken waves grow again behind the breakwater under the influence of wind. The effectiveness depends also on the crest height of the breakwater, with a higher breakwater giving more wave reduction.

Preliminary calculations indicate that wave reduction with a breakwater or barrier islands constructed to +3.0 m geodetic would reduce wave height by 70% if constructed 200 m offshore, 60% at 500 m offshore, and 45% at 2000 m offshore.

4.2 STRATEGY EVALUATION

Strategy 1 is the current standard approach for dike construction in Richmond. If sea level rise predictions prove accurate, the increases necessary in dike height to address increased wave heights during storm surge events could be substantial. These increases would have impacts on neighbouring properties and it may be preferable to install wave dissipation infrastructure to reduce crest levels (Strategies 2 and 3).

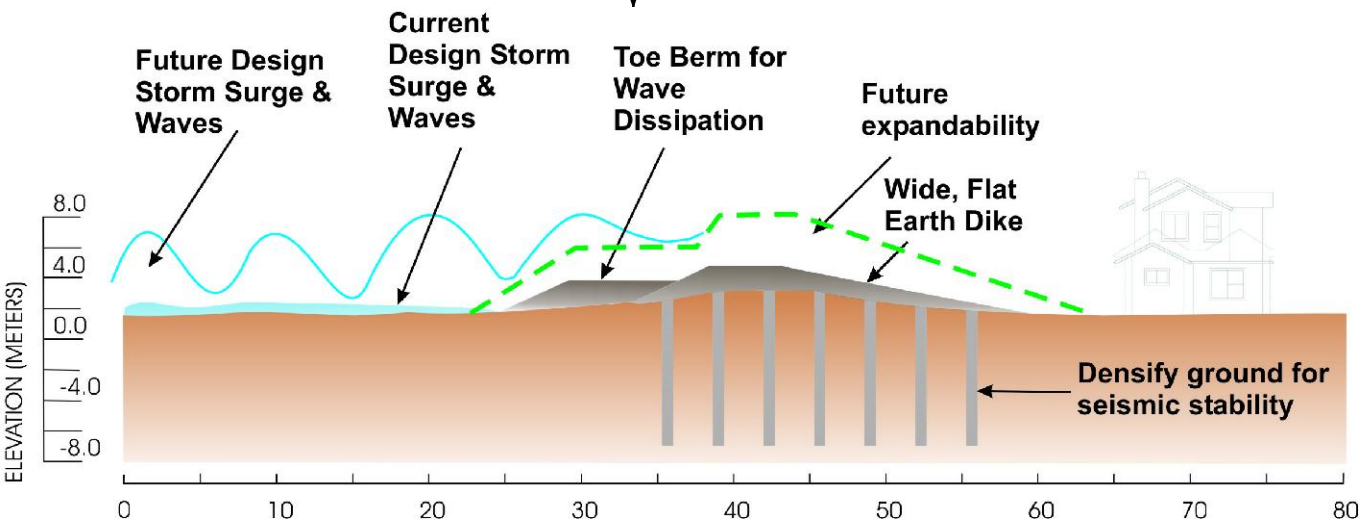
Preliminary discussions with Fisheries and Oceans Canada identified that both Strategies 2 and 3 could result in significant adverse impacts on fish habitats. Habitat compensation would be necessary, and given the potentially large footprint of the barrier islands, breakwaters, or toe dikes, this could be prohibitive.

If sea level rise is observed and future tidal conditions reduce or eliminate the existing intertidal marsh, then both strategies 2 and 3 may have the potential to create habitat and be used as a compensation site for other projects.

Strategy 3 may be an option at present day if the barrier islands or breakwaters could be constructed in waters of lesser habitat (deeper and further offshore) provided that the wave reductions are achieved.

4.3 RECOMMENDED WEST DIKE FLOOD PROTECTION STRATEGY

The primary option for flood protection in this area will be to raise and strengthen the existing West Dike in its current alignment over the long term. This will meet the City's flood protection requirements so long as it is raised to keep pace with sea level rise and protected from increased wave action. Additional work is required to identify the preferred approach to wave mitigation.



LEGEND:

- CURRENT DIKE ALIGNMENT
- PRIMARY ALIGNMENT 1 - LULU ISLAND ALIGNMENTS
- PRIMARY ALIGNMENT 2 - STEVESTON ISLAND
- REACH BOUNDARIES
- FEDERAL/PROVINCIAL OWNED LAND
- CITY OWNED LAND

