Ministry of Forests, Lands and
Natural Resource Operations

Cost of Adaptation - Sea Dikes & Alternative Strategies

FINAL REPORT

With federal funding support through
Natural Resources Canada's Regional
Adaptation Collaboration Program

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Canada

Submitted By

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Executive Summary

Sea level rise will affect a significant part of Metro Vancouver, and the Province of British Columbia is planning for this eventuality. Protection will require an increase in the height of existing flood defences and the construction of new flood defences. In addition to dike construction, the adoption of alternative non-structural options for dealing with flood risk will be a necessary part of the overall strategy.

In 2011 the Province published *Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use - Draft Policy Discussion Paper* (Ausenco Sandwell, 2011), which outlines expected sea level rise and flood protection requirements.

The scope of this project was to develop a 'Class D' estimate of the cost to adapt flood protection to meet the rise in sea level predicted by 2100. This estimate is important in order to define and communicate the scale of the work ahead, and to then develop a strategy for investment and implementation.

The study area covers the Metro Vancouver coastal shoreline and the Fraser River shoreline as far east as the Port Mann Bridge, totaling over 250 km. This includes shorelines of West Vancouver, the District of North Vancouver, the City of North Vancouver, Port Moody, Vancouver, Burnaby, New Westminster, Richmond, Burnaby, Vancouver International Airport, Delta, Surrey and White Rock. Within the areas listed above there are both diked shorelines and low-lying areas that may require protection as the sea level rises.

The shorelines within the study area were divided into 36 reaches based on common elements within those reaches such as urban or rural land use, river or sea shorelines, and whether currently diked or undiked. It should be noted that broad generalizations are required when dividing the study area into only 36 reaches. There will likely be several separate future flood protection projects within each of these reaches, as a typical flood protection project may range from several hundred metres to several kilometres in length.

The *Sea Dike Guidelines* (Ausenco Sandwell, 2011) have updated sea dike design methodology for coastal flood protection measures. The new design criteria developed by Ausenco Sandwell include sea level rise, subsidence, storm surge, and wave effects, and provide a higher level of protection than previous guidelines. Dike crest levels used to develop the cost estimates in this study are therefore significantly greater than existing dike levels, which are based on design criteria from the 1970s. The methodology given in the *Sea Dike Guidelines* (Ausenco Sandwell, 2011) was followed to estimate the designated flood level and crest height for each shoreline.

The Province has also issued new draft seismic design guidelines for dikes – *Seismic Design Guidelines for Dikes* (Golder Associates, 2011). These seismic guidelines are not related to sea level rise, but all future dike design and construction must be consistent with the requirements, and therefore an estimated seismic construction cost component is included for all proposed structural options.

A range of structural and alternative non-structural options were developed for this estimate, with protection methods determined for each reach. Two workshops were held during the options selection process, and these were attended by the project team, relevant municipalities and Provincial representatives. These workshops were an important part of the selection process for each reach.

This estimate is intended to be used for planning and program development. It includes costs for structural improvements, property acquisition, seismic and geotechnical improvements, environmental compensation, and engineering and project management. The estimated costs are summarized in **Table E1**.

Table E1 - Estimated Cost of Adaptation to Sea Level Rise by 2100				
			$ (million)	$ (million)
Structural Flood Protection				880
Utility Impacts, Pump Stations and Flood Boxes				350
Property Acquisition:				
Agricultural	1,420	ha	320	
Residential	60	ha	550	
Commercial/Industrial	180	ha	720	
				1,580
Seismic[1]				
Vibro-Replacement			640	
Deep Soil Mixing[2]			2,610	
				3,250
Environmental				90
Site Investigation, Project Management and Engineering[3]	15%			190
Sub-Total				6,310
Contingency	50%			3,160
TOTAL				9,470

Notes:

1. The Seismic Guidelines are under review to explore options that would reduce costs and still achieve seismic resilience. See Section 6 of this report and Appendix B for further discussion.
2. This cost results only from reaches 7, 8, and 22, which are Fraser River frontage dikes located in Richmond and Surrey.
3. Site Investigation, Project Management and Engineering are calculated as 15% of *Structural Flood Protection, Utility Impacts, Pump Stations and Flood Boxes and Environmental*. Engineering and management of Seismic work is included in that item.

This cost estimate is based on sea level rise estimates provided in the *Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use - Draft Policy Discussion Paper* (Ausenco Sandwell, 2011) and represent currently accepted estimates of sea level rise by 2100. The selected options (or others that may be suggested by more detailed study of particular reaches) do not need to be fully constructed immediately, but incrementally over the next several decades. A measured approach will be a benefit because predicted rates of sea level rise will most likely be revised as empirical data becomes available and the science improves.

It is suggested that these large investments in flood protection infrastructure should be made within an overall Regional Flood Protection Plan. This strategy would be led by the Province with municipalities and other agencies as stakeholders.

Adaptation measures would be implemented in a phased approach. The important action to be taken now is to plan the phases on a regional basis, so that the necessary resources, including land, are available when needed.

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1. Introduction

1.1 Background

The Province recently published the following reports to address adaptation to climate change:

Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use - Draft Policy Discussion Paper (Ausenco Sandwell 2011).

In addition, the Province published the following draft design guidelines:

- *Sea Dike Guidelines,* (Ausenco Sandwell 2011).
- *Guidelines for Management of Coastal Flood Hazard Land Use,* (Ausenco Sandwell 2011).
- *Coastal Floodplain Mapping – Guidelines and Specifications,* (Kerr Wood Leidal 2011).
- *Seismic Design Guidelines for Dikes,* (Golder Associates 2011).

1.2 Project Scope

The scope of this project was to develop a 'Class D' estimate of the cost to adapt flood protection to meet the rise in sea level predicted by 2100.

A range of flood protection options have been assessed for a number of shoreline reaches, and for each reach a conceptual option was chosen and the cost estimated. The required flood protection crest elevation was determined using the methodology set out in *Sea Dike Guidelines*, (Ausenco Sandwell 2011).

The cost estimate considers the full costs of establishing flood protection to current provincial dike safety standards including land acquisition, engineering, geotechnical design (including seismic), environmental design, relocation of utilities, and upgrading of pump stations and other appurtenant works.

1.3 Study Area

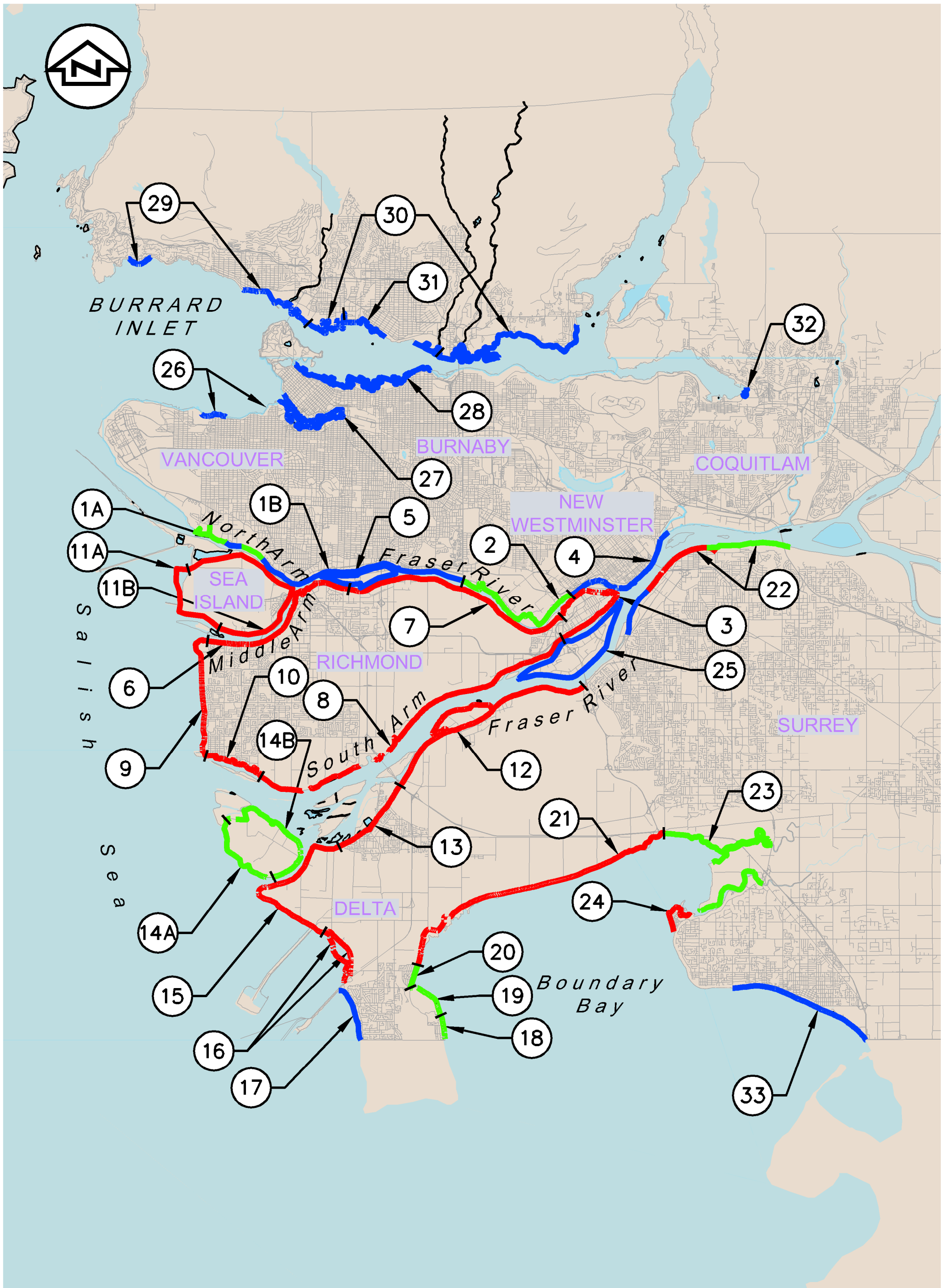
The study area includes Metro Vancouver coastal shoreline as well as Fraser River shoreline as far east as the Port Mann Bridge, totaling over 250 km. The study area is shown in **Figure 1.1**.

The original study area only covered the shoreline of the Fraser River delta. The project was expanded to also include shorelines in Burrard Inlet.

1.4 Acknowledgements

Preparation and publication of this document was made possible by funding support from Natural Resources Canada and BC Ministry of Forests, Lands & Natural Resource Operations and administrative support by the Fraser Basin Council. Participation and assistance of staff from several Metro Vancouver municipalities and diking authorities provided valuable input into the document.

FIGURE 1.1 SHORELINE REACHES



LEGEND:

EXISTING DIKE

EXISTING DIKE (NON-STANDARD)

LOW LYING SHORELINES WITH NO DIKE

1A	SOUTH VANCOUVER
1B	SOUTH VANCOUVER
2	BURNABY
3	QUEENSBOROUGH
4	NEW WESTMINSTER
5	MITCHELL ISLAND
6	RICHMOND URBAN / HIGH DENSITY
7	RICHMOND RURAL / LOW DENSITY NORTH
8	RICHMOND RURAL / LOW DENSITY SOUTH
9	RICHMOND WEST DIKE
10	STEVESTON
11A	SEA ISLAND (SEA)
11B	SEA ISLAND (RIVER)
12	TILBURY/SUNBURY
13	LADNER
14A	WESTHAM ISLAND (SEA)
14B	WESTHAM ISLAND (RIVER)
15	DELTA WEST DIKE
16	TSAWWASSEN FIRST NATION
17	TSAWWASSEN BEACH
18	BOUNDARY BAY VILLAGE
19	BOUNDARY BAY REGIONAL PARK
20	BEACH GROVE
21	BOUNDARY BAY
22	SURREY FRASER
23	MUD BAY
24	CRECENT BEACH
25	ANNACIS ISLAND
26	KITSLANO ENGLISH BAY
27	FALSE CREEK
28	VANCOUVER BURRARD
29	WEST VANCOUVER
30	DISTRICT OF NORTH VANCOUVER
31	CITY OF NORTH VANCOUVER
32	PORT MOODY
33	WHITEROCK / SOUTH SURREY

2. Protection Requirements

2.1 Information Sources

This report uses available information on existing dikes, soil conditions and land use from the following sources:

- Existing dike crest elevation information from dike surveys and as-built drawings.
- Digital topographic information from LIDAR and GIS data where dike surveys and as-builts were not available.
- Bathymetrical data from Admiralty Charts of the Strait of Georgia 2008.
- Google Earth Mapping

Information from these sources was assumed to be accurate and suitable for this cost estimate.

2.2 Shoreline Reaches

The study area encompasses over 250 km of shoreline and dikes, which were divided into 36 reaches (**Figure 1.1**). Division of reaches was based on general characteristics that influence the available flood protection options.

- Diked or Undiked – many locations in the study area have already been diked. In some cases the dikes were constructed over 100 years ago to support agricultural activities and then upgraded to protect urban development. Most of the existing dikes are located in the Fraser River delta and around Boundary Bay.
- Rural or Urban – the nature of the land-use behind the shoreline influences available options and the cost of those options. The categories Rural and Urban were used to describe the amount of space available prior to impacting structures.
- Sea or River – whether the shoreline is coastal or river frontage defines flood conditions and impacts available options.

It should be noted that broad generalizations were required when dividing the study area into 36 shoreline reaches. In the future, there will likely be several separate flood protection projects within each of these reaches.

2.3 New Requirements

The purpose of this project was to develop a 'Class D' cost estimate to provide flood protection for anticipated sea level rise by 2100 using the methodology discussed in the *Sea Dike Guidelines (*Ausenco Sandwell 2011). For vertically static areas, the report recommends that affected areas allow for a 1.0 meter rise in sea level.

The protection design level required by the new guidelines is a combination of sea level rise, subsidence, maximum high tide, storm surge, wave effects and freeboard.

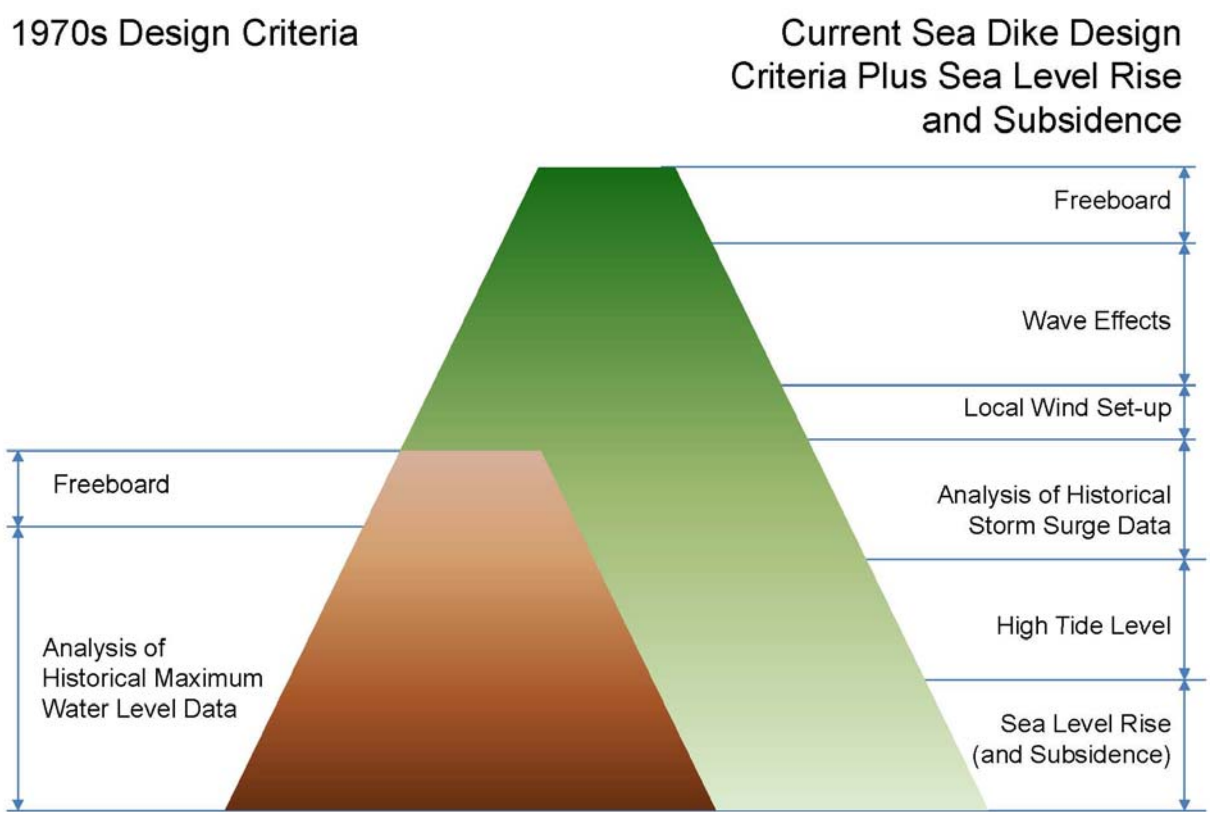
2.3.1 Coastal Areas

The design approach for coastal dikes in BC has evolved over the past 40 years. In the early 1970s the Fraser River Flood Control Program considered maximum historic water levels and added a freeboard allowance for wave action and uncertainties. Later design studies were based on a frequency analysis of maximum annual water levels plus freeboard. The 2003 *Dike Design and Construction Guide* published by the Provincial Dike Safety Program recommended separate analyses of storm surge and wave effects and that these values be added to the maximum high tide, an approach consistent with updated coastal engineering practice. The methodology in the *Sea Dike Guidelines* (Ausenco Sandwell 2011) follows this 2003 approach but also adds sea level rise and subsidence values (see Figure 2.1 below).

Dike crest levels as defined in the *Sea Dike Guidelines (*Ausenco Sandwell 2011) were used to develop the cost estimates in this study. These are significantly greater than existing dike levels (based on the 1970s criteria) because of the higher level of protection created by including the following factors in the design:

- Sea level rise
- Subsidence
- Storm surge, which is analyzed separately, then added to the maximum high tide. This is a more conservative approach than earlier methods.
- Wave effects, which are analyzed separately, then added. It is now recognized that the 1970s criteria did not take wave effects adequately into account.

Figure 2.1 – Conceptual differences between old and new sea dike design approach



Also, because the size of the waves and wave run-up is depth limited, increased depth of water at the toe of the dike magnifies the height of the wave run-up.

Sea Level Rise, Subsidence, High Tide Level and Storm Surge data have been taken directly from the *Sea Dike Guidelines (*Ausenco Sandwell 2011). Local Wind Set-up and Wave Height vary based on local shoreline conditions so calculations were performed for each dike reach. A more detailed description of this analysis is included in **Appendix A**.

2.3.2 Fraser River

The Fraser River flood profile was most recently updated in 2008 by Northwest Hydraulic Consultants. Potential sea level rise was discussed at that time but not included in the prediction of Fraser River flood levels. For this project, Northwest Hydraulic Consultants (NHC) was retained by the Province to provide a preliminary indication of how sea level rise might affect Fraser River dike design levels for the purposes of this cost estimate. The existing MIKE 11 model was run for both winter storm and freshet conditions with downstream boundary conditions adjusted for sea level rise. A detailed description of this analysis is included in **Appendix A**.

The levels shown in **Appendix A** are not intended to be design levels. Further detailed review of downstream boundary conditions and other modeling factors are required. While the preliminary analysis shows that the Fraser River flood profile is impacted by sea level rise east of the study area, beyond the Port Mann Bridge, further detailed studies are required to determine a design profile incorporating sea level rise.

The point in the Fraser River profile when the governing flood level changes from storm surge condition to freshet condition occurs around Annacis Island. Downstream of this point, the winter design condition will result in higher water levels. Storm surge and freshet events can still extend upstream and downstream of this point but this is where the governing condition will be set. As the ocean levels rise, the winter storm profile is likely to govern over an increasingly longer reach.

2.3.3 New Protection Levels

The new flood level as determined using the methodology defined by the *Sea Dike Guidelines (*Ausenco Sandwell 2011) is used for estimating the size of a potential flood protection option. In the case of structural options the new guidelines set the new crest level and in the case of non-structural options may determine the level of flood proofing or the extent of impacted areas.

Table 2.1 shows the potential new crest level for a 2100 sea level rise scenario for each shoreline reach. It also includes the existing ground levels or top of dike elevations. Existing ground level is based on dike survey, as-builts and GIS data as available. **Figure 2.2** illustrates the increases graphically.

2.3.4 Seismic Guidelines

The Province has also issued new seismic design guidelines for dikes – *Seismic Design Guidelines for Dikes* (Golder Associates, 2011). While these seismic guidelines are not related to sea level rise, all future dike design and construction must be consistent with the requirements, and therefore an estimated seismic construction cost component is included for all proposed structural options.

The guidelines specify a level of performance in terms of vertical and lateral dike deformation in response to different seismic events.

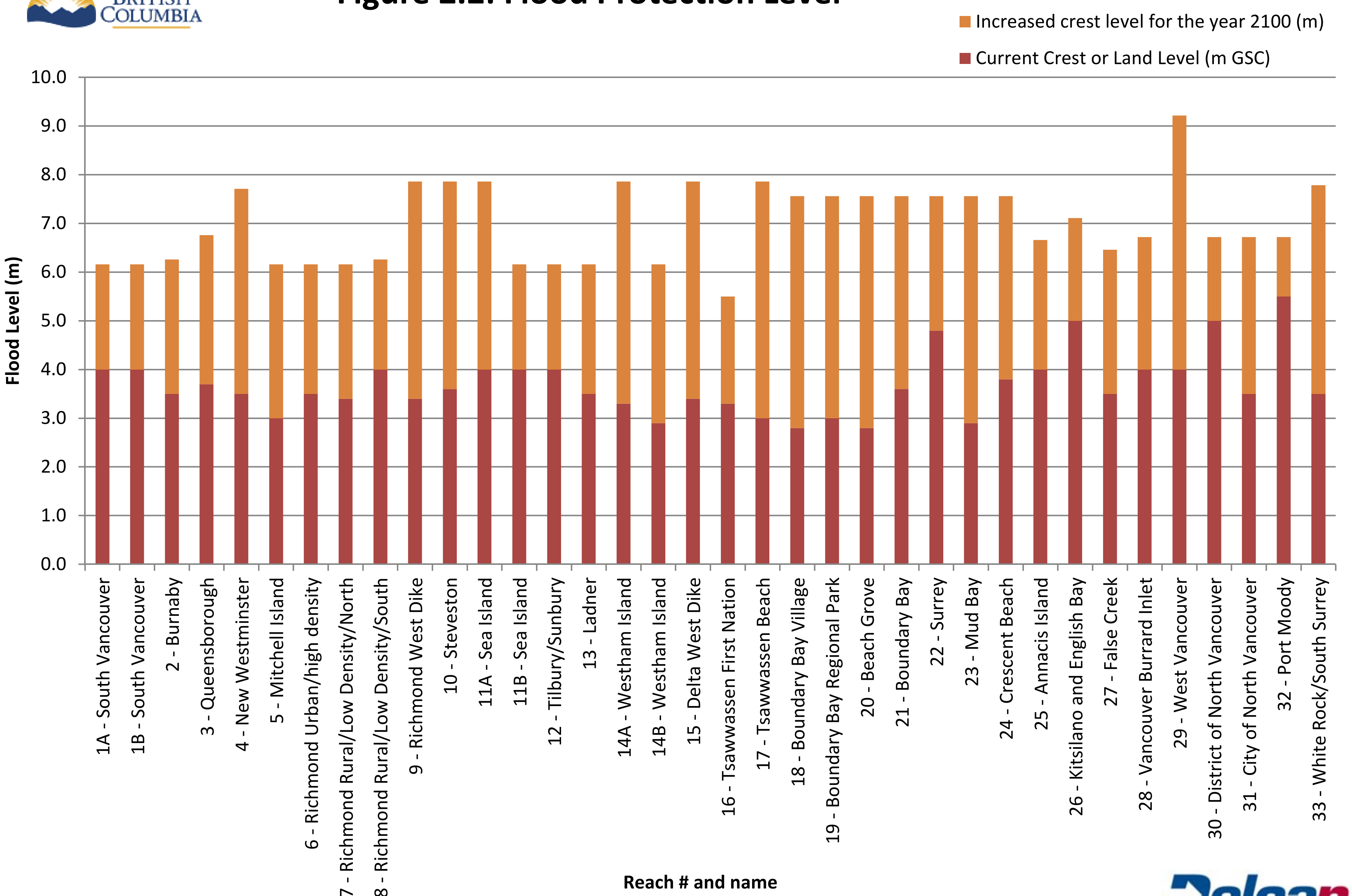
Further discussion on the seismic guidelines is in the report by Thurber Engineering in **Appendix B**.

Table 2.1 - Potential 2100 Crest Levels

Reach #	Reach Name	Municipality	Reach length (m)	Predominantly urban or rural	Standard dike, non-standard dike or undike	Current Crest or Land Level (m GSC)	Crest Level Source (see note 1)	Designated Flood Level (m GSC)	Required crest level (m GSC)	Increased crest level for the year 2100 (m)
1A	South Vancouver	City of Vancouver	3245	Urban	non-standard	4.0	3	4.5	6.2	2.2
1B	South Vancouver	City of Vancouver	11325	Urban	undike	4.0	3	4.5	6.2	2.2
2	Burnaby	Burnaby	7710	Urban	undike	3.5	3	4.6	6.3	2.8
3	Queensborough	New Westminster	7190	Urban	dike	3.7	2	5.1	6.8	3.1
4	New Westminster	New Westminster	6700	Urban	undike	3.5	2	5.6	7.7	4.2
5	Mitchell Island	City of Richmond	7905	Urban	undike	3.0	3	4.5	6.2	3.2
6	Richmond Urban/high density	City of Richmond	9015	Urban	dike	3.5	1	4.5	6.2	2.7
7	Richmond Rural/Low Density/North	City of Richmond	11440	Rural	dike	3.4	1	4.5	6.2	2.8
8	Richmond Rural/Low Density/South	City of Richmond	16190	Rural	dike	4.0	1	4.6	6.3	2.3
9	Richmond West Dike	City of Richmond	6390	Urban	dike	3.4	1	4.9	7.9	4.5
10	Steveston	City of Richmond	3640	Urban	dike	3.6	1	4.9	7.9	4.3
11A	Sea Island	Vancouver Airport Authority (YVR)	4850	Urban	dike	4.0	3	4.9	7.9	3.9
11B	Sea Island	Vancouver Airport Authority (YVR)	10550	Urban	dike	4.0	3	4.5	6.2	2.2
12	Tilbury/Sunbury	Corporation of Delta	15450	Urban	dike	4.0	1	4.5	6.2	2.2
13	Ladner	Corporation of Delta	4300	Urban	dike	3.5	1	4.5	6.2	2.7
14A	Westham Island	Corporation of Delta	4560	Rural	non-standard	3.3	1	4.9	7.9	4.6
14B	Westham Island	Corporation of Delta	6940	Rural	non-standard	2.9	1	4.5	6.2	3.3
15	Delta West Dike	Corporation of Delta	8840	Rural	dike	3.4	1	4.9	7.9	4.5
16	Tsawwassen First Nation	Corporation of Delta	2820	Urban	dike	3.3	1	4.9	5.5	2.2
17	Tsawwassen Beach	Corporation of Delta	2775	Urban	undike	3.0	1	4.9	7.9	4.9
18	Boundary Bay Village	Corporation of Delta	1215	Urban	non-standard	2.8	1	4.6	7.6	4.8
19	Boundary Bay Regional Park	Corporation of Delta	2205	Rural	non-standard	3.0	1	4.6	7.6	4.6
20	Beach Grove	Corporation of Delta	1165	Urban	dike	2.8	1	4.6	7.6	4.8
21	Boundary Bay	Corporation of Delta	14775	Rural	dike	3.6	1	4.6	7.6	4.0
22	Surrey	City of Surrey	7150	Urban	dike	4.8	1	5.9	7.6	2.8
23	Mud Bay	City of Surrey	15870	Rural	non-standard	2.9	3	4.6	7.6	4.7
24	Crescent Beach	City of Surrey	2590	Urban	dike	3.8	2	4.6	7.6	3.8
25	Annacis Island	Corporation of Delta	13550	Urban	undike	4.0	3	5.0	6.7	2.7
26	Kitsilano and English Bay	City of Vancouver	1280	Urban	undike	5.0	3	4.8	7.1	2.1
27	False Creek	City of Vancouver	7600	Urban	undike	3.5	3	4.8	6.5	3.0
28	Vancouver Burrard Inlet	City of Vancouver	8300	Urban	undike	4.0	3	4.8	6.7	2.7
29	West Vancouver	West Vancouver	7300	Urban	undike	4.0	3	4.9	9.2	5.2
30	District of North Vancouver	District of North Vancouver	5800	Urban	undike	5.0	3	4.8	6.7	1.7
31	City of North Vancouver	City of North Vancouver	2000	Urban	undike	3.5	3	4.8	6.7	3.2
32	Port Moody	Port Moody	875	Urban	undike	5.5	3	4.8	6.7	1.2
33	White Rock/South Surrey	White Rock and Surrey	2500	Urban	undike	3.5	3	4.8	7.8	4.3

Note 1: Crest Level Source
1 Dike survey
2 As-builts
3 GIS contours / LIDAR

Figure 2.2: Flood Protection Level



3. Adaptation Options

Options for managing flood risk can be divided into two broad groups of options – structural and non-structural. The *Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper* (Ausenco Sandwell, January 2011) further categorized the options into four groups – one group of structural options under the heading Protect, and three groups of non-structural options – Accommodate, Retreat and Avoid. Further discussion of adaptation options and their potential for implementation can be found in the *Sea Level Rise Adaptation Primer* (The Arlington Group, July 2012) which has recently been completed by the Province.

Specific methods of achieving the structural and non-structural options were developed for this report, and are shown in **Figure 3.1** as items A. to L.

3.1 Protect

To protect against flooding is to construct protective works that form a barrier between the hazard and the public and private property behind the hazard. Protection works can be 'hard' protection such as dikes and floodwalls or 'soft' options such as dunes or tidal marshes.

The protection works serve to dissipate wave energy and to provide a barrier to flood waters during extreme events.

3.1.1 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 the Fraser Valley and are the most common form of structural flood protection. Many of these dikes were constructed or upgraded during the Fraser River Flood Control Program which ran between 1968 and 1994. These dikes typically have 3.5 to 4.0 metre top widths, 2.5:1 to 3:1 side slopes and incorporate 0.6 metres of freeboard over the designated flood level (at the time of construction). In the study area dikes typically have crest levels between 3.0 and 4.0 metres (GSC).

Both upgrading of existing dikes and construction of new dikes are potential options to protect against sea level rise.

General practice in flood management discourages the construction of new dikes to enable new development. However, new dike construction is considered for areas where sea

Figure 3.1: Grouping of Flood Protection Options

Structural							Non-Structural				
Protect							Accommodate			Retreat	Avoid
Dikes			Floodwalls		Foreshore						
A. Widen footprint to land side	B. Widen footprint to water side	C. Special Structures	D. Permanent	E. Demountable	F. Breakwater / Barrier Islands	G. Coastal wetlands	H. Flood proofing	I. Secondary Dikes	J. Emergency preparedness and response	K. Managed Retreat	L. Planning and Development Controls

level rise will create a new flood hazard in areas where development already exists.

There are several broad options for upgrading existing dikes, and these are heavily influenced by local conditions:

- Expand to the land side.
- Expand to the water side.
- Steepen side slopes to construct higher dikes within the same footprint.
- Modify cross-sections to dissipate wave energy.
- Alter seepage paths by using special structures.

For this cost estimate, the option choices have been simplified to be either: 'Expand to Land Side' or 'Expand to Water Side.' In practice at the site level, there can be a lot of variation and innovation in dike design.

3.1.2 Floodwalls

A floodwall is a constructed barrier designed to hold back flood waters to protect the community behind. Floodwalls are typically used in locations where space is limited and a dike would interfere with other land uses or structures, such as existing buildings and historical areas.

Floodwalls can be constructed from a number of different materials including reinforced concrete, or steel or plastic sheet piles. Floodwalls can also be designed to be demountable, where they can be erected prior to an imminent flood and taken down afterwards.

3.1.3 Foreshore Structures/ Improvements

In some areas raising shoreline dikes to the full crest height required by design guidelines is impractical. In such cases offshore improvements could be constructed to dissipate wave energy and allow for lower dike crest levels. These improvements can be engineered structures such as breakwaters or more natural structures such as barrier islands or constructed coastal wetlands.

3.1.4 Sea Gates and Surge Barriers

Sea gate and storm surge barriers are structures that can be used across a river mouth or harbour entrance. They allow movement of water and boats through the gate or barrier during normal water levels but can be closed during high water conditions. Sea gate and surge barriers can be a practical solution where a permanent barrier such as a dike or wall, would interfere with other needs, such as boat traffic.

3.2 Accommodate

This approach means that the decision is made to accept occasional flooding and protect infrastructure or property accordingly.

3.2.1 Flood Proofing

Building codes can be used to require that habitable or work space be constructed above the designated Flood Construction Level (FCL). There are numerous measures to achieve this at the individual property level depending on the specific features of the property and development. Some measure include filling land or raising buildings on stilts or high foundations.

3.2.2 Secondary Dikes

Secondary dikes work in conjunction with primary dikes to reduce the impact of a flood in case the primary dike is breached. Secondary dikes can be used to limit flooding to less developed areas in order to protect highly populated urban areas.

3.2.3 Emergency Preparedness

A common strategy for reduction of flood risk is to be prepared to respond to flood events. This requires that systems are in place for flood warnings, communication to residents, temporary protection plans (i.e. sandbags, gabion baskets, etc.), and evacuation plans.

3.3 Retreat

An option 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 approach includes the concept of managed retreat: the idea that an area with current development would be decommissioned over time and returned to a passive land use.

3.4 Avoid

The avoid option prevents development in flood prone areas. This option could be implemented by designating flood prone lands to uses less impacted by flooding (i.e. parks, open spaces, etc.).

3.5 Option Selection

Two important workshops were held during the options selection process. These were attended by the project team, relevant municipalities and Provincial representatives.

The workshops began with a summary of the new dike and seismic guidelines, anticipated 2100 dike crest levels, and a list of feasible adaptation options for each reach. Each reach was then discussed with the use of existing and possible future cross-sections. The discussion covered the technical, social, and economic challenges that will be faced by municipalities adapting to sea level rise.

Appendix C contains the reach evaluations and option selection based on the reach characteristics, results from workshops, and project team experience in flood risk management.

Table 3.1 shows the selected options.

Table 3.1 Selected Adaptation Option

#	Reach Name	Selected Option
1A	South Vancouver	Dike
1B	South Vancouver	Dike
2	Burnaby	Dike
3	Queensborough	Dike
4	New Westminster	Flood wall
5	Mitchell Island	Flood proofing
6	Richmond Urban/high density	Dike
7	Richmond Rural/Low Density/North	Dike
8	Richmond Rural/Low Density/South	Dike
9	Richmond West Dike	Dike
10	Steveston	Dike, Breakwater and Storm Surge Barrier
11A	Sea Island (Sea)	Dike
11B	Sea Island (River)	Dike
12	Tilbury/Sunbury	Dike
13	Ladner	Dike
14A	Westham Island (Sea)	Dike
14B	Westham Island (River)	Dike
15	Delta West Dike	Dike
16	Tsawwassen First Nation	Dike and Breakwater
17	Tsawwassen Beach	Flood proofing
18	Boundary Bay Village	Dike
19	Boundary Bay Regional Park	Dike
20	Beach Grove	Dike
21	Boundary Bay	Dike
22	Surrey Fraser	Dike
23	Mud Bay	Managed Retreat
24	Crescent Beach	Dike
25	Annacis Island	Dike
26	Kitsilano and English Bay	Dike
27	False Creek	Storm Surge Barrier
28	Vancouver Burrard Inlet	Flood proofing
29	West Vancouver	Dike
30	District of North Vancouver	Dike
31	City of North Vancouver	Dike
32	Port Moody	Dike
33	White Rock/South Surrey	Dike

4. Cost Estimate

The goal of the project is to develop a 'Class D' estimate of the cost to adapt to predicted sea level rise in Metro Vancouver. A 'Class D' estimate is a high level estimate that is intended to be accurate within an order of magnitude.

Where the selected option was a Protect option, costs were determined from conceptual typical cross-sections, prepared as part of this project. These sections are included in **Appendix D**. Where the selected option was non-structural, the cost estimate was based on assumptions described in Section 4.3.

4.1 Construction Costs

Where the selected option is structural, the construction cost estimate was based on the unit prices listed in the following sections. Unit prices are in 2012 dollars.

4.1.1 Embankment

Site Preparation: \$15 /m^3 - Clearing and removal of topsoil.

Core Material: \$40 /m^3 - Supplying and installing the dike material.

Rip-Rap: \$50 /m^3 - Rip-rap protection for the water side of the dike.

Surface Restoration: \$100 /m^2 - If there is currently a road on the dike, the cost includes construction of a typical asphalt road structure.

4.1.2 Structures

Sea wall/retaining wall: \$5,000 /m - For Reach 4 (New Westminster), the selected option is to build a seawall to raise the existing protection level. The wall would be approximately 1.5 metre high and include a pedestrian walkway and landscaping.

4.1.3 Utilities

Utilities relocation: Existing utilities are often impacted by dike construction. The cost of utility impacts is very site specific. Analysis of recent dike upgrade projects in urban areas shows that utility relocation was 20%-25% of the total construction cost. Therefore, it was assumed for this estimate that dike construction in urban areas will include 25% extra for utility relocation.

For rural areas, GIS mapping is used to approximate the extent of utilities near the dike alignment. It was found that utility impacts near these dikes would be minor. Therefore 5% was added for rural areas where minor utility conflicts are expected.

Pump Stations: Existing pump stations would likely require upgrades for additional pumping capacity to account for higher seepage, higher head and less gravity drainage. For new dike reaches in the study area, it was assumed that new major pump stations would not be required since those areas are generally not low enough to require constant pumping. Construction costs for pump stations constructed in the Lower Mainland in the last three years have ranged from \$500,000 to \$5,000,000. For this estimate it was assumed that each pump station upgrade is \$2.5 million.

Floodbox: Flood boxes allow for gravity drainage of water behind the dike. These will require adjustment for higher sea level. Some may require conversion to pump stations, as gravity drainage may no longer be possible. A per unit price of \$500,000 was assumed for flood box upgrades and small pump station installations.

4.2 Property Costs

Land and right-of-way acquisition: A major component of the adaptation cost will be the land acquisition required for expanded structure footprints. The cost of land on a per-square-metre basis was derived from an analysis of recent construction projects and from input provided by municipalities. For this estimate the actual footprint area of the improvement was used for the estimate. In reality the area of property acquisition might increase to a full property purchase if the remaining piece of property is not viable for development or agricultural use. Or a narrower structure might be used to avoid purchase of a particularly valuable piece of land. Also, in many cases the actual purchase of land is not required and a right-of-way agreement can be established for public access and control of the land for the purpose of dike construction and maintenance.

The cost of the ROW may not be the full cost to purchase the land. In some cases a dike ROW can be made to work with current land use such as a part of a waterfront promenade or driving surface for commercial use. In these cases the cost of the ROW would be less than the full purchase price because the land still has some value for the private land owner. However, for the purpose of this estimate the full purchase cost has been included.

The following property values are used:

- Agricultural: \$22/m^2 (\$90,000/acre)
- Residential: \$850/m^2 (\$3,500,000/acre)
- Commercial/Industrial: \$400/m^2 (\$1,600,000/acre)

The land values were based on BC Assessment data and property costs provided by some municipalities for various projects involving property acquisition from 2010 to 2012.

4.3 Costs for Alternative Strategies and Special Structures

For a number of reaches, the selected option is non-structural – flood proofing and managed retreat. These options cannot be estimated in the same way as structural options.

4.3.1 Managed Retreat

In this approach, the 'retreated' properties would be decommissioned over years or decades and the land returned to a natural or low-value condition that would be flooded periodically. The actual implementation and timeframe of this approach would significantly impact the cost. For this estimate, the cost of this option was assumed to be equal to the purchase price of the impacted land for compensation to the existing owners, in 2012 dollars.

4.3.2 Flood-Proofing

Methods of flood-proofing individual properties would be different for every property, and the costs therefore difficult to quantify with any degree of accuracy. Flood proofing typically occurs when there is no public flood protection and property owners are responsible for private works. Therefore, for this estimate it was assumed that flood-proofing would be the responsibility of the individual property owner and the cost is not included in the estimate.

4.3.3 Special Structures

There are some locations within the study area where unique situations would require specialized solutions.

Steveston, City of Richmond

The Steveston area is currently being studied by the City of Richmond to determine a potential flood protection solution. Steveston has a densely developed waterfront with many historic buildings. One of several options being investigated is the use of Shady Island as part of a breakwater/barrier island with a sea gate that would be closed during storm surge conditions to limit sea levels to a maximum elevation for the harbour and waterfront. The cost of sea gate structures can range from \$5,000,000 to \$40,000,000 based on international project experience. This structure was estimated at \$10,000,000 and is included in the improvements considered for this dike reach.

False Creek, City of Vancouver

A sea gate may also be a viable option to protect False Creek. At the opening to False Creek a sea gate could provide protection from rising sea levels. It would be open during normal conditions and closed in storm surge conditions. Such a structure would reduce the height of necessary shoreline defences around the perimeter of False Creek. As noted above, the cost of these structures can vary significantly based on local conditions. This sea gate was estimated at \$25,000,000.

Mud Bay, City of Surrey

Managed retreat may be a viable option for Mud Bay. However, the decision to retreat is complicated and would be made with extensive stakeholder input and economic analysis. This strategy would require the construction of new sea gates at the mouths of the Nicomekl and Serpentine Rivers. The cost of these was assumed to be \$10,000,000 each and was added to the cost of the option.

4.4 Environmental Compensation

Dikes impact shoreline environments that often support important habitats for fish and wildlife. The functional capacity of a shoreline environment may be affected by dike construction or improvements. This impact is dealt with through impact mitigation and compensation elements incorporated into the design of such works. Options for impact mitigation and compensation vary by shoreline reach.

General options for impact mitigation and compensation consist of:

1. **Integrated features -** integrated within the face of dike, such as marsh benches and pockets.

2. **Extended features -** for example, groynes and spits that not only incorporate habitat features, but also provide recreational opportunities and ancillary benefits (such as erosion prevention) to shoreline protection.

3. **Landside features** - located landward of a dike, such as a slough or a lagoon, that receives and discharges tidal flows through a flood box/gate and/or pump station.

4. **Disconnected features** - essentially disconnected from the dyke and also called off-site compensation. They may be associated with offshore protection structures, such as a breakwater or 'barrier' island, or associated with existing shoals or islands.

A specific solution is dependent upon the type of environment impacted, the nature of the works and the location of the impact in the regional setting.

The cost of environmental mitigation and compensation is extremely variable site by site. For this estimate broad categories of compensation and a range of compensation costs were developed.

The expected cost range is from $50 to $500 per square metre of land required to compensate for a wider dike footprint that impacts shoreline habitat. Therefore $250 per square metre is selected as an average environmental compensation cost.