City of Richmond Dike Master Plan
West Dike Toe Berm
Figure 4.1

Richmond

EB3763 March 2013

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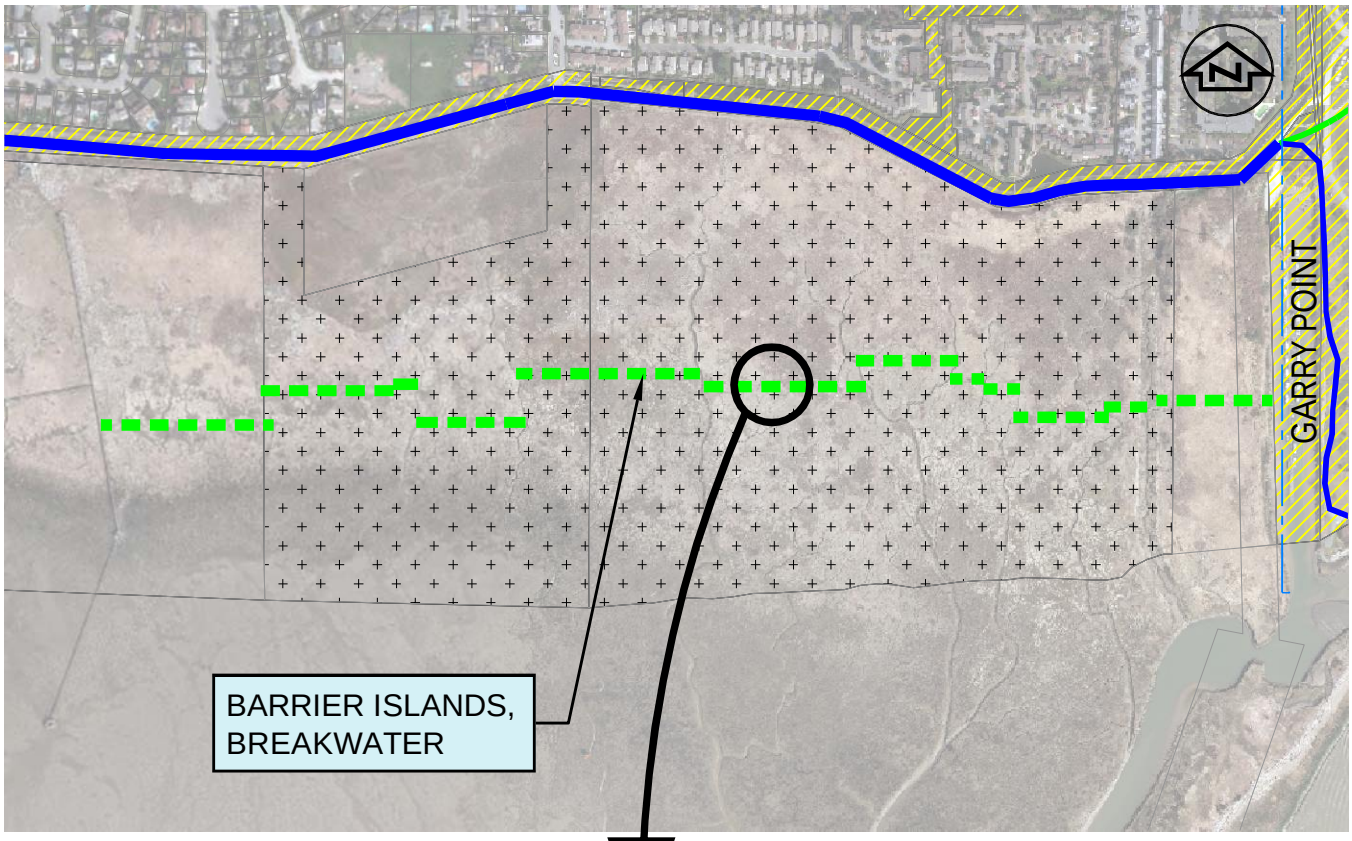