4.5 Seismic and Geotechnical Costs

Metro Vancouver is an area of seismic risk. To address this risk, the Province issued new draft *Seismic Design Guidelines for Dikes* (Golder Associates, August 2011) that require consideration of seismic effects in the design of new or upgraded dikes. The guidelines specify a level of dike performance in terms of vertical and lateral dike deformation in response to different seismic events. Thurber Engineering has prepared a technical memorandum summarizing the impact of the guidelines and detailing the potential cost of constructing dikes with the required seismic reinforcement. This technical memorandum is attached in **Appendix B**.

In areas where seismic activity could deform the dike, or more specifically the soil beneath the dike, improvements will be required to strengthen the soil.

There are several different mitigative methods to reduce dike deformation to meet the criteria set by the *Seismic Design Guidelines for Dikes* (Golder 2011). This project scope did not permit site-specific assessment of the most appropriate method for each section of the dike alignment. Therefore two common ground improvement techniques, vibro-replacement and deep soil mixing, were assessed and estimated.

4.5.1 Seismic Costs

To estimate the cost of the required seismic improvement it is necessary to make some assumptions about each method and the volume of soil to be improved. These are a product of soil type and water side slopes/geometry.

For this project the study area was categorized into two soil types:

Soil Profile A: a thin layer of silt over a thick deposit of loose sand.

Soil Profile B: a thick layer of silt or silt-sand combination over loose sand.

Thurber's technical memorandum contained in **Appendix B** shows the assumed extent of these two soil types.

The other important factor in determining seismic mitigation is whether the water side slope at the toe of the dike would lead to soil under the dike being confined during a seismic event (gentle slope or mudflats) or if spreading into the water would be unrestrained (steep river slope). Spreading occurs when the soil beneath the dike would be able to expand laterally into the river channel. **Figure 4.1** illustrates an unconfined river slope and shows how the liquefied soil could expand into the water after an earthquake. **Figure 4.2** illustrates a confined slope where the liquefiable soil spreading is limited.

For this project it was assumed that a 4:1 slope is the divide between the confined and unconfined situations. The dike reaches were classified as either Steep (steeper than 4:1) or Flat (flatter than 4:1) based on existing bathymetry and Admiralty Charts.

The shoreline reaches were classified as being one of the four scenarios shown in **Table 4.1** and estimated accordingly.

Vibro-Replacement: Vibro-replacement is the process of constructing stone columns using a vibratory probe. After the probe penetrates to the desired depth of treatment, stone fill is deposited into the hole from the ground surface or through feed tubes to the tip of the probe as it is withdrawn.

For vibro-replacement a unit price of \$20 /m^3 was used.

Deep Soil Mixing: Deep soil mixing is a soil improvement technology used to treat soils in situ to improve strength by mixing grout or binder with the soil to create cemented or improved soil.

For deep soil mixing a unit price of \$250 /m^3 was used.

Table 4.1:

Soil	Waterside Slope	Method	Extent of improvement: width x height (metres)
Profile A	Steep	Vibro-replacement	(20 x 15)
Profile A	Flat	Vibro-replacement	(20 x 10)
Profile B	Steep	Deep soil mixing	(20 x 15)
Profile B	Flat	No seismic improvement required	none

Figure 4.1: Example Unconfined Shoreline Slope

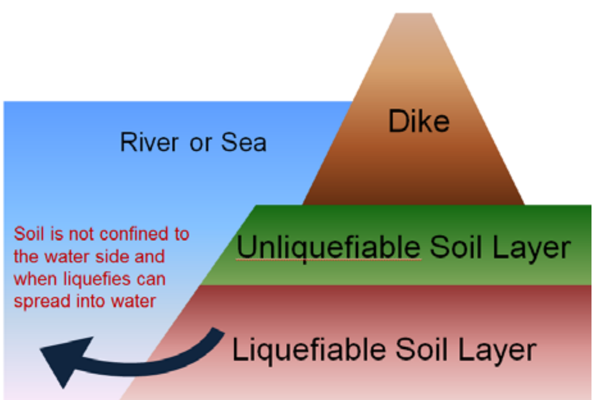
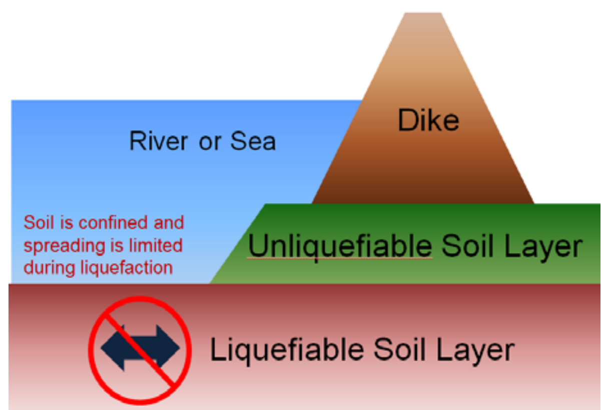


Figure 4.2: Example Confined Shoreline Slope



4.5.2 Toe Berms

Toe berms on the land side of a dike may be required to prevent uplift of land in a high water condition. The application of a toe berm would be very site specific. For estimation it is assumed that 10% of dikes on Soil Profile A would require a toe berm. Relief wells would be an alternative strategy to deal with this potential problem. The property impacts of toe berms have not been included because it is assumed that if property costs are significant, then relief wells or other options would be used to avoid property acquisition.

4.6 Engineering and Management

An additional allowance for engineering and project management of protection works has been included. These costs include site investigation, geotechnical studies, and design. Engineering costs for projects of this nature are typically 10-20% of capital cost. For this estimate 15% of Structural Flood Protection, Utility Impacts, Pump Stations and Flood Boxes and Environmental has been added to the total.

4.7 Contingency

Risk and uncertainty is captured in the cost estimate as a contingency. Contingencies for ‘Class D’ cost estimates typically range from 30% to 50%. Given the scale of the project and very long timeframe a contingency of 50% is used for this estimate.

4.8 Cost Summary

The total estimated cost for adaptation to sea level rise for the study area is summarized in **Table 4.2** below. **Table 4.3** contains a more detailed breakdown.

The costs in **Table 4.3** can be reproduced by multiplying the quantities in Appendix D by the unit cost by the length of the dike reach. For example Richmond West dike upgrade required 166 cubic metres of dike fill per metre of dike. Multiply that number by $40/cubic metre and 6390 metres of dike to get $42 million dollars.

Table 4.2: Estimated Cost of Adaptation to Sea Level Rise by 2100

Item			$ (millions)	$ (millions)
Structural Flood Protection				880
Utility Impacts, Pump Stations and Flood Boxes				350
Property Acquisition				
Agricultural	1,420	ha	320	
Residential	60	ha	550	
Commercial/Industrial	180	ha	720	
				1,580
Seismic[1]				
Vibro-Replacement			640	
Deep Soil Mixing[2]			2,610	
				3,250
Environmental				90
Site Investigation, Project Management and Engineering[3]	15%			190
Sub-Total				6,310
Contingency	50%			3,160
TOTAL				9,470

Notes:
1. The seismic guidelines are under review to explore options that would reduce costs and still achieve seismic resilience. See Section 6 of this report and Appendix B for further discussion.
2. This cost only results from reaches 7, 8, and 22, which are Fraser River frontage dikes located in Richmond and Surrey.
3. Site Investigation, Project Management and Engineering are calculated as 15% of *Structural Flood Protection, Utility Impacts, Pump Stations and Flood Boxes and Environmental*. Engineering and management of Seismic work is included in that item.

Table 4.3A: Cost Estimate for Shoreline Reaches

Municipality		Burnaby	New Westminster		Surrey			Richmond						YVR		Vancouver				
Reach Name		Burnaby	Queensborough	New Westminster	Surrey	Mud Bay	Crescent Beach	Mitchell Island	Richmond Urban/high density	Richmond Rural/Low Density/Nort	Richmond Rural/Low Density/Sout	Richmond West Dike	Steveston	Sea Island	Sea Island	South Vancouver	South Vancouver	Kitsilano and English Bay	False Creek	Vancouver Burrard Inlet
Reach #		2	3	4	22	23	24	5	6	7	8	9	10	11A	11B	1A	1B	26	27	28
Option (see legend)		**A**	**A**	**D**	**A**	**K**	**A**	**H**	**A**	**A**	**A**	**B**	**A+C+F**	**B**	**A**	**A**	**A**	**A**	**C**	**H**
Reach Length (m)		7710	7190	6700	7150	15870	2590	7905	9015	11440	16190	6390	3640	4850	10550	3245	11325	1280	7600	8300
	Unit Price ($)																			
Embankment																				
Site preparation	$15	0.34	0.63		0.42		0.21		0.51	0.65	1.12	0.58	0.22	0.34	0.49	0.11	0.37	0.06		
Core material	$40	9.47	39.95		19.16		7.48		22.72	28.83	56.73	42.43	6.52	13.68	28.27	2.21	7.70	1.31		
Rip-rap	$100	3.32	4.53		3.15		1.27		3.43	4.35	6.96	5.75	1.09	4.51	3.17	0.76	2.66	0.36		
Surface Restoration	$100																	0.77		
Structures																				
Sea wall/retaining wall	$5,000			33.5																
Misc																				
Utilities relocation		3.28	11.28		5.68		0.45		6.66	8.46	16.20	12.19	1.96	4.63	7.98	0.77	2.68	0.62		
Pump station	$2,500,000		7.50		7.50		2.50		17.50	15.00	22.50	7.50	5.00	12.50	10.00					
Flood box	$500,000	8.00	1.00		2.50											1.50	5.50	1.00		
Property																				
Land acquisition Agr	$22					286.00				4.28	7.84		0.80							
Land acquisition Res	$850						55.04													
Land acquisition C/I	$400	83.27	43.14		77.22				61.30						88.62	19.47	67.95			
Seismic and Geotechnical Costs																				
Vibro-replacement	$20	46.26	43.14				10.36		36.06			25.56	14.56	19.40	63.30	19.47	67.95			
Deep Soil Mixing	$250				536.25					858.00	1214.25									
Toe Berm	$40	1.16	1.08				0.39		1.35			0.96	0.55	0.73	1.58	0.49	1.70			
Special Considerations																				
Special Considerations						i		iv					ii						iii	iv
Special Considerations						20.00							10.00						25.00	
Environmental compensation																				
Compensation river/sea side	$250											36.74		26.68						
Site Investigations, Project Management and Engineering	15%	3.8	9.9	5.0	5.8	3.0	1.8		7.8	8.6	15.5	15.9	3.8	9.5	7.7	0.9	3.1	0.6	3.8	
Sub-total		158.9	162.1	38.5	657.6	309.0	79.5		157.4	928.2	1341.1	147.6	44.5	91.9	211.1	45.6	159.6	4.7	28.8	
Contingency	50%	79.5	81.1	19.3	328.8	154.5	39.8		78.7	464.1	670.6	73.8	22.3	46.0	105.6	22.8	79.8	2.4	14.4	
Total		**238.37**	**243.20**	**57.79**	**986.46**	**463.50**	**119.30**		**236.04**	**1392.23**	**2011.68**	**221.46**	**66.76**	**137.89**	**316.71**	**68.47**	**239.42**	**7.09**	**43.13**	

Flood Option Key:

A. Widen footprint to land side	Dikes	Protect	Structural
B. Widen footprint to water side	Dikes	Protect	Structural
C. Special Structures	Dikes	Protect	Structural
D. Permanent	Floodwalls	Protect	Structural
E. Demountable	Floodwalls	Protect	Structural
F. Breakwater / Barrier Islands	Foreshore	Protect	Structural
G. Coastal wetlands	Foreshore	Protect	Structural
H. Flood proofing		Accommodate	Non-Structural
I. Secondary Dikes		Accommodate	Non-Structural
J. Emergency preparedness and response		Accommodate	Non-Structural
K. Managed Retreat		Retreat	Non-Structural
L. Planning and Development Controls		Avoid	Non-Structural

Notes:

i Sea dams on Nicomekl and Serpentine

ii Storm surge barrier at Steveston Harbour

iii Breakwater and storm surge barrier at entrance to False Creek

iv Floodproofing costs not included because they are incurred at the site level and are the responsibilty of the private land owner.

Table 4.3B: Cost Estimate for Shoreline Reaches

Reach Name		Tilbury/Sunbury	Ladner	Westham Island	Westham Island	Delta West Dike	Tsawwassen First Nation	Tsawwassen Beach	Boundary Bay Village	Boundary Bay Regional Park	Beach Grove	Boundary Bay	Annacis Island	West Vancouver	District of North Vancouver	City of North Vancouver	Port Moody	White Rock/South Surrey	Sub Total
Municipality		Corporation of Delta																	
	Reach #	12	13	14A	14B	15	16	17	18	19	20	21	25	29	30	31	32	33	
	Option (see legend)	B	B	A	A	A+B	B+F	H	A	A	A	A	A	A	A	A	A	A	
	Reach Length (m)	15450	4300	4560	6940	8840	2820	2775	1215	2205	1165	14775	13550	7300	5800	2000	875	2500	**246010**
	Unit Price ($)																		
Embankment																			
Site preparation	$15	1.28	0.35	0.44	0.51	0.84	0.42		0.09	0.16	0.09	1.15	0.49	0.57	0.23	0.11	0.03	0.18	12.98
Core material	$40	43.82	20.40	30.64	26.76	54.45	14.64		4.56	8.28	4.38	73.58	14.09	29.00	4.41	3.90	0.41	7.73	627.52
Rip-rap	$100	13.91	3.87	2.87	2.78	7.87	1.24		0.80	1.46	0.77	8.13	4.07	4.89	1.33	0.86	0.14	1.45	101.72
Surface Restoration	$100	18.54													3.48	1.20		1.58	25.56
Structures																			
Sea wall/retaining wall	$5,000																		33.50
Misc																			
Utilities relocation		19.39	6.16	1.70	1.50	3.16	0.82		0.27	0.49	0.26	4.14	4.66	8.61	2.36	1.52	0.03	2.73	140.66
Pump station	$2,500,000	10.00	5.00			2.50	2.50			2.50		2.50							132.50
Flood box	$500,000	4.00	1.00	3.50	6.50	1.00			1.00			2.00		3.50	3.00	1.00	0.50	1.50	48.00
Property																			
Land acquisition Agr	$22			2.61	3.97	1.36				1.60		8.13							316.58
Land acquisition Res	$850		98.69				47.94		34.08		32.68			217.18				59.50	545.10
Land acquisition C/I	$400	135.96											86.72		39.44	20.00			723.09
Seismic and Geotechnical Costs																			
Vibro-replacement	$20	92.70	17.20	18.24	41.64	35.36	11.28						81.30						643.78
Deep Soil Mixing	$250																		2608.50
Toe Berm	$40	2.32	0.65	0.68	1.04	1.33	0.42						2.03					0.38	18.82
Special Considerations																			
Special Considerations								iv											
Special Considerations																			55.00
Environmental compensation																			
Compensation river/sea side	$250					11.05	13.40												87.86
Site Investigations, Project Management and Engineering	15%	17.0	5.6	6.0	5.9	12.3	5.0		1.0	1.9	0.8	13.7	3.8	7.0	2.2	1.3	0.2	2.3	192.62
Sub-total		358.9	158.9	66.7	90.6	131.2	97.7		41.8	16.4	39.0	113.4	197.2	270.7	56.5	29.9	1.3	77.4	6313.78
Contingency	50%	179.5	79.5	33.3	45.3	65.6	48.8		20.9	8.2	19.5	56.7	98.6	135.4	28.2	14.9	0.6	38.7	3156.89
Total		**538.35**	**238.39**	**99.99**	**135.84**	**196.86**	**146.51**		**62.73**	**24.64**	**58.49**	**170.03**	**295.74**	**406.10**	**84.71**	**44.83**	**1.92**	**116.05**	**9470.67**

Notes: iv Floodproofing costs not included because they are incurred at the site level and are the responsibilty of the private land owner.

Flood Option Key:

A. Widen footprint to land side	Dikes	Protect	Structural
B. Widen footprint to water side	Dikes	Protect	Structural
C. Special Structures	Dikes	Protect	Structural
D. Permanent	Floodwalls	Protect	Structural
E. Demountable	Floodwalls	Protect	Structural
F. Breakwater / Barrier Islands	Foreshore	Protect	Structural
G. Coastal wetlands	Foreshore	Protect	Structural
H. Flood proofing		Accommodate	Non-Structural
I. Secondary Dikes		Accommodate	Non-Structural
J. Emergency preparedness and response		Accommodate	Non-Structural
K. Managed Retreat		Retreat	Non-Structural
L. Planning and Development Controls		Avoid	Non-Structural

5. Implementation

5.1 Timescale for Adaptation

This cost estimate is based on the estimates for sea level rise by 2100 given in the reports *Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use - Draft Policy Discussion Paper* (Ausenco Sandwell 2011) and *Sea Dike Guidelines,* (Ausenco Sandwell 2011).

The selected options (or others that might be suggested by more detailed study of particular reaches) do not require immediate construction. There would in fact be a benefit in a measured approach, because over the years the actual rate of sea level rise will likely cause the 2100 estimate to be revised.

Adaptation measures should be implemented in a phased approach. The important action to be taken now is to plan that phased approach on a regional basis so that the necessary resources, including land, are available when needed.

5.2 Phased Implementation

The scale of the necessary adaptation measures requires that an implementation plan must be phased over decades rather than years. The nature of sea level rise, and the current planning horizon of 2100, means that the necessary time is available.

A long-term phased approach will allow for the necessary funding to be planned and budgeted, and areas at highest risk and/or highest economic value can be prioritized.

Structural protection measures, which in some cases will ultimately have significantly higher crest levels than today, can be built in stages so that disruption to communities and the environment is minimized. It is straightforward to design and build earth dikes and flood walls to be incremental, if the ultimate height and configuration is established at the planning stage.

5.3 Cost-Benefit

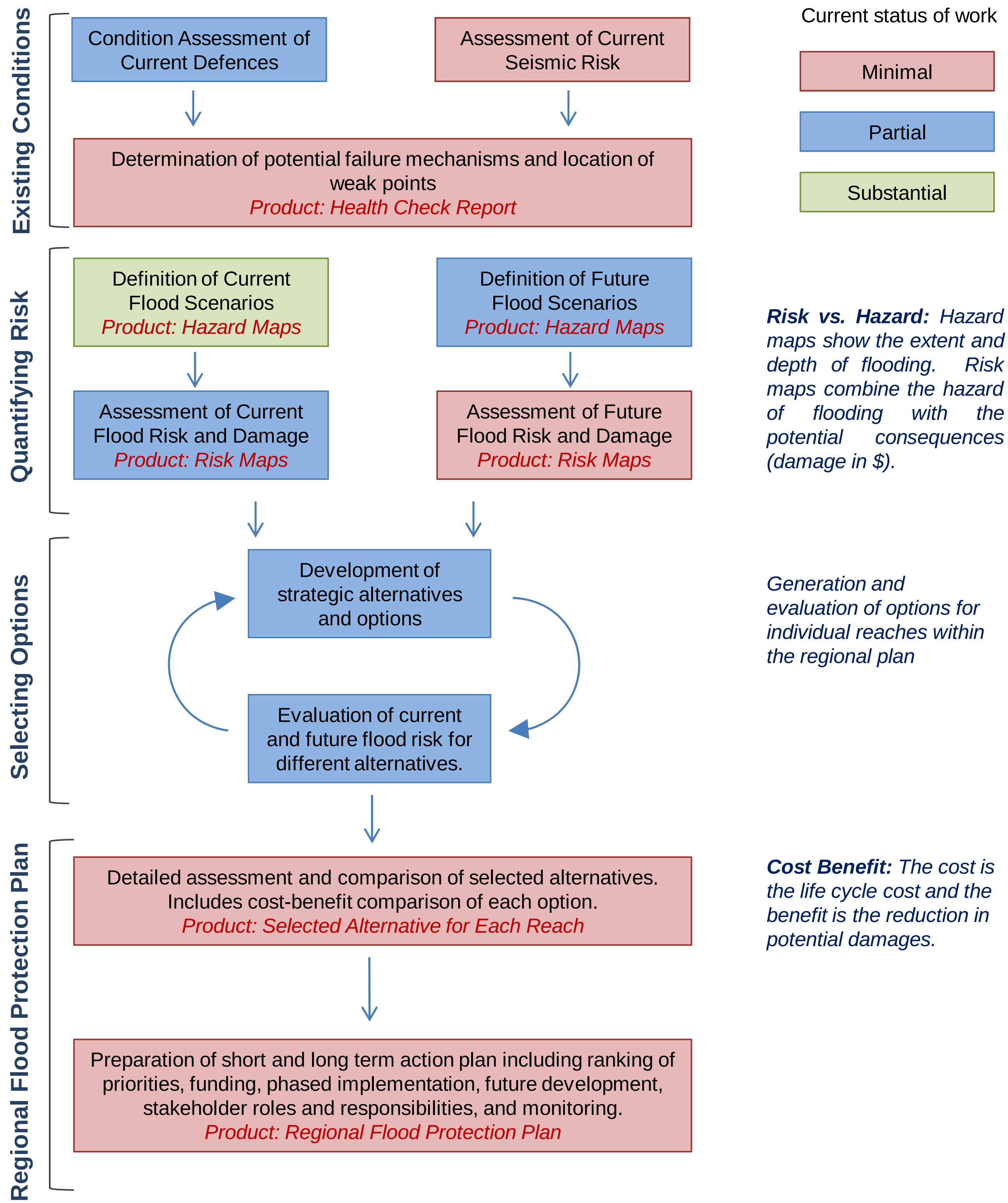
The scope of this project was to provide a high level cost estimate for adaptation to predicted sea level rise by 2100. Looking only at the cost of an adaptation program does not provide a full picture. On the other side of the equation are the benefits of that investment. The cost of constructing flood protection must be offset against the benefits of protecting infrastructure behind those defences (ie. the cost of reconstruction if they were to be flooded), and of not interrupting economic activity.

A number of such cost-benefit analyses have been performed in the Lower Mainland – for Richmond, Surrey, Delta and New Westminster. These analyses have considered the social, environmental and economic costs and benefits. The result of each of these studies was a recommended level of protection corresponding to the value of the infrastructure protected, and this is different for each location.

5.4 Next Steps

The decision to make large investments in flood protection infrastructure should be made within an overall Regional Flood Protection Strategy. This strategy would ideally be developed with the Province or regional body as a lead and municipalities and other agencies as stakeholders. Some of the elements that should be included are outlined in **Figure 5.1.** As indicated in the colour coding, some of the work to prepare a regional strategy is already in place or has been partially completed.

Figure 5.1: Next Steps to Develop a Regional Flood Protection Plan



6. Limitations

1. The costs presented in this report are intended for high-level long-term budgeting purposes. Actual costs can be expected to differ from these estimates for a variety of reasons. These estimates should not be used to estimate the cost for small individual projects which would need more detailed investigation. Any third party use of the costs presented in this report, in whole or in part, should be updated and verified.

2. This cost estimate only covers the cost to upgrade and does not include the ongoing costs of monitoring and maintenance that are required to maintain structures.

3. The *Seismic Design Guidelines for Dikes* (Golder 2011) document is under review to explore options that would reduce costs and still achieve seismic resilience. See Appendix B for further discussion.

4. Seismic improvement costs were not a criterion for selecting each protection option. For reaches 7, 8, and 22, which are dikes located in Richmond and Surrey, with a total length of 35 kilometres, the cost estimate for seismic mitigation exceeded $80,000 per metre. For these sections of extremely high seismic cost an alternative approach would be adopted when considering the implementation. Options might include:
    a. Realignment of the dike,
    b. Construction of a wide 'superdike' where a portion of the dike would be allowed to fail, or limited seismic ground improvement used,
    c. Cheaper and/or new future methods for soil improvement

5. Municipal consultation and discussion during the workshops were an important part of the options selection process. However, the selected options do not necessarily reflect the preferences of the contributing municipalities.

6. The costs presented in this report are relevant only to the defined study area downstream of the Port Mann Bridge and for the Metro Vancouver shorelines indicated in **Figure 1.1**. For the Fraser River, sea level rise will impact dike design levels some distance upstream of the Port Mann Bridge. All BC coastal communities should be included in future work.

7. References

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Appendix A
Flood Level Requirements

A. Flood Level Requirements

The basis for the cost estimates in this report is the requirement to protect for predicted sea level rise for the year 2100. Around the world, there are various models and data on the amount of sea level rise to be expected. Locally, apart from the general discussion on sea level rise, there is also some discussion on different methods for calculating storm surge and wave effects during a future scenario. For the purpose of this project, as specified in the Terms of Reference, global sea level rise and dike design methodology shall be consistent with the *Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use* (Ausenco Sandwell 2011).

The protection design level proposed by the new guidelines is a combination of sea level rise, maximum high tide, storm surge, wave effects and freeboard.

A.1. Coastal Reaches

The project area is divided into 36 different reaches. Hydraulic data on storm surge conditions is based on the *Sea Dike Guidelines* (2011) and the data is presented in **Table A.1** below.

Sea Level Rise, Subsidence, Reference Tide and Storm Surge

As noted above, the basis for the cost estimate is the 2011 guidelines. Therefore Sea Level Rise, Subsidence, Reference Tide and Storm Surge data have been taken directly from that document. Local Wind Set-up and Wave Height can vary based on local shoreline conditions so calculations were performed for each dike reach.

Local Wind Setup

Local wind set up data is taken from the *Sea Dike Guidelines* (2011). For the scope of this study it is considered sufficiently accurate to apply these three values over the different reaches. The study area is divided into three different zones (West, South, & River). Within each zone the wind-set up is assumed to be uniform. The development of a two dimensional wave and storm surge model for the Lower Fraser Delta, in order to arrive at estimates with higher accuracy, is outside the scope of this study and could be considered as a recommendation for further works.

Wave Calculations

Wave growth calculations have been made at a number of reaches to adjust the applicability of values from **Table A.1** for local conditions. The coastal area is subject to severe storms. Wind speed, depth of water at sea and length of fetch determine the size of wave developed. The characteristics of the wind driven waves in the coastal area are determined by Bretschneider calculations (The Rock Manual, 2007). Below is an example of parameters used in calculating potential wave effects.

Table A.1 - Summary of Sea Dike Elevations from Dike Guidelines (adapted from Appendix C of the Sea Dike Guidelines (Ausenco Sandwell 2011)

Required crest height	Location of dike		
	Granville Island	Richmond West	Boundary Bay
Reference Tide level (m CGD)	2.1	2.0	1.8
Sea Level Rise 2100 (m)	1.0	1.2	1.2
Storm surge 1/500 AEP (m)	1.3	1.3	1.3
Local wind set up (m)	0.2	0.4	0.5
Wave run-up (2%)	0.6	2.7	2.6
Freeboard (m)	0.6	0.6	0.6
Minimum Crest Height	5.8	8.2	8.0

Table A.2: Factors Used to Determine Wave Characteristics for Richmond West Dike

Factor	Value	Source
Wind speed	30 m/s (58 knots)	Vancouver airport wind rose
Fetch	32 km	Google Earth, distance from Vancouver Island to Vancouver
Depth	6m	Water depth above mud flats during extreme conditions from British Admiralty Chart

Table A.3: Wave Characteristics for West Dike

Factor	Value
Significant wave height (Hs)	1.75 m
Significant wave period (Tp)	4.9 s

For the run up or overtopping calculations, it is assumed that the waves hit the flood defenses perpendicularly. This is the governing direction for wave run-up and overtopping. The run-up calculation for embankments uses wave run-up methodologies outlined in the *Technical Report: Wave Run-up and Wave Overtopping at Dikes* (Technical Advisory Committee on Flood Defences, May 2002). **Tables A.2** and **A.3** show some of the key factors in calculating wave effects. Wave heights are generally depth limited so the increased depth caused by potential sea level rise contributes to larger waves impacting the shoreline defences.

The *Sea Dike Guidelines* (Ausenco Sandwell 2011) recommends that the required crest height in the year 2100 be based on wave run-up calculations with a slope gradient of 3:1 (horizontal : vertical) and 2% wave overtopping.

A.2. Fraser River Reaches

Northwest Hydraulic Consultants (NHC) was retained by the Province to provide a preliminary indication of how sea level rise might affect Fraser River dike design levels for the purposes of this cost estimate. The existing MIKE 11 model was run for both winter and freshet conditions with downstream boundary conditions adjusted for sea level rise. The update to the model is based on new downstream boundary conditions at the mouth of the Fraser River for both winter and freshet events. There are a number of ways to predict extreme water levels for storm surge conditions using computer models or statistical analysis. As stated earlier, the focus of this project is to provide a high level cost estimate for adaptation to sea level rise, so detailed coastal water level analysis was not performed. Boundary conditions were based on the *Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use* (Ausenco Sandwell 2011), which in turn were based on previous studies of the area.

The levels shown in this report are not intended to be design levels. Further detailed reviews of downstream boundary conditions and other modeling factors are required. While the preliminary analysis shows that the Fraser River flood profile is impacted by sea level rise east of the study area limit (Port Mann Bridge) further work is required to determine a design profile incorporating sea level rise.

Mouth of the Fraser Boundary Conditions

To rerun the Fraser River Mike 11 model, a new boundary condition was required. The model was run for two scenarios: Spring Freshet and Winter Storm Surge. Because the Fraser River flood profile is a snow-melt driven event, the Fraser River flows are higher during the spring but this is not the time of year when extreme storm surges typically occur. During the winter months, the largest storm surges are observed, but Fraser River water levels are moderate. Therefore, two different boundary conditions are required.

1. For the winter period downstream boundary conditions, the 2011 Ausenco Sandwell guidelines recommend the factors shown in **Table A.4**. Therefore, 4.5 metres is used as the high point for the downstream boundary condition in the winter event.

Table A.4 – Winter Sea Level Boundary Conditions for Fraser River

Component	Amount (m)	Source
Sea Level Rise	1.0	Table 3-2, Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper
Subsidence	0.2	Mean subsidence for estimate for Richmond (Source: Table of projected relative sea-level rise by year 2100 for locations of tide gauge and GPS stations in British Columbia - Addendum to Thomson, R.E., Bornhold, B.D., and Mazzotti, S. 2008.)
High Tide	2.0	Table 3-2, Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper
Storm Surge	1.3	Table 3-2, Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Sea Dike Guidelines
Total:	**4.5**	(GSC)

Table A.5 –Spring Sea Level Boundary Conditions for Fraser River

Component	Amount (m)	Source
Sea Level Rise	1.0	Table 3-2, Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper
Subsidence	0.2	Mean subsidence for estimate for Richmond (Source: Table of projected relative sea-level rise by year 2100 for locations of tide gauge and GPS stations in British Columbia - Addendum to Thomson, R.E., Bornhold, B.D., and Mazzotti, S. 2008.)
High Tide	2.0	Table 3-2, Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper
Storm Surge	0.4	Adapted from Fraser Basin Model, Downstream Boundary Conditions Report (Triton Consultants 2006).
Total:	**3.6**	(GSC)

2. For the spring freshet boundary conditions, different assumptions are required. The major difference is the storm surge component. As part of the Fraser River Model update, in 2006 Triton Consultants Ltd. used a number of methods to estimated storm surge for various return periods in each month of the year. For this project a 1/10 year spring storm surge was selected. **Table A.5** shows the factors used.

River Profile

The results of Northwest Hydraulic Consultants modeling runs are attached. The revised river profiles are used in calculations of the future crest heights.

Wave Effects

For river reaches, there is not enough fetch for wind to generate large waves. The wave loads near the river reaches are mainly caused by boat movement. Ship movement causes relatively short waves. For this study it is assumed the ship induced waves have the characteristics as shows in **Table A.6**.

Table A.6: Wave Characteristics for Fraser River

Factor	Value
Significant wave height (Hs)	0.6 m
Significant wave period (Tp)	4.0 s

New Crest Levels

The future design crest level is a key input into estimating the size of the potential mitigation measure (in the case of dike and wall protection options). **Table 2.1** shows the potential new crest level for a 2100 sea level rise scenario. It also includes the existing ground levels at the shoreline. A representative value for the ground level was selected based on a combination of dike survey, as-builts and GIS data.

Fraser River Hydraulic Modelling

Northwest Hydraulic Consultants

30 Gostick Place | North Vancouver, BC V7M 3G3 | 604.980.6011 | www.nhcweb.com

northwest hydraulic consultants

Project No. 300050
March 30, 2012

MINISTRY OF FORESTS, LANDS AND NATURAL RESOURCE OPERATIONS (MFLNR)
395 Waterfront Crescent, 3rd Floor
Victoria, BC V8T 5K7

Attention: **Mr. Jesal Shah, P.Eng.**
Project Manager

Dear Mr. Shah:

Subject: **Cost of Adaptation – Sea Dikes and Alternative Strategies**
Fraser River Hydraulic Modelling
Draft Report

1 INTRODUCTION

In 2006, NHC and Triton Engineering[1] developed a design flood profile for the Fraser River from Mission to Georgia Strait based on hydraulic modelling using the MIKE11 software by the Danish Hydraulic Institute. Two separate scenarios were modelled: 1) the estimated flood of record (which occurred in 1894) combined with spring tide conditions; and, 2) the 200-year winter storm surge with high tide combined with a Fraser winter flood. The two profiles were then overlaid and the higher of the two was used to develop the overall design profile. The profile did not include an allowance for sea level rise.

Delcan Corporation (Delcan) is currently working on a project for MFLNRO to assess the cost of adaptation to sea level rise. Increases in the ocean level will affect the long-term design of land development and infrastructure, not only at the coast but also along rivers draining into the ocean. To assist Delcan with the project, MFLNRO retained Northwest Hydraulic Consultants (NHC) to re-run the Fraser River Hydraulic Model using increased ocean levels as the model boundary condition. Based on ocean levels predicted for year 2100 by Delcan, the design profile for the Fraser River downstream of the Port Mann Bridge was simulated.

Climate change is also expected to have an impact on the winter and freshet design flows. However, for the present project no flow adjustments were made.

The local configuration of the channels and the trifurcation structure at New Westminster control the distribution of flow downstream of New Westminster. For modelling, it was assumed that entrance conditions will remain unchanged.

[1] NHC-Triton, 2006. Lower Fraser River, Final Report, Fraser Basin Council, December 2006.

2 SEA LEVEL SCENARIOS

Recent studies commissioned by the BC Ministry of Environment (BC MOE) on the impact of climate change on sea levels suggest adopting a net rise of 1.2 m in the Fraser River delta by the year 2100[2]. Attachment A by Delcan specifies that the following winter and freshet peak water levels be used:

- Winter maximum ocean level = 4.5 m GSC
- Freshet maximum ocean level = 3.6 m GSC

Winter and freshet ocean boundary levels for the present model are 2.9 m and 1.8 m GSC.

The present 200 year tidal time series was shifted to account for the sea level rise so that the peak water level corresponded to 4.5 m (maintaining the same difference between the high and low tides).

The spring freshet level specified by Delcan corresponds to a 10-year spring storm surge. As for the winter condition, it was assumed that the tidal time series had the same shape as the event before sea level rise, shifting it up so that the peak freshet water level corresponded to 3.6 m.

3 PROFILE SIMULATIONS AND RESULTS

The 2100 winter design profile was simulated using a discharge of 9,130 m^3/s at Mission, corresponding to the estimated 200-year winter flood, in combination with the specified increased winter ocean level of 4.5 m at the four outlets of the Fraser: the North, Middle and Main Arms and Canoe Pass. The model was then re-run using the freshet discharge of 18,900 m^3/s at Mission and an ocean level of 3.6 m at the outlets. The two sets of profiles where superimposed and the higher one selected for the design profile.

The resulting design profiles are tabulated in Table 1 (to Geodetic Datum). Corresponding chainage locations are shown in plan-view on Figure 1. Longitudinal profiles are plotted for the North Arm (Figure 2), Middle Arm (Figure 3), Main Arm (Figure 4) and Canoe Pass/Ladner Reach (Figure 5). The figures show the intersection points where the governing profile changes from the winter to the freshet profile. Downstream of New Westminster, the winter design condition will result in higher water levels for all four distributary channels. As the ocean levels rise, the winter design profile will govern over an increasingly longer reach.

The tabulated and plotted water levels do not include a freeboard allowance. Current MOE standards call for a freeboard allowance of 0.6 m to be added to the estimated Fraser River design water levels to obtain Flood Construction Levels (FCL's).

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[2] Ausenco Sandwell 2011. Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use, Guidelines for Management of Coastal Flood Hazard Land Use, for BC Ministry of Environment, 27 January 2011, 22pg.

Table 1: Summary of year 2100 design profile water levels (no freeboard).

Location		Design Profile Water Levels (m GSC)
Branch	Chainage	Year 2100
North Arm	0	4.50
North Arm	13848	4.50
North Arm	15139	4.55
North Arm	17298	4.63
North Arm	18800	4.69
North Arm	20147	4.75
North Arm	22157	4.83
North Arm	24147	4.91
North Arm	25961	4.98
North Arm	27707	5.05
North Arm	29110	5.10
North Arm	31097	5.18
Middle Arm	0	4.50
Middle Arm	14066	4.50
Main Arm	0	4.5
Main Arm	9163	4.53
Main Arm	11980	4.53
Main Arm	15210	4.55
Main Arm	18508	4.57
Main Arm	21371	4.59
Main Arm	24152	4.61
Main Arm	27194	4.62
Main Arm	28002	4.63
Main Arm	28768	4.63
Main Arm	30284	4.83
Main Arm	32742	5.16
Main Arm	34089	5.35
Main Arm	36537	5.69
Main Arm	39151	6.04
Main Arm	43031	6.55
Canoe Passage	0	4.50
Canoe Passage	5564	4.52
Canoe Passage	8065	4.53
Canoe Passage	11783	4.54
Ladner Reach	5274	4.54
Ladner Reach	7171	4.55
Ladner Reach	8849	4.55

4 MODEL LIMITATIONS

NHC outlined limitations of the Fraser River Hydraulic Model[3]. The accuracy of water levels and other output data is limited by:

- The accuracy of the flow and water level data used for calibrating and validating the model.
- The range of flow conditions the model was calibrated to. The freshet design discharge is about 60% greater than the calibration flow recorded in 2007 and at this significantly higher flow, assumptions must be made regarding the hydraulic roughness. The same applies to other discharges that are greater and lower than the calibration flow.
- Topographic changes that occur in the channel and on the floodplain over time in response to degradation/aggradation, new infrastructure such as bridges or dikes etc. (Predicting river conditions nearly a century into the future is difficult. Dredging is assumed to continue, with removal volumes roughly equalling deposition.)
- Changes in flow confinement due to potential breaching of dikes or overbank spills. The model assumes that existing dikes have been raised so that the flow is fully confined.
- A fixed-bed channel geometry, which does not reflect changes due to scour during high flows.

Use of the profile data provided assumes recognition of the above limitations. Background information on the modelling is provided in NHC's 2006 and 2008 reports.

* * * * *

If you have any questions or require additional information, please do not hesitate to contact us at 604.980.6011.

Sincerely,

northwest hydraulic consultants ltd.

Prepared by:	Reviewed by:
original signed by	*original signed by*
Vanessa O'Connor, P.Eng. Hydraulic Engineer	Monica Mannerström, P.Eng. Associate

Cc: Mr. Thomas Reeve, Water Division - Delcan Corporation
4710 Kingsway, Suite 2300, Burnaby, B.C. V5H 4M2

[3] NHC, 2008. Fraser River Hydraulic Model Update – Final Report. Report prepared for BC Ministry of Environment.