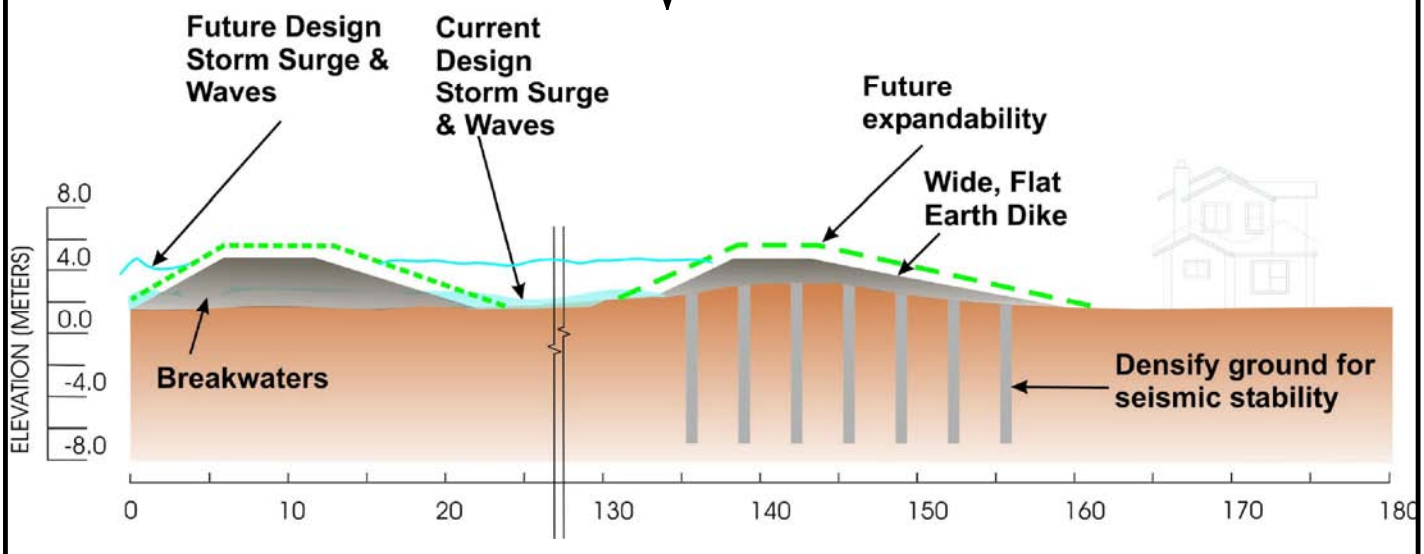

LEGEND:

- CURRENT DIKE ALIGNMENT
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- PRIMARY ALIGNMENT 2 - STEVESTON ISLAND
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- FEDERAL/PROVINCIAL OWNED LAND
- CITY OWNED LAND

City of Richmond Dike Master Plan
West Dike Breakwater
Figure 4.2

Richmond

EB3763 March 2013

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5 Recommendations

The following actions are recommended for the Steveston area and the West Dike.

5.1 STEVESTON AREA

1.0 Short Term Recommendations

a. Adopt the Steveston Island Dike (Primary Dike Alignment 2) as the preferred future primary dike alignment, subject to securing land tenure. This route includes raising a new dike on Steveston Island and installing structures and gates to enclose Steveston Harbour.

2.0 Medium Term Recommendations

a. Secure the land and rights to construct the Steveston Island Dike. This includes:

   i. Apply to MFLNRO for an Investigative license to identify land management jurisdictions and to permit geotechnical or other investigations. This may require a new survey to confirm boundaries and jurisdiction.

   ii. Request MFLNRO to liaise with Federal Government Agencies (e.g. Port Metro Vancouver, Fisheries and Oceans Canada/Small Craft Harbors, and Public Works Canada) to process a Statutory Right of Way application.

   iii. Liaise with First Nations group prior to the MFLNRO investigations and their First Nations consultations.

b. Complete preliminary designs and related investigations to assist with securing the land and obtaining regulatory approvals. Work is expected to include:

   i. A preliminary design that establishes the extent of land required for earth fill and related structures.

   ii. A geotechnical investigation that defines the extent of soil improvements required, and therefore the extent of the land required.

iii. An environmental investigation to determine the impact and potential habitat improvements associated with creating additional intertidal and marsh areas along the proposed alignment.

iv. A hydraulic study to assess the impact on sedimentation patterns and water quality.

3.0 Long Term Recommendations

a. Coordinate the design and construction of the Steveston Island dike with compatible Steveston Harbour Authority (SHA), City Parks, and Port Metro Vancouver (PMV) plans, including:

v. Coordinate with the Steveston Community Fishing Harbour development plan which includes narrowing the entrances to the harbour at both ends.

vi. Coordinate with Parks plans to create a sheltered space for the marine oriented public events like the Tall Ships Festival, and other improvements to the park and trail network.

vii. Work with PMV who are seeking environmental compensation and land reclamation opportunities similar to the intertidal habitat that may be created with the Steveston Island dike.

viii. Seek opportunities to coordinate fill activities with adjacent PMV dredging operations.

ix. Support PMV improvements to the Albion dike and other Roberts Bank structures and habitat creation that result in improved breakwater effects for Steveston.

b. Once the Steveston Island Dike alignment is secured, revise the dike standard behind the Steveston Island Dike to a consistent but relaxed standard that is more compatible with the surrounding property accesses. A 4.1m dike crest elevation is suggested as a starting point for discussion. This would be the current designated flood level of 2.9m plus a 1.2m allowance for sea level rise.

5.2 WEST DIKE

1.0 Short Term Recommendations

a. Continue to use the existing West Dike as the primary flood protection alignment.

b. Continue to plan for construction of the West Dike to a 4.7 m crest elevation

c. Coordinate with Port Metro Vancouver and Fisheries and Oceans Canada to:

i. Identify potential areas for constructed offshore barrier islands that would create habitat and provide wave dissipation for the West Dike.

ii. Confirm constructability of these islands using dredge sand.

2.0 Medium Term Recommendations

a. Develop a two dimensional wave and storm surge model for the Sturgeon Banks, to arrive at wave run-up estimates to confirm optimum barrier island configurations.

b. Monitor sea level rise.

3.0 Long Term Recommendations

a. If justified by observed sea level rise, design and construct offshore wave dissipation structures to minimize required onshore crest level increases.