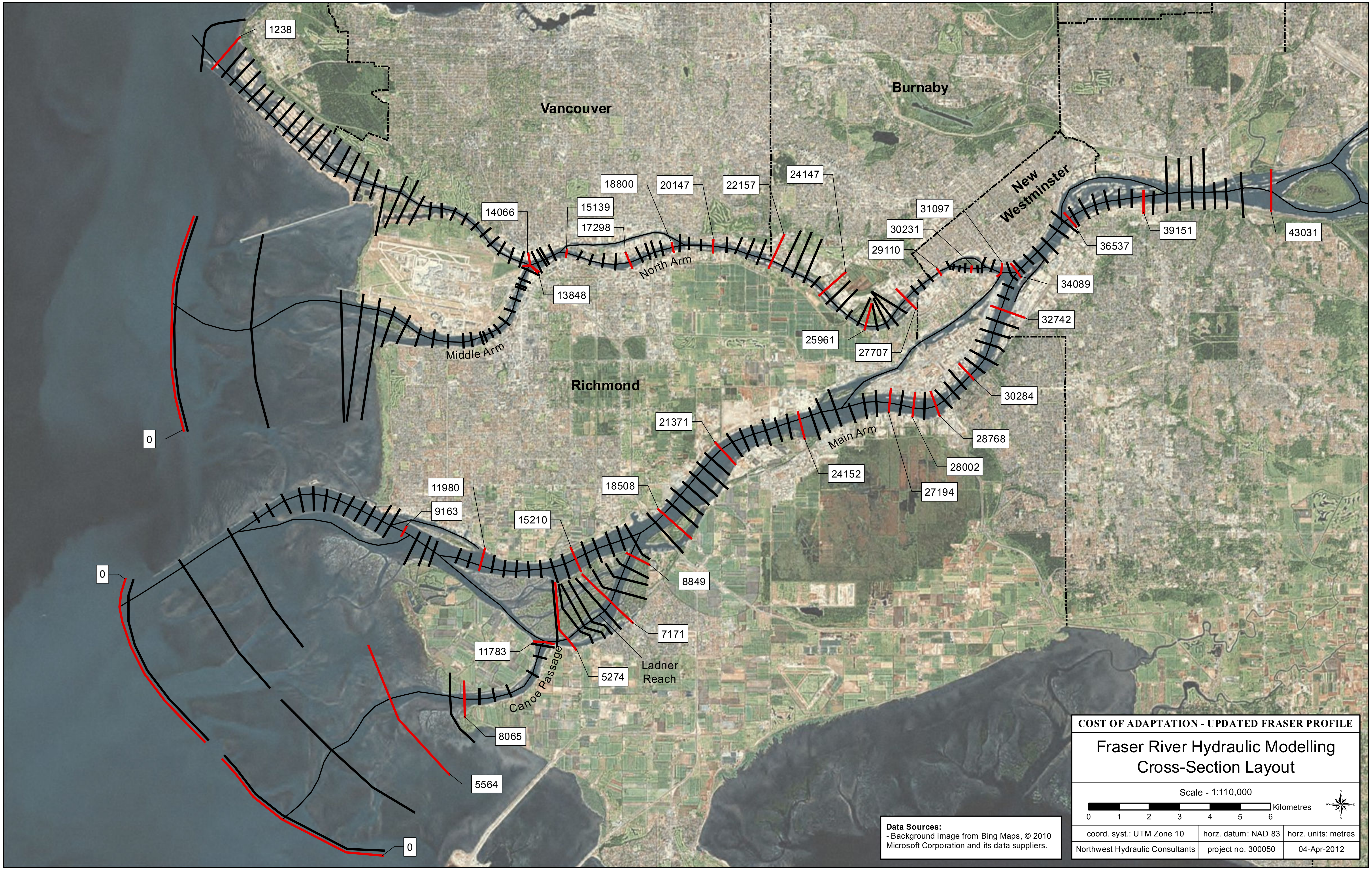

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Figure 1

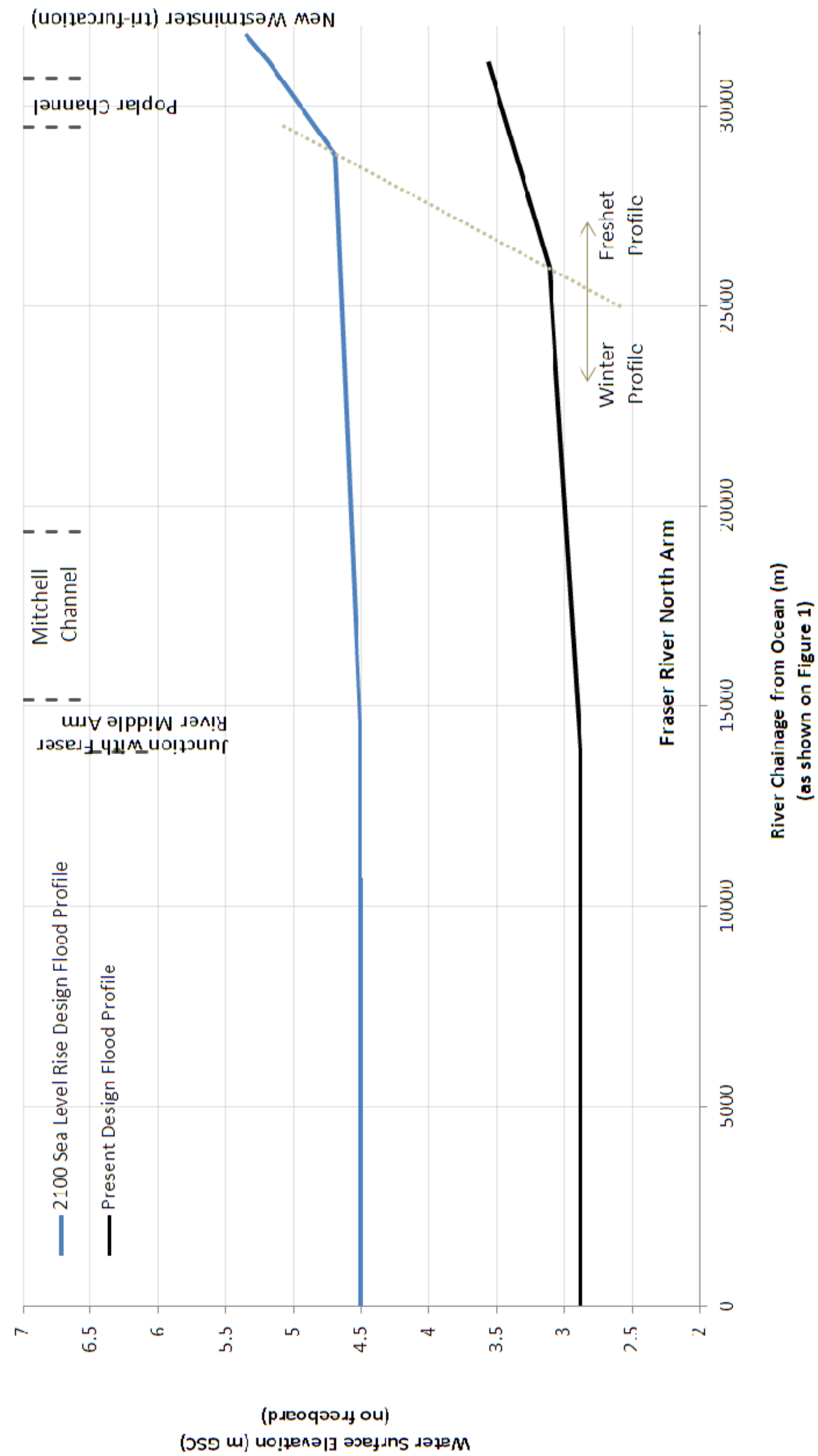

Figure 2: Design Flood Profiles
Fraser North Arm

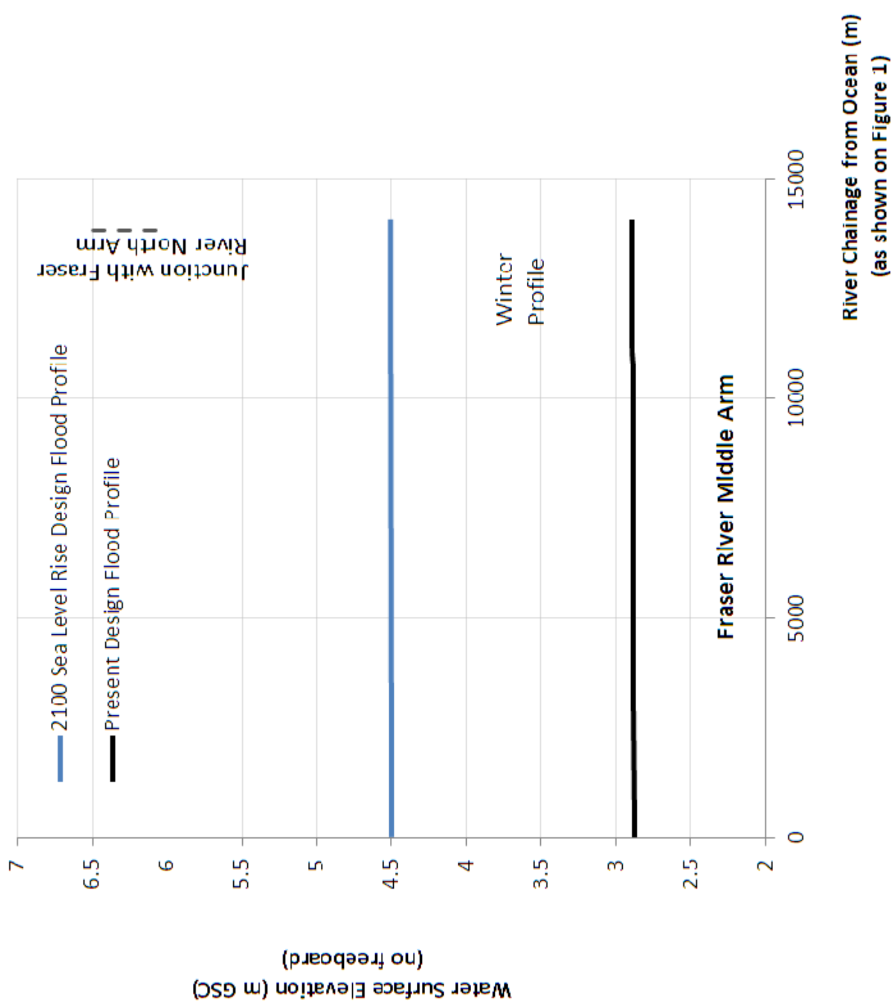

Figure 3: Design Flood Profiles
Fraser Middle Arm

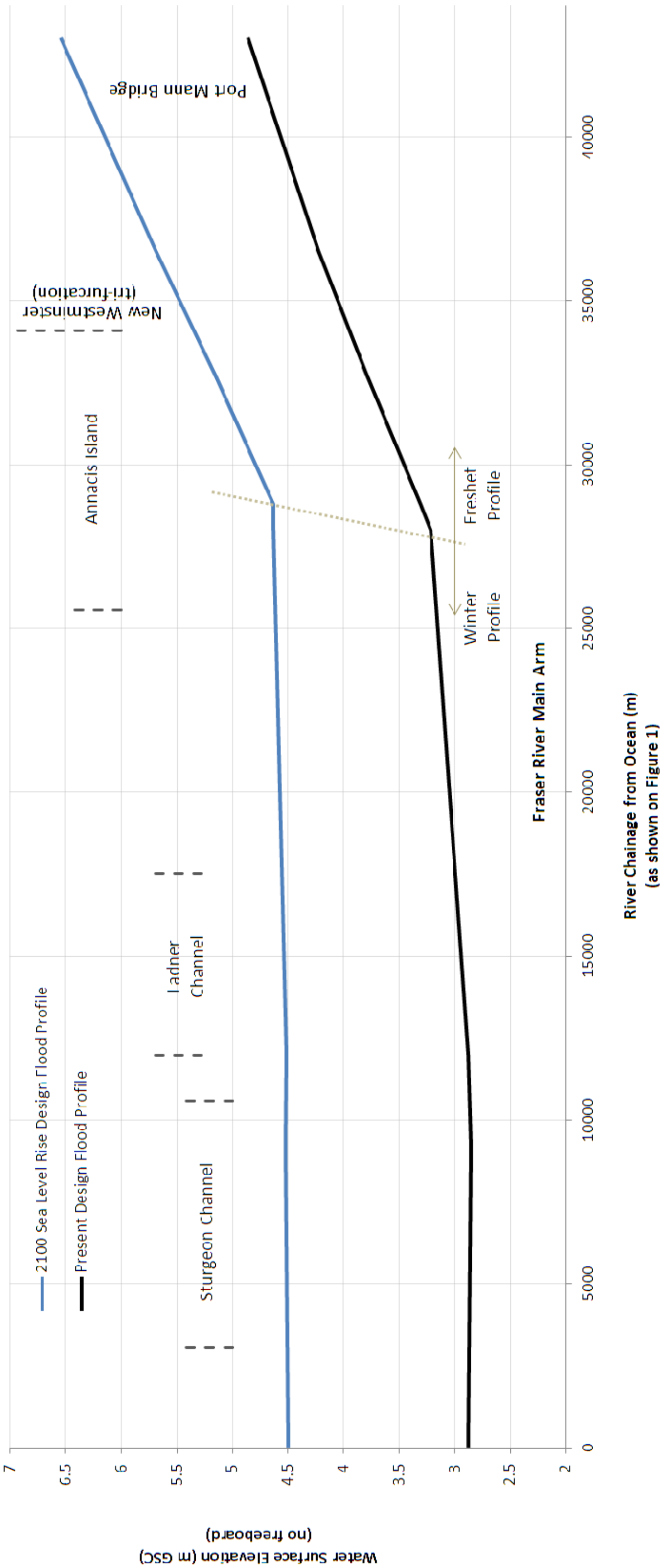

Figure 4: Design Flood Profiles
Fraser Main Arm

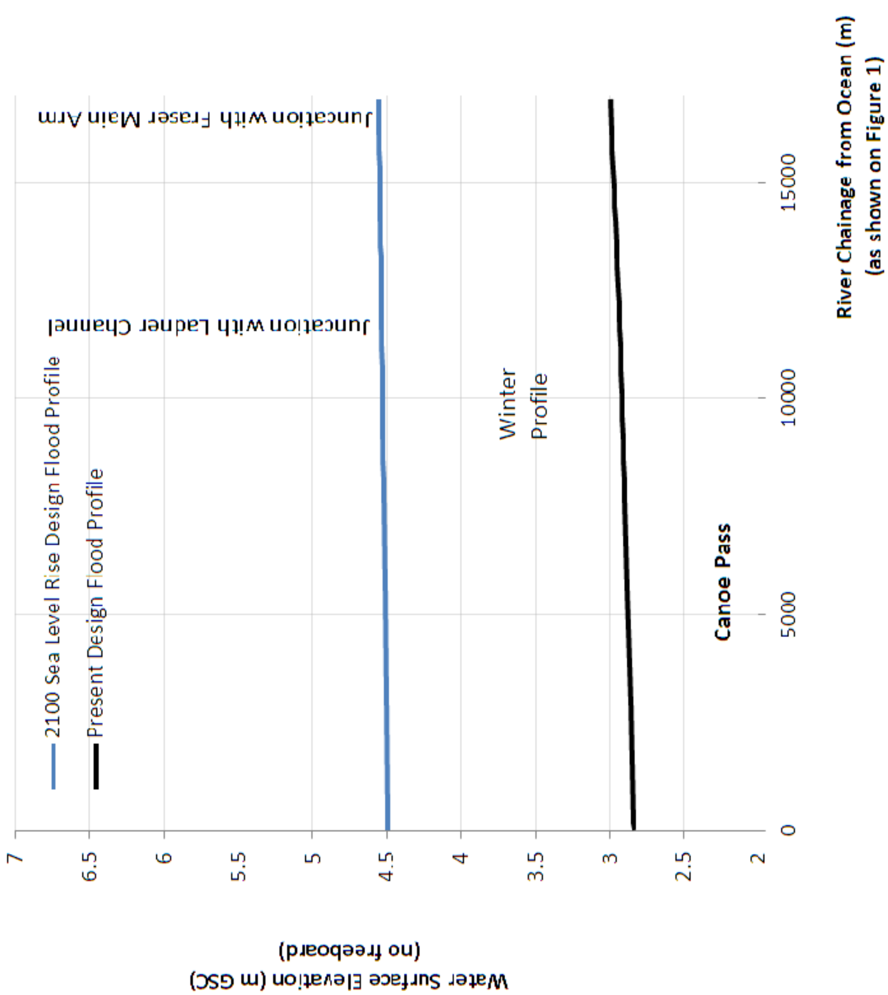

Figure 5: Design Flood Profiles
Canoe Pass and Ladner Reach

Appendix B

Geotechnical Assessment

THURBER ENGINEERING LTD.

October 10, 2012 File: 17-454-113

Delcan Corporation
Suite 2300, 4710 Kingsway Avenue
Burnaby, BC V5H 4M2

Attention: Mr. Thomas Reeve, P.Eng.

FRASER RIVER FLOOD CONTROL DYKES -
SEA LEVEL RISE AND SEISMIC DESIGN GUIDELINES
GEOTECHNICAL ASSESSMENT

Dear Sirs:

In 2011, the Inspector of Dykes (IoD) for BC issued two new sets of guidelines for the design and construction of flood control dykes (i) to address sea level rise and (ii) to mitigate the effects of seismic events on dyke integrity. The IoD has since retained Delcan Corporation and Thurber Engineering Ltd. (TEL) to undertake a high level overview study to develop approximate costs for adopting both sets of guidelines for the Fraser River flood protection works. The study area comprises the Fraser River dykes, downstream of the Port Mann Bridge, including the West Dykes along the Richmond and Delta shorelines. This report provides our comments and recommendations regarding the geotechnical aspects of both sea level rise and seismic issues.

Use of this report is subject to the attached Statement of Limitations and Conditions.

1. BACKGROUND

1.1 Seismic Design Guidelines

The requirements for the design and construction of flood control dykes in BC were originally documented in a report entitled "Dike Design and Construction Guide, Best Management Practices in British Columbia", dated July 2003. In that report, it was noted that, other than for major pumping facilities, dykes and dyke structures were historically not designed for earthquake forces. The report stated that the guidance was essentially due to the economic impact of implementing seismic mitigation measures. In the 1970s and 1980s, the Fraser River Flood Control Program rationalized the practice on the basis of the rare chance of occurrence of a major flood peak simultaneously with a large earthquake.

In November 2010, interim guidelines were put in place that required the design of dykes to consider the effects of seismic activity on the integrity of the structure and required the Owner to demonstrate that it would be possible to re-construct the dyke within 6 months of the earthquake to retain a 1:10 year return period flood.

While re-construction may be feasible for discrete, short sections of dyke, re-construction of the dykes or repair of widespread damage throughout the dyking system may not be practical when dyke re-construction will be competing for resources for re-construction of other, possibly more critical, infrastructure such as water supply, sewer, roads and bridges. If the dykes cannot be repaired promptly, large sections of the community in low lying areas would be vulnerable to flooding, even due to low return period events.

To mitigate this risk, the IoD issued new guidelines in August 2011 that required consideration of seismic effects in the design of sections of new dyke or dyke upgrading and specified a level of required dyke performance in terms of vertical and lateral dyke deformation in response to three different levels of earthquake events. The deformation criteria are given in Table 1.

Table 1. 2011 Deformation Criteria in 2011 Seismic Design Guidelines

Performance Category	Earthquake Shaking Level (Return Period Yrs)	Maximum Allowable Vertical Displacement (mm)	Maximum Allowable Horizontal Displacement (mm)
A	1:100	<30	<30
B	1:475	150	300
C	1:2,475	500	300 – 900

Additionally, in Performance Category A, there should be no significant damage to internal structures and post-seismic flood protection ability must not be compromised. Performance Category B permits some repairable damage to internal structures but post-seismic flood protection ability must not be compromised. In Performance Category C, significant damage to internal structures would be expected and post-seismic flood protection ability may possibly be compromised. In all cases, the dyke must have adequate post-earthquake free-board relative to the design flood level to meet performance expectations.

1.2 Sea Level Rise Guidelines

For the purpose of this project, global sea level rise and dyke design methodology are consistent with the "Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use" (Ausenco Sandwell 2011). The dyke crest elevations established for this study contemplated the anticipated sea level rise for the year 2100.

The new design level will accommodate a combination of sea level rise, maximum high tide, storm surge and wave impacts. For areas up the Fraser River, it will also address flood level during a winter storm surge event and/or a spring freshet impacted by sea level rise.

In essence, the guidelines result in an increase in dyke crest height to accommodate sea level rise due to climate change, storm surge and set-up and wave action and will apply higher water levels to the water side of the dyke and result in higher groundwater pressures in the dyke foundation and landside subgrade soils. Geotechnical input is provided for the design and construction of higher dykes and the effects of higher groundwater levels on the dyke and landside facilities.

1.3 Project Limitations

As discussed in the following sections of the report, there are a wide range of geotechnical and geometric conditions along the many kilometres of dyke within the study area. However, due to the overview nature of this study and the limited funding resources available, it was necessary to make many simplifying assumptions regarding these factors. Furthermore, numerical analysis of mitigative measures could not be completed within the project scope. Therefore, the comments and suggested remedial measures given herein to provide conformance with the Guidelines are primarily based on experience and must be considered as conceptual in nature and site specific investigation, analysis and design must be carried out for each section of new dyke or dyke upgrading in the future. This report is not intended to serve as a design guide for future dyke design and/or construction.

With respect to construction of mitigate measures for sea level rise, we have assumed that the dykes will be raised to the ultimate design elevation incrementally over many years thus reducing the build-up of construction pore pressures in the soft foundation soils.

The existing Fraser River dykes have been constructed over the past 100 years and the design and construction methodology used for many of the dykes is unknown. The upgrades completed under the Fraser River Flood Control Program in the 1970s and 1980s are documented on the as-constructed drawings available from the MFLNRO website. However, identification or definition of the quality of the existing dykes was not in our scope of work.

There are several different mitigative methods to reduce dyke deformation to within the criteria set by the 2011 Seismic Design Guidelines. The scope of the study did not permit site specific assessment of the most appropriate method for each section of the dyke alignment. Due to the limitations on our scope of work, we have considered use of only two common ground improvement techniques, vibro-replacement and deep soil mixing, in our assessment.

The Guidelines permit the use of site specific numerical analysis as well as providing prescriptive procedures based on the 2010 National Building Code of Canada to assess seismic response. The prescriptive procedures yield conservative results with peak ground accelerations well in excess of what would be predicted using numerical analysis, particularly for large earthquake events. However, completion of site specific analyses along the entire dyke alignment was not possible within the constraints of this study. Notwithstanding, we have used judgement based on our experience and previous reports prepared by others in the study area in our assessment of the seismic response rather than following the prescriptive procedure.

Although the Guidelines are relatively stringent in terms of displacement, they do not specify where the horizontal and vertical displacements are to be applied e.g. the entire dyke or the dyke crest only. We have assumed that the intent is to protect the dyke crest and upper portions of the dyke slopes and that larger displacement of the lower portions of the dyke slopes would be acceptable.

There is highly variable ground topography on the landward side of the dyke. It was not possible to take consideration of local landside geometry in this overview study.

2. PROJECT SETTING

2.1 Surficial Geology

The majority of the dykes that comprise the flood protection system for the Lower Mainland are located near the top of bank of the major channels of the Fraser River.

The Fraser River delta was formed by the deposition and aggradation of sand and silt since de-glaciation over 9,000 years ago. Dykes along the edges of the river channels are therefore typically underlain by these alluvial sand and overbank silt materials. Based on surficial geological mapping and our experience with geotechnical investigations throughout the delta, the typical soil profile along the channel margins typically comprises 2 to 6 m metres of silt which is firm near surface becoming soft with depth, overlying a deposit of loose to compact sand varying from about 10 to greater than 40 m in thickness. The sand is generally underlain by a thick deposit of silt, often interbedded with thin sand layers. The silt is underlain by very dense pre-glacial deposits at depths of less than 50 m along the perimeter of the delta to 300 m or more in the central area of the delta. The pre-glacial deposits are considered “firm ground” from a seismic design perspective.

The groundwater table is typically close to the ground surface and it varies in response to rainfall, drainage, tidal and/or flood level in the river. While the soil pore pressure response time lag for tidal fluctuations is short, especially in the sands, the amplitude of the groundwater variation becomes progressively subdued with distance from the river.

Drawing 17-454-113-1 shows the alignment of the existing dykes overlain on the surficial geology mapping of the Lower Mainland. For this study, where the dykes overlie units F_b and F_c, the dyke foundation has been assumed to comprise about 3 m of silt overlying 10 to 40 m of potentially liquefiable sand. Where the dyke is underlain by unit SA_b and $SA_{d,}$ the foundation has been assumed to comprise thick deposits of peat, organic silt and silt from 10 to up to 30 m depth, underlain by loose to compact alluvial sand.

2.2 Seismic Response

The 2011 Design Seismic Design guidelines require consideration of three levels of seismic event namely the 1:100, 1:475 and 1:2,475 year return period earthquakes. The severity of the earthquake shaking, for engineering purposes, is represented by the magnitude of horizontal ground acceleration (as a % of g) and the duration of shaking. Natural Resources Canada provides estimates of spectral and peak ground accelerations (PGA) for sites throughout Canada. Liquefaction triggering analysis uses the surface PGA to assess the likelihood of seismically induced soil liquefaction.

During earthquake shaking, where there are thick deposits of soft or loose soil overlying firm ground, the vibrations transmitted to the soil column can be amplified or de-amplified as the shear stresses travel upwards from the firm ground to the ground surface. The magnitude of amplification or de-amplification is dependent on a number of factors including severity of the firm ground shaking, the layering of the soil profile and the thickness of the soft or loose sediments over firm ground. Since these factors vary greatly across the delta, there is no unique value of amplification that can be adopted for this overview level of study. PGAs and a range of amplification values for these earthquakes, based on the work of Idriss (1991), the National Building Code of Canada (2010) and experience with site specific response analysis, are given in Table 2. A site specific response analysis of the ground accelerations should be carried out for each specific section of dyke for detailed design of new dykes and dyke upgrading.

Table 2. Seismic Response

Return Period	PGA (g)	Amplification Factor		Resultant PGA (g)	
		2011 Seismic Design Guidelines[1]	Numerical Analysis Method	2011 Seismic Design Guidelines[1]	Numerical Analysis Method
1:100	0.124	2.1	N/A	0.26	0.26
1:475	0.265	2.1	0.8 – 1.4	0.55	0.26 – 0.37
1:2,475	0.502	2.1	0.6 – 1.0	1.05	0.3 – 0.5

(1) From prescriptive seismic response analysis method in 2011 Seismic Design Guidelines and based on the 2010 National Building Code of Canada

Table 2 indicates that the resultant PGA for the 1:2,475 earthquake is expected to be on the same order of magnitude as a 1:475 year event. However, the larger earthquake is expected to last much longer, on the order of 2 minutes, than the 1:475 event, which is expected to last on the order of 20 to 30 seconds. It is generally expected that shaking will have largely ceased by the time the soil has liquefied in the 1:475 earthquake whereas shaking is expected to continue after the onset of liquefaction in the larger event. Therefore, more severe damage and ground movements are expected as a result of the 1:2,475 earthquake than the 1:475 earthquake, despite the similar PGAs.

2.3 Dyke Geometry

The crest elevation of the existing dykes varies along the river with the crest elevation increasing in the upstream direction. The majority of the dykes in the study area are located along the lower reaches of the river, the front of the delta and along Boundary Bay. In these areas the dyke crest is typically between about El. 3.3 and 3.5 m and the ground surface on the landward side is at about El. 1.5 m. There are many areas where the dyke crest and ground surface differ from these levels. However, for this overview study, these are considered to be the typical geometric conditions upon which this assessment was based.

The IoD dyke inventory of existing dyke records a dyke as being “standard” or “non-standard” based, in part, on the dyke slope and crest geometry. The standard dyke geometry comprises a 2.5H:1V riverside slope, a 4 m wide crest and a 3H:1V landside slope. Minor modifications to the standard dyke geometry are common on a site-specific basis depending on the presence of riprap armour, flatter slopes for stability and/or filter drains, ditches or relief wells for seepage control.

3. SEISMIC DESIGN OF DYKES

3.1 Effects of Earthquake Shaking on Fraser Delta Deposits

Shaking of loose granular soils generally causes these soils to compress. Below the water table, this compression of the soil matrix causes a build-up of pore water pressure in the soil which, if severe enough can result in near total loss of soil strength. This phenomena is referred to as seismically induced soil liquefaction. The soil behaves as a viscous liquid with a strength that is in the order of 10% to 20% of the pre-liquefied strength. The effects of shaking on fine grained soil may not be as severe but most soft, sensitive silts will experience cyclic mobility and strain softening, also resulting in a loss of strength but likely on the order of a 20% reduction in strength.

The results of liquefaction include the following:

- Flow slides where soil liquefaction occurs below steep river bank slopes
- Post seismic ground settlement that occurs as the pore water pressures in the sand dissipate after shaking
- Lateral ground movement (lateral spreading) of gently sloping ground
- Floating of manholes and other underground chambers and pipes
- Crust rupture and formation of sand boils

During shaking but prior to the onset of liquefaction, the body and slopes of the dyke experience horizontal inertial forces that could also cause instability of the dyke slopes. However, since most dykes in the Lower Mainland are relatively low and the slopes relatively flat (2.5H:1V to 3H:1V), the risk of slope instability by this mechanism alone is relatively low provided the dykes have been well constructed using good construction techniques and materials.

From our experience with liquefaction assessments throughout the Lower Mainland and from a number of reports by others provided to us for this study, extensive liquefaction of the alluvial sand deposit is expected in both the 1:475 and 1:2,475 return period earthquakes. Prediction of the depth of liquefaction is difficult due to the effects of amplification/de-amplification and there is also uncertainty with prediction of soil behaviour below about 25 m depth. This is not to say that liquefaction below this depth does not occur. It simply means that there is limited evidence to correlate our predictions with actual soil behaviour at depth in an earthquake event. However, it is not unreasonable to assume that liquefaction could occur at depths on the order of 25 m or more throughout the delta.

When liquefaction occurs in the dyke foundation soils, flow slides are expected where the dyke is adjacent to a steep river channel slope, lateral spreading may occur in areas of gentle sloping ground and post-seismic ground settlement is expected along the majority of the dyke alignment. Other negative impacts on pumping infrastructure and pipes below the dykes may also occur.

Liquefaction can be prevented or limited by ground improvement. There are several methods of ground improvement that could be utilized depending on the soil conditions and these are described in detail in the 2011 Seismic Design Guidelines and have not been repeated herein. However, the two most common methods in the Lower Mainland are vibro-replacement to densify loose sand deposits and deep soil mixing to strengthen soft, fine grained soils.

Based on estimates provided by local contractors experienced in these techniques, the cost of ground improvement treatment is estimated to be on the order of \$10 - \$20 /m^3 for vibro-replacement and \$250 /m^3 for deep soil mixing. These costs should be considered approximate as there are a number of site specific factors that would impact the cost at any particular site such as dimensions of the zone to be treated, management of fines laden water generated at the surface during densification, site access and potential damage to adjacent structures. The costs are in 2011 dollars. The volume of treatment can be estimated per lineal metre of dyke by multiplying the width of the ground improvement zone by the depth of improvement. Recommendations for these dimensions are given later in the report.

3.2 Estimated Ground Surface Displacement

3.2.1 Settlement

Drawing No. 17-454-113-1 can be used to delineate sections of dyke that are expected to be underlain by (i) F_b and F_c units (thin silt layer overlying sand) hereafter referred to as Soil Profile A and (ii) SA_b and SA_d thick deposits (thick fine grained and possibly organic soil over sand) hereafter referred to as Soil Profile B. For analysis and design of remedial works, these sections have been sub-divided into reaches where the dyke is adjacent to mudflats or gently sloping ground (Sections A1 and B1) or to a steep river channel bank (A2 and B2).

Post-seismic settlement is typically estimated to be 2% to 5% of the thickness of the liquefied layer(s). Since the allowable vertical displacement in the 1:475 year return period earthquake is 150 mm, the maximum thickness of liquefiable soil would be on the order of 3 to 7.5 m to satisfy the vertical displacement criterion in the Guidelines. In our experience and the aforementioned reports by others, the thickness of the liquefiable zone is typically much greater than 7.5 m. A possible option, subject to approval by the IoD, would be to overbuild the dyke crest elevation to accommodate potential future settlement. In the absence of this approval, where the dyke is underlain by Section A soil profile, ground improvement, as described above, will be required to satisfy the guidelines regardless of the risk of lateral ground movement.

As a minimum and where flow slides are not expected to occur, the depth of densification could be limited to about 10 m to reduce the magnitude of potential settlement to within the criterion set by the 2011 Seismic Design Guidelines. Figure 2 shows the approximate extent of ground improvement to mitigate potential settlement where the risk of flow slides and lateral spread is low. Site specific investigation and analysis will be required for final design and construction of mitigative measures to reduce potential settlement. For the purpose of this assessment, we suggest that the depth of densification assumed for cost estimating be 10 m.

Post-seismic settlement is not expected to be excessive where the dyke is underlain by Soil Profile B.

3.2.2 Flow Slides

Flow slides result where the residual soil strength after liquefaction of loose sand is insufficient to resist the shear stresses that exist in the underlying soil due to the ground surface slope profile. Flow slides are most likely to occur where the dyke is founded over Soil Profile A and the is adjacent to a steep, relatively high river channel banks such as a shipping channel or along a section of river bank that is being actively eroded by the river. Flow slides result in very large lateral ground movements that would greatly exceed both the horizontal and vertical displacement criteria in the 2011 Seismic Design Guidelines.

Flow slides are not expected where the submarine slopes are in soft silt, although seismic shaking could induce slope instability depending on the severity of soil strength degradation during shaking, the slope inclination and earthquake intensity. Although there is some bathymetry information available to determine the actual slopes along the river channels at this time, the limited scope or our work precludes assessment of the wide range of submarine river slope conditions and soil strengths inputs that impact the risk of instability in this soil profile.

Flow slides can be resisted by preventing liquefaction and increasing the soil strength. Where the foundation comprises Soil Profile A (thin silt over a thick deposit of loose sand), vibro-replacement would be an appropriate mitigative method. The depth of densification should extend to the depth of potential liquefaction. Based on our experience, the typical depth of liquefaction is on the order of 20 to 25 m for the 1:475 year. A sketch showing the approximate extent of densification is given in Figure 1. For the purpose of this project, we suggest that the cost estimate be based on densification to 20 m depth.

As noted above, assessment of the various submarine geometries is not possible within the scope of this study. Therefore, for the assessment of slopes in soft silt, we have assumed that where mudflats are not present in front of the dyke, the river channel slopes downward at about 2H:1V down to the river bottom. This is a relatively severe condition. Where the foundation comprises Soil Profile B, deep soil mixing would be an appropriate mitigative method. The depth of soil mixing should be at least to the depth of the channel base plus at least 10% of the overall bank height. A sketch showing the approximate extent of ground improvement is given in Figure 3.

Site-specific investigation and analysis will be required for final design and construction of the ground improvement measures to mitigate flow slides.

3.2.3 Lateral Spreading

Lateral spreading occurs where the ground liquefies and the static shear stresses are insufficient to cause a flow slide but shear stresses induced by inertial forces from cycles of earthquake shaking result in incremental movement of the soil mass. The magnitude of lateral spreading is significantly less than that which would be expected in a flow slide. There are a number of methods available to estimate the magnitude of lateral spreading ranging from highly analytical to empirical relationships based on measurements taken after previous earthquakes. Notwithstanding, the magnitude of lateral spreading may still be sufficient to exceed the lateral displacement criteria in the 2011 Seismic Design Guidelines.

Lateral spreading can be mitigated using similar techniques as for the mitigation of flow slides i.e. by vibro-densification to the depth of liquefaction.

4. GEOTECHNICAL ASPECTS OF DYKE DESIGN FOR SEA LEVEL RISE

A preliminary application of the guidelines for sea level rise result in flood water levels against the dyke face on the order of El. 4.5 to 5 m (Geodetic) and dyke crest heights varying from El. 6 to 8 m. The increased dyke heights and retained water pressures pose geotechnical issues for design and construction of dyke upgrading. A discussion of the main geotechnical issues involved in raising the dyke crest elevation is given in the following sections.

4.1 Dyke Slope Stability (Static)

The feasibility of raising the dyke crest using the standard dyke geometry to the required crest elevation on the Soil Profile A and B foundation conditions was assessed using limit equilibrium slope stability analyses. Furthermore, we assumed that the ground improvement measures suggested for conformance with the 2011 Seismic Design Guidelines have been implemented, thus improving the dyke foundation strength in the improved ground zones. Using assumed soil strength parameters based on experience, the analyses indicate that adequate Factors of Safety (FS) are obtained for the standard dyke slope geometry for Soil Profile A. Where the dyke would be founded over Soil Profile B, the FS obtained was marginal and highly dependent on the soil strength parameters input into the analysis. An acceptable FS is obtained for Soil Profile B if fully drained soil strength parameters and stabilized groundwater conditions are used in the analysis as would be appropriate if the dyke is raised incrementally over a number of years. It may be necessary to construct a toe berm to increase the FS to conventionally accepted levels if the dyke crest is raised rapidly. The toe berm required could be on the order of 15 m wide and up to 2.5 m high.

It should be noted that where the dyke is underlain by Soil Profile B, special construction procedures, such as installation of wick drains and staged construction, may be necessary to construct the dyke to the design crest elevation.

4.2 Piping

Piping and soil erosion are phenomena where seepage through a dyke or its foundation exits the landward side and where the seepage exit gradient is sufficiently high to cause erosion and loss of material at the exit point. As material is removed from the exit point, the flow path is shortened and the hydraulic gradient (water pressure/flow path length) increased, resulting in transport of more material from the exit point. If left uncontrolled, the process continues with headward internal erosion occurring below the ground surface, ultimately reaching the river-side slope and resulting in a zone of high permeability or an eroded "pipe" through which large volumes of water can flow with even ever increasing erosive power leading to catastrophic failure of the dyke. The location where the water exits the ground surface is commonly referred to as a "boil".

High hydraulic gradients can also be caused by the presence of a zone of high permeability soil in the dyke or foundation. Such a zone would transmit the river side water pressure through the dyke or foundation, shortening the length of the effective seepage path and thus increasing the hydraulic gradient and increasing the risk of piping.

Generally, where an impervious embankment is constructed over a pervious foundation, high exit gradients and piping would not be expected where the average hydraulic gradient is on the order of 0.1 or less. The average hydraulic gradient can be estimated as the differential water pressure between the water and landward sides of the dyke divided by the width of the base of the dyke.

Examination of the standard dyke geometry and the typical foundation conditions indicate that excessive hydraulic gradients are not expected under normal or high water conditions. Hence, the risk of piping is generally considered to be low. However, there may be locations where the presence of a deep drainage ditch or a high permeability zone within the dyke section or the foundation would require special consideration. Site specific investigation and geotechnical assessment is required for each section of new or upgraded dyke.

4.3 Uplift of Landside Low Permeability Cap Layer

If the water pressure in the sand layer underlying the relatively impervious silt layer cap is greater than the weight of the silt layer, uplifting and rupturing of the silt layer may occur, resulting in sand boils or blow outs. Where space is available, the risk of uplift can be mitigated by construction of a landside berm to increase the weight of the cap layer. Alternatively, relief wells can be installed at the landside toe of the dyke to reduce the water pressure on the base of the cap layer. While construction of a berm is a permanent measure and requires virtually no maintenance, additional dyke right of way width is required for construction. On the other hand, relief wells may not increase the required right of way but are expensive to install and require maintenance for continued safe functioning.

Review of a typical dyke section indicates that, under normal operating conditions, uplift is not expected to be sufficient to require remedial measures. However, under maximum flood conditions (high tide and storm surge) the uplift resistance is marginal. Site specific assessment is required to determine the extent of the uplift and resisting forces and, if necessary, relief wells could be installed to address this concern. It would be prudent to include an arbitrary allowance for construction of toe berms for Soil Profile A where the silt cap is thin. We suggest that 10% of the dyke section underlain be Soil Profile A be assumed to require a toe berm. The berm should have similar dimensions to that suggested in Section 4.1.

5. DISCUSSION OF 2011 SEISMIC DESIGN GUIDELINES

Introduction of design guidelines that result in more robust flood protection should be a societal goal and the 2011 Seismic Design Guidelines would most certainly be a major step in that direction. However, as written, we believe achieving the specified performance will be very expensive and will reduce the extent of dyke building/upgrading in the future due to the increased construction costs. Following are some suggestions for consideration by IoD to modify the guidelines to require a more robust dyke design and construction process but at lower cost.

5.1 Focus on Analytical Procedure to Assess Liquefaction Potential

The recent 2011 Seismic Design Guidelines specify dyke performance in terms of vertical and lateral displacement of the dyke and to the level of damage to internal structures. The allowable displacements are relatively small and are considered stringent considering the typical dyke foundation conditions in the Fraser delta. Although most seismic assessments would be carried out using site specific numerical analysis to estimate PGA for liquefaction assessment, the guidelines focus on a prescriptive design process that is extremely conservative. The guidelines do permit use of numerical analysis but this is only mentioned in one sentence in the report. We suggest that the focus of the design process be placed on the use of numerical methods to estimate the PGA and for the liquefaction assessment to obtain more realistic seismic response output. Due to the wide variation of estimated lateral spreading obtained from the various available methods, we suggest that the 2011 Seismic Design Guidelines specify the analytical method for estimation of lateral deformation to ensure a uniform design approach is adopted by the geotechnical engineering community in determining conformance with the guidelines.

5.2 Acceptable Mitigation Methods

The current Seismic Design Guidelines require that the dyke be designed to resist both vertical and lateral movement. We suggest that, where the dyke may not be subject to large lateral movements e.g. where there is an extensive mudflat in front of the dyke that could serve to buttress upstream slope or for secondary dykes distant from a free face, that post-seismic settlement be accommodated by over-building the dyke crest elevation.

5.3 Acceptable Displacement Criteria

As an alternative to specifying the dyke performance in terms of horizontal and lateral displacement, we suggest consideration of adopting a post-seismic dyke performance criterion, such as retention of the full crest width (> 4 m) and the entire downstream slope with no loss of flood level retention. The designer could be required to provide an analysis, using both limit equilibrium and rigorous numerical analytical methods, to predict the post-seismic dyke geometry as assurance that, as a minimum, the dyke crest and slope would be intact after the earthquake event. Notwithstanding, remedial work would still likely be required to the dyke to re-establish the pre-earthquake dyke profile. It should be noted that the suggested revised criterion would be expected to result in lower construction costs but increased remedial costs after a major earthquake. The balance of cost of initial construction vs that of remedial work requires further investigation and assessment.

6. CLOSURE

We trust that this letter is sufficient for your needs. Should you require clarification of any item or additional information, please contact us at your convenience.

Yours truly,
Thurber Engineering Ltd.
David Tara, P.Eng.
Review Principal

October 10, 2012

David Hill, P.Eng.
Principal

Attachments: Statement of Limitations and Conditions
Figures 1 – 4
Drawing No. 17-454-113-1

THURBER

STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This study and Report have been prepared in accordance with generally accepted engineering or environmental consulting practices in this area. No other warranty, expressed or implied, is made.

2. COMPLETE REPORT

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 us by the Client, communications between us and the Client, and to any other reports, writings, proposals or documents prepared by us for the Client relative to the specific site described herein, all of which constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. WE CANNOT BE RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to us by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the document, subject to the limitations provided herein, are only valid to the extent that this Report expressly addresses proposed development, design objectives and purposes, and then only to the extent there has been no material alteration to or variation from any of the said descriptions provided to us unless we are specifically requested by the Client to review and revise the Report in light of such alteration or variation or to consider such representations, information and instructions.

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT OUR WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS WE MAY EXPRESSLY APPROVE. The contents of the Report remain our copyright property. The Client may not give, lend or, sell the Report, or otherwise make the Report, or any portion thereof, available to any person without our prior written permission. Any use which a third party makes of the Report, are the sole responsibility of such third parties. Unless expressly permitted by us, no person other than the Client is entitled to rely on this Report. We accept no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without our express written permission.

5. INTERPRETATION OF THE REPORT

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 this report is delivered on 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. Where 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 us. We have relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, we cannot 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 us. We are entitled to rely on such representations, information and instructions and are not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

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THURBER

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

d) Construction Services: During construction we must be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions 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. RISK LIMITATION

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause an accidental release of those substances. In consideration of the provision of the services by us, which are for the Client's benefit, the Client agrees to hold harmless and to indemnify and defend us and our directors, officers, servants, agents, employees, workmen and contractors (hereinafter referred to as the "Company") from and against any and all claims, losses, damages, demands, disputes, liability and legal investigative costs of defence, whether for personal injury including death, or any other loss whatsoever, regardless of any action or omission on the part of the Company, that result from an accidental release of pollutants or hazardous substances occurring as a result of carrying out this Project. This indemnification shall extend to all Claims brought or threatened against the Company under any federal or provincial statute as a result of conducting work on this Project. In addition to the above indemnification, the Client further agrees not to bring any claims against the Company in connection with any of the aforementioned causes.

7. SERVICES OF SUBCONSULTANTS AND CONTRACTORS

The conduct of engineering and environmental studies frequently requires hiring the services of individuals and companies with special expertise and/or services which we do not provide. We may arrange the hiring of these services as a convenience to our Clients. As these services are for the Client's benefit, the Client agrees to hold the Company harmless and to indemnify and defend us from and against all claims arising through such hirings to the extent that the Client would incur had he hired those services directly. This includes responsibility for payment for services rendered and pursuit of damages for errors, omissions or negligence by those parties in carrying out their work. In particular, these conditions apply to the use of drilling, excavation and laboratory testing services.

8. CONTROL OF WORK AND JOBSITE SAFETY

We are responsible only for the activities of our employees on the jobsite. The presence of our personnel on the site shall not be construed in any way to relieve the Client or any contractors on site from their responsibilities for site safety. The Client acknowledges that he, his representatives, contractors or others retain control of the site and that we never occupy a position of control of the site. The Client undertakes to inform us of all hazardous conditions, or other relevant conditions of which the Client is aware. The Client also recognizes that our activities may uncover previously unknown hazardous conditions or materials and that such a discovery may result in the necessity to undertake emergency procedures to protect our employees as well as the public at large and the environment in general. These procedures may well involve additional costs outside of any budgets previously agreed to. The Client agrees to pay us for any expenses incurred as the result of such discoveries and to compensate us through payment of additional fees and expenses for time spent by us to deal with the consequences of such discoveries. The Client also acknowledges that in some cases the discovery of hazardous conditions and materials will require that certain regulatory bodies be informed and the Client agrees that notification to such bodies by us will not be a cause of action or dispute.

9. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on our interpretation of conditions revealed through limited investigation conducted within a defined scope of services. We cannot 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.

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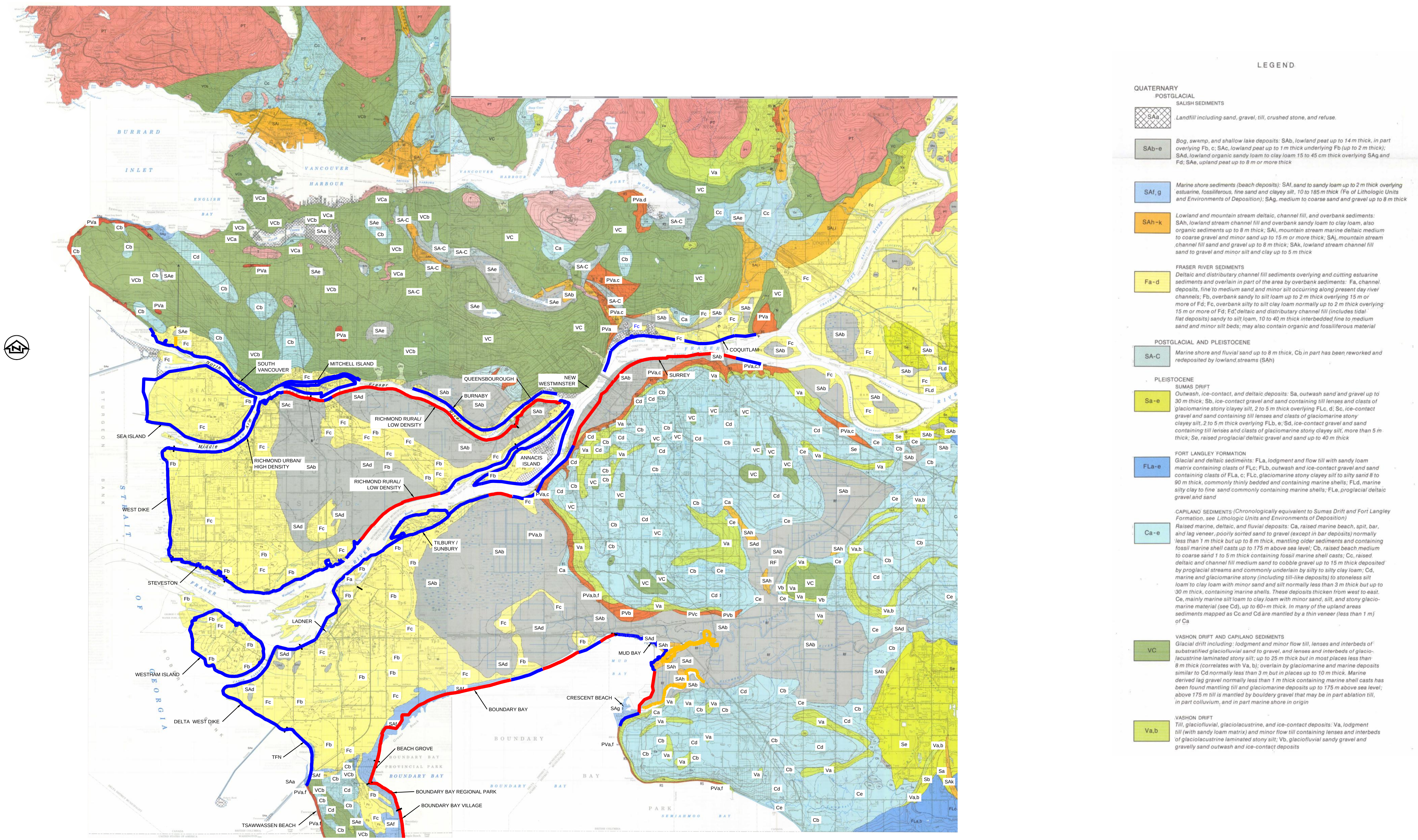

NOTES:

LEGEND:

SOIL PROFILE A

SOIL PROFILE B

DELCAN CORPORATION

DIKE WITH SURFICIAL GEOLOGY MAP

SEA DIKES

BC

THURBER ENGINEERING LTD.

ENGINEER:	DRAWN:	APPROVED:
BSP	JL	
DATE: MARCH 27, 2012	SCALE: 1:200000	DRAWING No. 17-454-113-1

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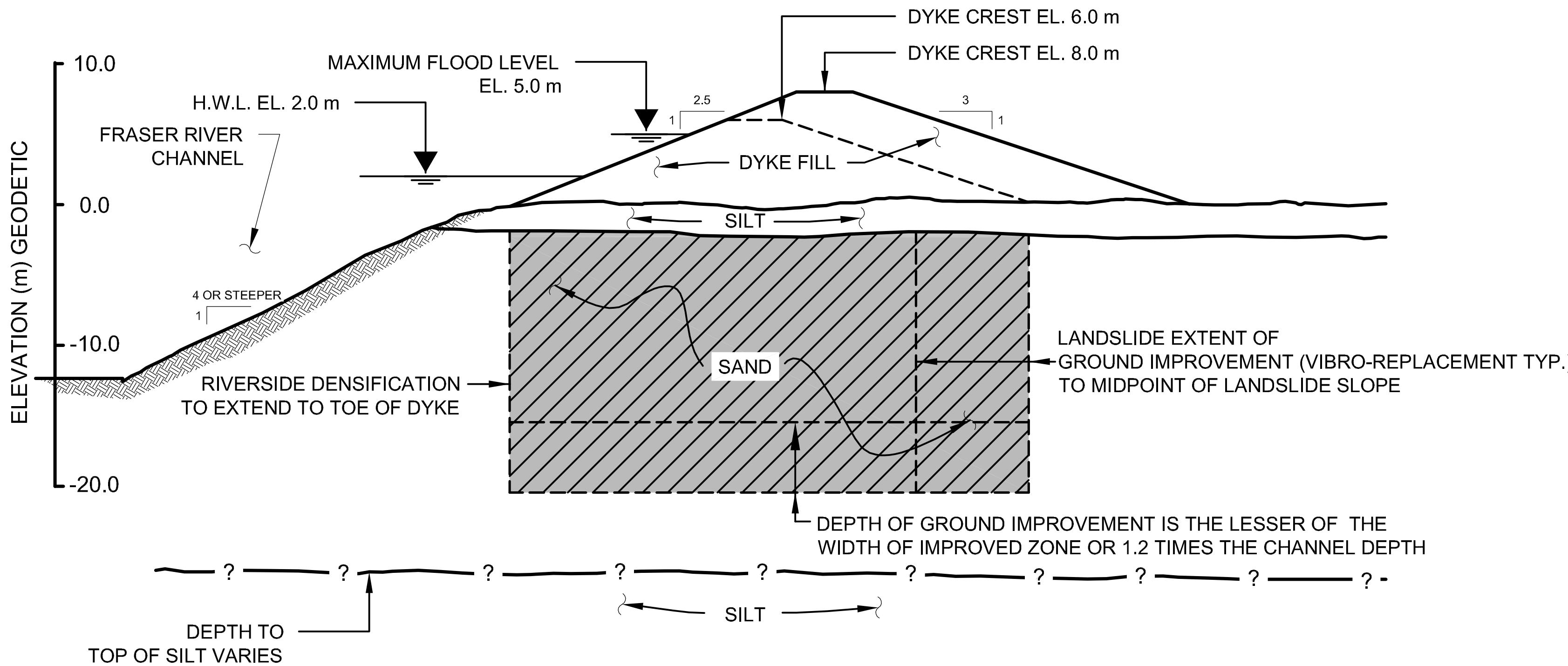

FIGURE 1 SOIL PROFILE A - SECTION A2 - STANDARD DYKE SECTION

LEGEND:

ZONE OF GROUND IMPROVEMENT

DELCAN CORPORATION

CONCEPTUAL EXTENT OF GROUND IMPROVEMENT

SEA LEVEL RISE AND SEISMIC GUIDELINES
COST OF ADAPTATION

B.C.

THURBER ENGINEERING LTD.

ENGINEER : DWH	DRAWN : JL	FILE NO : 17-454-113
DATE : APRIL 2012	SCALE : NTS	FIGURE No. 1

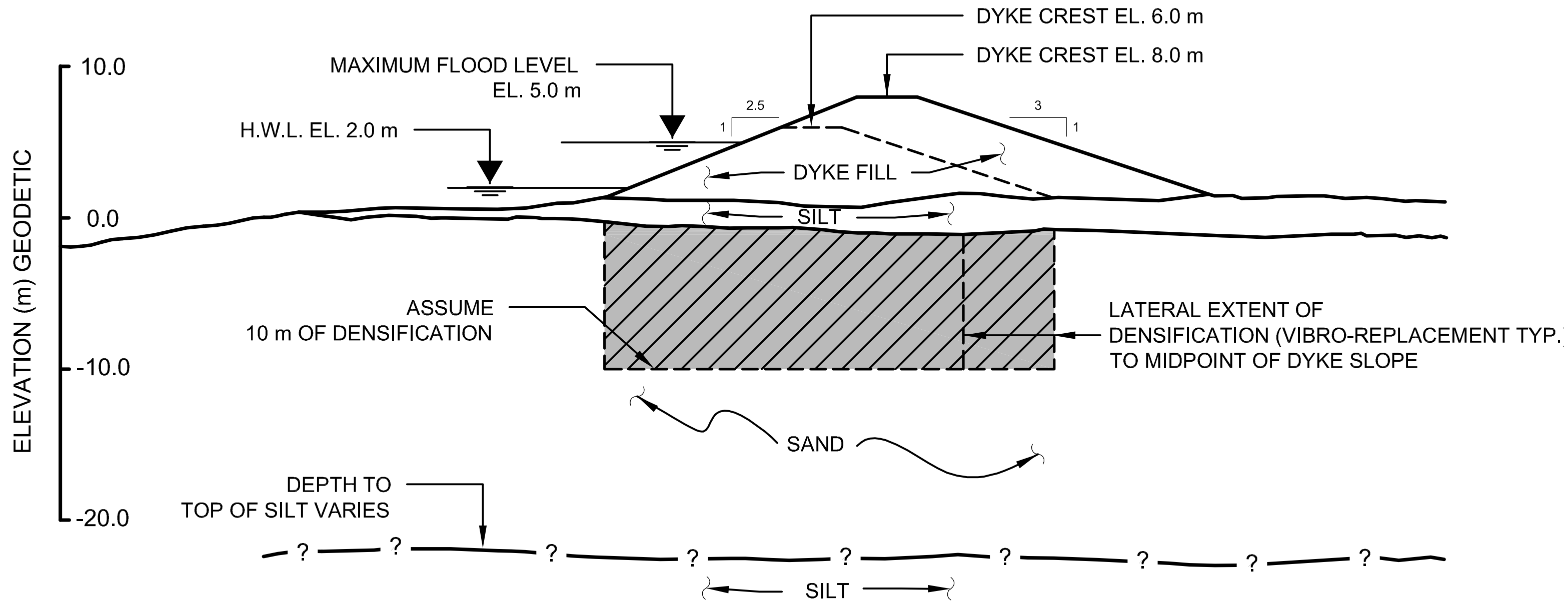

FIGURE 2 SOIL PROFILE A - SECTION A1 - STANDARD DYKE SECTION

LEGEND:

ZONE OF GROUND IMPROVEMENT

DELCAN CORPORATION

CONCEPTUAL EXTENT OF GROUND IMPROVEMENT

SEA LEVEL RISE AND SEISMIC GUIDELINES
COST OF ADAPTATION

B.C.

THURBER ENGINEERING LTD.

ENGINEER : DWH	DRAWN : JL	FIGURE No. 17-454-113
DATE : APRIL 2012	SCALE : NTS	2

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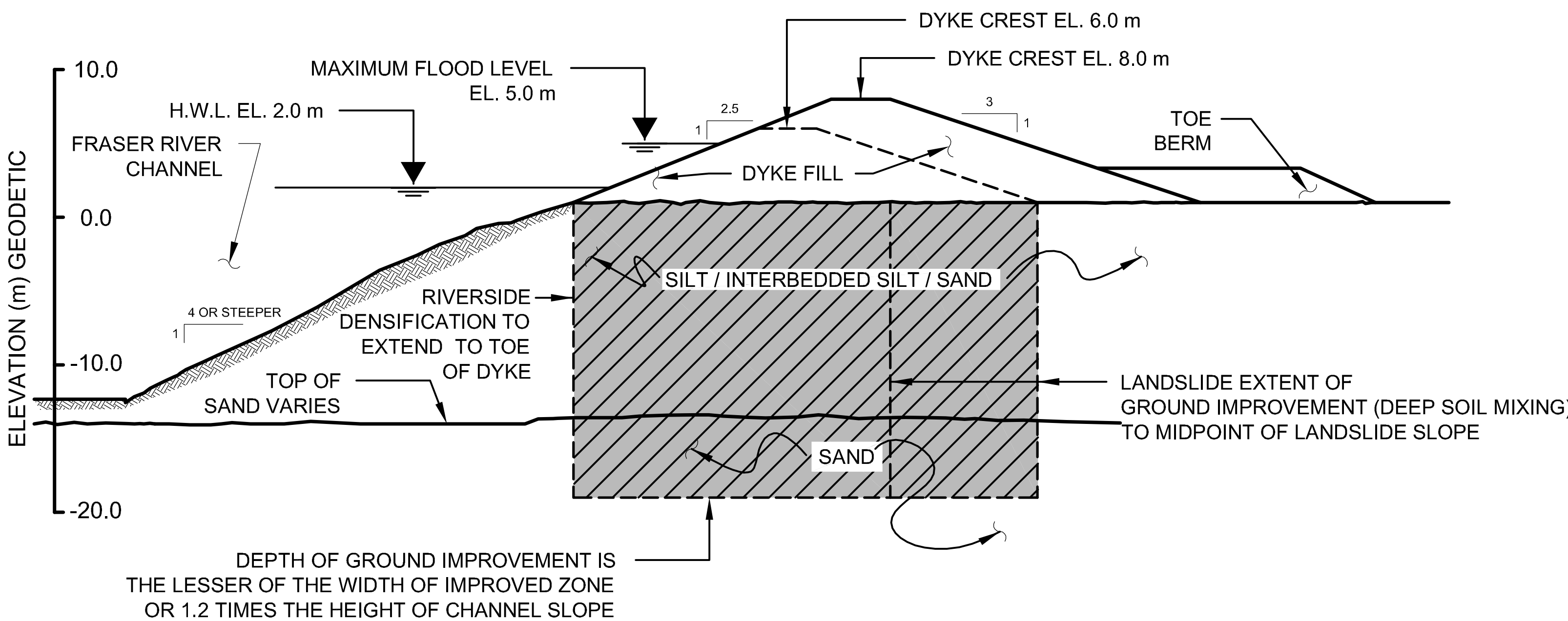

FIGURE 3 SOIL PROFILE B - SECTION B2 - STANDARD DYKE SECTION

LEGEND:

ZONE OF GROUND IMPROVEMENT

DELCAN CORPORATION

CONCEPTUAL EXTENT OF GROUND IMPROVEMENT

SEA LEVEL RISE AND SEISMIC GUIDELINES
COST OF ADAPTATION

B.C.

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ENGINEER :	DRAWN :	FILE NO :
DWH	JL	17-454-113
DATE : APRIL 2012	SCALE : NTS	FIGURE No. 3

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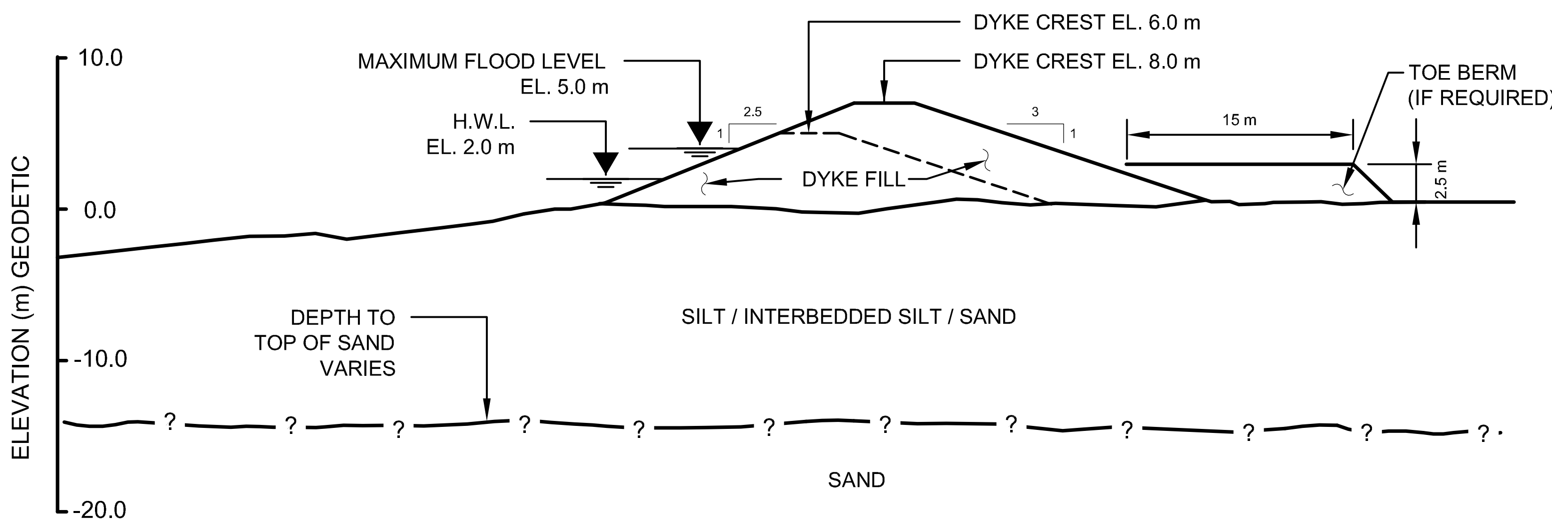

FIGURE 4 SOIL PROFILE B - SECTION 1

LEGEND:

ZONE OF GROUND IMPROVEMENT

NOTES:

DELCAN CORPORATION

CONCEPTUAL DYKE CONFIGURATION

SEA LEVEL RISE AND SEISMIC GUIDELINES
COST OF ADAPTATION
B.C.

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DWH	JL	17-454-113
DATE : APRIL 2012	SCALE : NTS	FIGURE No. 4

Appendix C

Reach Evaluations

Reach Evaluations

The following pages document the option selection process for each reach:

1. Examine all options and eliminate those considered to be technically unfeasible.
2. Consult municipal staff regarding the remaining feasible options.
3. Select the option.

Two workshops were held during the options selection process. These were attended by the project team, relevant municipalities and Provincial representatives, and were an important part of the process. Protection options were discussed in general and the issues around implementation were explored. Each reach was then discussed individually, or in groups of similar reaches, with the use of typical existing and possible future cross-sections. The discussion covered the technical, social and economic challenges that would be faced by municipalities adapting to sea level rise.

The following pages document the option selection. Not all municipalities participated and options selected here are not necessarily indicative of municipal plans or preferences. They should only be used as part of this project.

The reaches where structural protection options were selected have a conceptual cross-section associated with them. These are found in **Appendix D** and the figure number corresponds to the reach number.

Reach #:	1A	Reach Name:	South Vancouver - Southlands

Description: Portions of the Southlands Area in South Vancouver are at risk of flooding from the Fraser River and from storm surges. There are some historic dikes in the area but they have been orphaned and/or are their condition is unknown. The area is a mix of residential and golf course developments.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	An orphaned dike exists on part of the reach. New dike construction is a possibility. Right-of-way is partially existing but not wide enough for a dike.
			B.	Widen footprint to water side	No existing dike.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	A possibility for this reach. Passive land uses could be allowed to flood with commercial/industrial land uses required to develop lot specific flood protection.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	No interest to retreat expressed by staff. First Nations Land and high value land would be a barrier to retreat.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike Construction
Rationale:	While controlling flood risk through implementation of flood proofing is an alternative, a dike would provide more protection of recreation and older developments.

Reach #:	1B	Reach Name:	South Vancouver

Description: This area of South Vancouver is at risk of flooding from the Fraser River and from storm surges. The area is a mix of industrial and commercial land uses. Some new residential construction is occurring near the shoreline and is required to be built to current FCL.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No existing dike. New dike construction is a possibility. Right-of-way is partially existing but not wide enough for dike.
			B.	Widen footprint to water side	No existing dike.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Potentially an option for small portions of the shoreline where access is required to support economic activity.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	A possibility for this reach and already required by the City for some new developments. Commercial/industrial land uses required to develop lot specific flood protection.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	No interest to retreat expressed by staff. Difficult to implement in fairly heavily developed area.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike Construction
Rationale:	While controlling flood risk through implementation of flood proofing is an alternative, a dike would provide more protection of recreation and older developments.

Reach #:	2	Reach Name:	Burnaby

Description: The Burnaby foreshore area is at risk of flooding from the Fraser River or from storm surges. There are some existing non-standard dikes along the foreshore. The development in the floodplain is agricultural, industrial, commercial, and parks.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Non-standard dikes exist. Could be widened and raised.
			B.	Widen footprint to water side	Existing dikes could potentially be expanded to the waterside but in most cases there is aquatic habitat impacted so environmental compensation would be required.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Potentially an option for small portions of the shoreline where access is required to support economic activity.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Has been applied in the past but levels applied are no longer sufficient. The City has determined that this will be a secondary level of protection and dikes will be the primary.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	No interest to retreat expressed by staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike Construction
Rationale:	Although other solutions may be applicable on a smaller scale in this area, dike construction works as an overall strategy for the area.

Reach #:	3	Reach Name:	Queensborough

Description: Queensborough is on the east end of Lulu Island. It is low, flat land and entirely developed into an urban land use consisting of residential, industrial, and commercial.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Standard dikes exist. Could be widened and raised.
			B.	Widen footprint to water side	Dike could potentially be expanded to the waterside but in most cases there is aquatic habitat impacted so environmental compensation would be required.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Potentially an option for small portions of the shoreline where access is required to support economic activity.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Has been applied in the past but levels applied do not cover all developments. The City has determined that this will be a secondary level of protection and dikes will be the primary.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Area fully developed into high value urban land use. No interest to retreat expressed by staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike construction to land side
Rationale:	The Queensborough area is committed to dike construction with FCLs as a potential second level of defence. In some cases, waterside expansion or walls will be preferred but overall land side dike construction has been selected.

Reach #:	4	Reach Name:	New Westminster

Description: New Westminster has a small floodplain along the shore of the Fraser River. In the downtown area there has been dense urban development up to the shoreline. Other areas of New Westminster have industrial development to the edge of the shoreline

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Some non-standard dikes exist. These could be widened and raised. New dikes could have major property impacts.
			B.	Widen footprint to water side	Existing non-standard dikes could potentially be expanded to the waterside but in most cases there is aquatic habitat impacted so environmental compensation would be required.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Existing shoreline floodwalls could be raised to account for higher flood levels. New floodwalls could be constructed where property impacts limit space for dikes.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Floodplain has high value recent development that could not be protected with localized flood proofing.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Area fully developed into high value urban land use. No interest to retreat expressed by staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	D. Floodwall
Rationale:	The existing defences are a shoreline wall with recreation trail, park land or development close to the top. Therefore shoreline walls will be carried forward for the whole reach.

Reach #:	5	Reach Name:	Mitchell Island

Description: Mitchell Island is on a low island on the north arm of the Fraser River. The island is used for industrial land use.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No dike exists. A new dike is possible but could be challenging because of the industry need to have access to the water.
			B.	Widen footprint to water side	No existing dike.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Presently shoreline floodwalls have been constructed in some locations to facilitate access to the water. They do not provide flood protection at present and would be difficult to raise.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Flood proofing by individual properties is possible. Heavy industry historically has been adaptable to accommodate flooding.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Area fully developed into high value land use. No appetite to retreat expressed by staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	H. Flood Proofing
Rationale:	Flood proofing is selected based on consideration for current land use and the nature of the current and potential economic activity.

Reach #:	6	Reach Name:	Richmond Urban High Density

Description: This reach encompasses the portion of Richmond on the North Arm of the Fraser River that has been developed into an urban land use. It is currently protected by standard dikes.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility.
			B.	Widen footprint to water side	Widening to the water side is a possibility in areas where the river bottom not deep close to shore. This is considered a feasible option in area where land side widening has large impacts.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. The City of Richmond currently has flood proofing requirements but perimeter defences are the primary objective.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Area fully developed into high value land use. No appetite to retreat expressed by staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Widen Dike to Land Side
Rationale:	Richmond is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the land side was selected for this option.

Reach #:	7	Reach Name:	Richmond Rural Low Density North

Description: This reach encompasses the portion of Richmond on the North Arm of the Fraser River that has been developed to a low density / rural land use. It is currently protected by standard dikes. The dike is also a roadway.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility.
			B.	Widen footprint to water side	Widening to the water side is a possibility but give the low density, land side improvements are preferred.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. The City of Richmond currently has flood proofing requirements but perimeter defences are the primary objective.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	No interest to retreat expressed by City staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Widen Dike to Land Side
Rationale:	Richmond is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the land side was selected for this option.

Reach #:	8	Reach Name:	Richmond Rural Low Density South

Description: This reach encompasses the portion of Richmond on the main channel of the Fraser River that has been developed to a low density / rural land use. It is currently protected by standard dikes. The dike is also a roadway.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility.
			B.	Widen footprint to water side	Widening to the water side is a possibility but give the low density, land side improvements are preferred.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. The City of Richmond currently has flood proofing requirements but perimeter defences are the primary objective.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	No interest to retreat expressed by City staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Widen Dike to Land Side
Rationale:	Richmond is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the land side was selected for this option.

Reach #:	9	Reach Name:	Richmond West Dike

Description: This reach encompasses the portion of Richmond that faces west and is at risk from storm surge flooding. Immediately outside the existing dikes are large mud flats.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility but drainage ditches and private property make this a challenging option.
			B.	Widen footprint to water side	Widening to the water side is a possibility and in many cases does not impact aquatic habitat.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	This is a possibility for reducing wave impacts and overall dike height required.
			G.	Coastal wetlands	This is a possibility for reducing wave impacts and overall dike height required.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. The City of Richmond currently has flood proofing requirements but perimeter defences are the primary objective.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	No interest to retreat expressed by City staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Widen Dike to Water Side
Rationale:	Richmond is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the water side was selected for this option because of the presence of a large ditch and homes on the land side. Additionally, in this location the water-side is predominantly terrestrial habitat.

Reach #:	10	Reach Name:	Steveston

Description: The Steveston Reach is in the southwest of Richmond and is potentially at risk of flooding from storm surges. The area is an historic community and much development is right along the shoreline. An artificial barrier island is located off of the shoreline.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility where space exists.
			B.	Widen footprint to water side	Widening to the water side is generally not possible in this reach due to the active use of the Steveston Harbour.
			C.	Special Structures	The barrier island option could be implemented with the construction of a storm barrier/gate at the harbour entrance.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	There is already a barrier island that has been formed in part by river dredging. This island could be connected to the shoreline to form part of the overall perimeter defences.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. The City of Richmond currently has flood proofing requirements but perimeter defences are the primary objective.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	No interest to retreat expressed by City staff.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A combination of A, C, and F.
Rationale:	The City of Richmond is exploring alternative flood protection approaches for Steveston. Therefore, the approach of combining a breakwater with a surge barrier and minimal dike raising has been selected.

Reach #:	11A	Reach Name:	Sea Island – Sea Side

Description: Sea Island contains the Vancouver International Airport (YVR). YVR sits at a low elevation and is protected by dikes. This reach encompasses the west side of Sea Island. The height of the dikes is limited by airport operations: if the dikes are too high then access on top of the dikes would not be allowed.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility where space exists but height restrictions could be an issue.
			B.	Widen footprint to water side	Widening to the water side is a possibility but height restrictions could be an issue.
			C.	Special Structures	Not applicable.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	A breakwater could be installed to lower the required elevation of the dike. This could be used because it would aid in airport operations. It would still require some raising of the dike.
			G.	Coastal wetlands	Not considered at this point but could be used a part of a breakwater option.
Non-Structural	Accommodate		H.	Flood proofing	Not possible to raise the airport infrastructure beyond current levels.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Not possible to retreat the airport.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	B. Widen to Water Side
Rationale:	Widening and raising to the water side was selected. It would allow the airport to construct a maintenance road within the existing dike which would be required since a higher dike would not be traversable by vehicles without impacting air traffic.

Reach #:	11B	Reach Name:	Sea Island – River Side

Description: Sea Island contains the Vancouver International Airport. YVR sits at a low elevation and is protected by dikes. This reach encompasses the portions surrounded by the Middle and North Arms of the Fraser River.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility.
Structural	Protect	Dikes	B.	Widen footprint to water side	Not possible for this reach because of river depths.
Structural	Protect	Dikes	C.	Special Structures	Not applicable.
Structural	Protect	Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
Structural	Protect	Floodwalls	E.	Demountable	Not preferred where a permanent structure is an option.
Structural	Protect	Foreshore	F.	Breakwater / Barrier Islands	Not applicable for this river shoreline.
Structural	Protect	Foreshore	G.	Coastal wetlands	Not applicable for this river shoreline.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence.
Non-Structural	Accommodate		I.	Secondary Dikes	Not applicable for this reach.
Non-Structural	Accommodate		J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
Non-Structural	Retreat		K.	Managed Retreat	Not possible to retreat the airport.
Non-Structural	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	B. Widen to Land Side
Rationale:	YVR is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the land side was selected for this option.

Reach #:	12	Reach Name:	Tilbury / Sunbury

Description:

This reach runs from the Alex Fraser Bridge downstream along the south shore of the Fraser River. The dike is generally set back from the river.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility.
			B.	Widen footprint to water side	Widening to the water side is a possibility and it would not impact the aquatic habitat as the dike is set back from the shore.
			C.	Special Structures	Not applicable.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for this river shoreline.
			G.	Coastal wetlands	Not applicable for this river shoreline.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. Flood proofing of new development is required by Delta.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Not possible to retreat this highly developed area.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	B. Widen to Water Side
Rationale:	The Corporation of Delta is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the water side was selected for this option. There would be no shoreline impacts along most of the dike reach because the dike is set back.

Reach #:	13	Reach Name:	Ladner

Description:

This reach runs along the south shore of the Fraser River in the community of Ladner. The dike is generally set back from the river and urban development that exists close to the dike. In some cases the dike is the roadway with properties on either side.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility but would have property impacts.
			B.	Widen footprint to water side	Widening to the water side is a possibility and for the most part it would not impact the aquatic habitat as the dike is set back from the shore.
			C.	Special Structures	Not applicable.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for this river shoreline.
			G.	Coastal wetlands	Not applicable for this river shoreline.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. Flood proofing of new development is required by Delta.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Not possible to retreat from this highly developed area.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A & B. Widen to Land / Water Side
Rationale:	The Corporation of Delta is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the water side was selected for this option. There would be no shoreline impacts along most of the dike reach because the dike is set back.

Reach #:	14A+B	Reach Name:	Westham Island

Description:

Westham Island is located at the mouth of the Fraser River and is subject to both river and sea boundary conditions. The island has been developed for agricultural land use.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility and would have minimal impact on structures
			B.	Widen footprint to water side	Widening to the water side is possible in some locations but overall would not compare well to widening landward.
			C.	Special Structures	Not applicable.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for the river shoreline of Westham Island and although a potential solution for the sea shorelines, low property impacts near the dike would not justify it.
			G.	Coastal wetlands	Not applicable for the river shoreline of Westham Island and although a potential solution for the sea shorelines, low property impacts near the dike would not justify it.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. Flood proofing of new development is required by Delta.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Managed retreat could potentially be a solution. There is a long dikes protection agricultural area. The retreat could be done gradually allowing the agriculture to continue and use flood proofing of homes however once there was a major flooding event the agricultural land use would likely be damaged.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Widen Dike to Land Side
Rationale:	Dike widening was selected. Managed retreat was considered but the economic cost was estimated to exceed a structural dike option. Retreat also has other social and community impacts such as loss of agricultural area and impact on residents.

Reach #:	15	Reach Name:	Delta West Dike

Description: This reach covers a portion of Delta that faces west and is at risk of storm surge flooding. Immediately outside the existing dikes are large mud flats. Behind the dikes is primarily agricultural land.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility but drainage ditches and private property make this a more challenging option.
			B.	Widen footprint to water side	Widening to the water side is a possibility as well and in some cases does not impact aquatic habitat.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	This is a possibility for reducing wave impacts but given the space to widening the dike, it is not preferable.
			G.	Coastal wetlands	This is a possibility for reducing wave impacts but given the space to widening the dike, it is not preferable.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. The Corporation of Delta currently has flood proofing requirements but perimeter defences are the primary objective.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	There is no higher ground to retreat to and widespread retreat of Delta is not considered an option.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	B. Widen to Water Side
Rationale:	The Corporation of Delta is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the water side was selected for this option.

Reach #:	16	Reach Name:	Tsawwassen First Nation

Description: This reach covers a portion of Delta that faces west and is potentially at risk from storm surge flooding. It is TFN land. Immediately outside the existing dikes are large mud flats and a breakwater has already been constructed. Behind the dikes is primarily residential with development underway creating commercial and Port-related land use.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Widening to the land side is a possibility but could impact some houses and the roadway
			B.	Widen footprint to water side	Widening to the water side is a possibility as well and in some cases does not impact aquatic habitat.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Because a breakwater already exists, increasing the height would be possible. A breakwater improvement would need to be combined with a smaller dike increase.
			G.	Coastal wetlands	Because a breakwater already exists as a foreshore solution, a coastal wetland would not be considered.
Non-Structural	Accommodate		H.	Flood proofing	Not preferred as a primary defence. TFN currently has flood proofing requirements that require new developments to raise their elevations to the current dike crest level.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	There is no higher ground to retreat to and widespread retreat of Delta is not considered an option.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	F. Breakwater and Raise Dike
Rationale:	Given that a breakwater is already in place the approach to expand those protection works was selected.

Reach #:	17	Reach Name:	Tsawwassen Beach

Description: This reach covers a portion of Delta that faces west and is at risk from storm surge flooding. Only one row of homes is along the water with the rest of the development up on Tsawwassen bluff.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Dike would only protect one row of homes and no public property exists.
			B.	Widen footprint to water side	Dike would only protect one row of homes and no public property exists.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option to only protect one row of homes
			E.	Demountable	Not preferred option to only protect one row of homes
		Foreshore	F.	Breakwater / Barrier Islands	Not preferred option to only protect one row of homes
			G.	Coastal wetlands	Not preferred option to only protect one row of homes
Non-Structural	Accommodate		H.	Flood proofing	This option can be considered. Only a small number of properties exist. Each property faces a different flood risk depending where on the property the house was built. Each property also varies in type of home between older smaller cottages and rebuilt larger homes. Flood proofing can be an effective solution because individual owners can make their own decisions on how to protect themselves from flooding.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	In this case, managed retreat could be accomplished by relocating at risk properties away from flood prone areas.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	H. Flood Proofing
Rationale:	Flood proofing was selected. This is because of the small number of properties at risk relative to the cost and challenges of protecting the area using other methods.

Reach #:	18,19,20	Reach Name:	Boundary Bay Village, Regional Park, and Beach Grove

Description: This reach covers a portion of Delta that faces east towards Boundary Bay. The area is at risk for flooding by storm surges. The area is currently protected by a combination of public dikes and privately maintained seawalls. The privately maintained seawalls are owned and maintained by individual property owners and do not form a continuous, uniform barrier. There is a publicly maintained dike along Boundary Bay Regional Park.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Construction of a dike would be possible. If to the landside it would impact the homes that front along the shoreline.
			B.	Widen footprint to water side	A dike could potentially be installed off the front of the private properties but in most cases there is aquatic habitat right in front so a large environmental compensation would be required.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	A permanent floodwall could be constructed with a smaller footprint then a dike. However, it would not be as reliable as a dike.
			E.	Demountable	Not preferred where a permanent structure is possible.
		Foreshore	F.	Breakwater / Barrier Islands	A breakwater or barrier Island could be constructed in this area. This would allow a smaller dike along the shoreline but not eliminate the need for a dike.
			G.	Coastal wetlands	Similar to a breakwater, coastal wetlands could be constructed / enhanced to break waves and lower the required height of the dike.
Non-Structural	Accommodate		H.	Flood proofing	This is a considered option. Because the seawall is not publically maintained the residents there do not have reliable flood defences and must protect themselves. This could be reinforced as a protection option for the community.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	In this case, managed retreat could be accomplished by retreating from these flood prone areas. However, the scale of this retreat would be large and the value of the 'retreated' properties would greatly exceed the cost of protection works.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike
Rationale:	Boundary Bay is a challenging area with several potential options. Retreat was considered but eliminated because of the comparatively high cost and high impact on the community. A dike could be constructed to protect the community.

Reach #:	21	Reach Name:	Boundary Bay

Description: This reach covers a portion of Delta that faces south towards Boundary Bay. The area is at risk of flooding by storm surges. The area is currently protected by a long publicly maintained dike. The land behind the dike is agricultural and in many locations there is a large ditch behind the dike.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Dike would be possible. If to the landside it would impact the homes that front along the shoreline.
			B.	Widen footprint to water side	Dike could potentially be expanded to the waterside but in most cases there is aquatic habitat impacted so a large environmental compensation would be required.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred where a dike is possible.
			E.	Demountable	Not preferred where a permanent structure is possible.
		Foreshore	F.	Breakwater / Barrier Islands	A breakwater or barrier Island could be constructed in this area. This would allow a smaller dike along the shoreline, but it would not eliminate the need for raising dike heights.
			G.	Coastal wetlands	Similar to a breakwater, coastal wetlands could be constructed / enhanced to break waves and lower the required height of the dike.
Non-Structural	Accommodate		H.	Flood proofing	Dike protects a large area and implementing flood proofing as a primary means of protection would not be feasible. Delta already required flood proofing for new structures.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Retreat is not possible in this area.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike to land side
Rationale:	The Corporation of Delta is committed to a dike system. The choice between land side and water side will vary in each location. Overall widening to the land side was selected for this option.

Reach #:	22	Reach Name:	Surrey Fraser River Dikes

Description: This reach covers the portion of Surrey along the Fraser River. The area is at risk of flooding from a Fraser River flood event. The land use along the shoreline is light industrial, port and railway. Currently the area is protected by a dike, which for much of its alignment is inland from the river.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	The dike could be raised to the land side.
			B.	Widen footprint to water side	The dike could be raised to the water side.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred where a dike is possible.
			E.	Demountable	Not preferred where a permanent structure is possible.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for this river shoreline.
			G.	Coastal wetlands	Not applicable for this river shoreline.
Non-Structural	Accommodate		H.	Flood proofing	Dike protects a large area and implementing flood proofing as a primary means of protection would not be feasible.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Retreat is not possible in this area.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Widen Dikes to Land Side
Rationale:	An earth dike would encounter space constraints so in some cases alternative protection may be required but in general a dike widening is proposed. The dike is generally not immediately on the riverbank.

Reach #:	23	Reach Name:	Mud Bay

Description:

This reach covers a portion of Surrey that faces south towards Mud Bay. The area is at risk of flooding by storm surges. The area is currently protected by a publicly maintained dike. The land behind the dike is agricultural and in many locations there is a large irrigation/drainage ditch behind the dike.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Dike would be possible. If to the landside it would impacted the homes that front along the shoreline.
			B.	Widen footprint to water side	Dike could potentially be expanded to the waterside but in most cases there is aquatic habitat impacted so a large environmental compensation would be required.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred where a dike is possible.
			E.	Demountable	Not preferred where a permanent structure is possible.
		Foreshore	F.	Breakwater / Barrier Islands	Shoreline not overly exposed to waves so foreshore works would not result in large drop in dike requirement.
			G.	Coastal wetlands	Shoreline not overly exposed to waves so foreshore works would not result in large drop in dike requirement.
Non-Structural	Accommodate		H.	Flood proofing	Dike protects a large area which is also susceptible to flooding from local rivers. Flood proofing is required in those areas already by the City of Surrey but it would not be considered feasible for the primary protection.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Retreat is possible in this area. Road infrastructure could form a new line of defence back from the current shoreline. It has added weight given the existing defences where constructed to unknown standards.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	K. Managed Retreat
Rationale:	There are several options for this reach. Managed retreat was selected here to represent the retreat approach for the purpose of this project. The economic cost of the Managed Retreat option in this reach is roughly the same as the Dike Improvement option.

Reach #:	24	Reach Name:	Crescent Beach

Description: This reach covers a portion of Surrey known as Crescent Beach, a low flat area of land protected from storm surges by a dike.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	Dike would be possible. If to the landside it would impact the homes that front along the shoreline.
			B.	Widen footprint to water side	Dike could potentially be expanded to the waterside but in most cases there is aquatic habitat impacted so a large environmental compensation would be required.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred where a dike is possible.
			E.	Demountable	Not preferred where a permanent structure is possible.
		Foreshore	F.	Breakwater / Barrier Islands	A breakwater or barrier island could be constructed in this area. This would allow a smaller dike along the shoreline, but it would not eliminate the need for raising dike height.
			G.	Coastal wetlands	Similar to a breakwater, coastal wetlands could be constructed / enhanced to break waves and lower the required height of the dike.
Non-Structural	Accommodate		H.	Flood proofing	Dike protects a large area and implementing flood proofing as a primary means of protection would not be feasible. Surrey already required flood proofing for new structures in this area.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Retreat is not possible in this area.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike to land side
Rationale:	The neighbourhood is currently protected by a dike and the City plans to continue to protect the neighbourhood in the event of sea level rise. Therefore widening the dike to the land side was selected as the preferred option.

Reach #:	25	Reach Name:	Annacis Island

Description: Annacis Island is located in the Fraser River just south of Queensborough. The island consists of predominantly commercial and industrial land use and presently no flood protection works exist.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No dike exists but dike could be constructed around the perimeter of the island.
			B.	Widen footprint to water side	No dike exists but dike could be constructed around the perimeter of the island.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Potentially an option for small portions of the shoreline where access is required to support economic activity of there is no space for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	Not as a primary level of protection. The Corporation of Delta has determined is already implementing FCLs for new development.
			I.	Secondary Dikes	Not applicable for this reach.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	Area fully developed into high value urban land use and has a high economic value to the region.
	Avoid		L.	Planning and Development Controls	Development has already take place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike construction to land side
Rationale:	A dike is proposed to protect the Island. The high economic value of the area ruled out any alternatives.

Reach #:	26	Reach Name:	Vancouver – Kitsalano / English Bay

Description: The shoreline of Vancouver is generally higher than predicted flood levels. Small portions of the area such as Kits Point are at risk of flooding from storm surges.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No existing dike. New dike construction is a possibility. Dike could be constructed on parkland with minimal impact to area.
			B.	Widen footprint to water side	No existing dike. No need to construct new dike immediately next to the water.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for deeper shorelines.
			G.	Coastal wetlands	Not applicable for deeper shorelines.
Non-Structural	Accommodate		H.	Flood proofing	This is a possibility for some of this reach, but it would leave a few historic neighbourhoods unprotected.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	High value land would be a barrier to retreat.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike Construction
Rationale:	Most of the shoreline consists of public parks and the flooding depths would be small. Therefore, a small dike would be sufficient to protect the area from flooding.

Reach #:	27	Reach Name:	False Creek

Description: False Creek has a unique physical setting from a flood risk perspective. There is a narrow inlet to the existing bay which is surrounded by high density urban development. Some neighbourhoods have been constructed on reclaimed marsh and are susceptible to ocean flooding if sea level increases. For most of the shoreline there is a retaining wall with a pedestrian pathway on top.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No existing dike. New dike construction is a possibility but could have major property impacts.
			B.	Widen footprint to water side	No existing dike. New dike construction is a possibility but could have major impacts on the shoreline.
			C.	Special Structures	Because of the unique location, a storm surge barrier at the entrance to False creek may reduce height requirements of shoreline defences around False Creek.
		Floodwalls	D.	Permanent	Increasing the floodwall height could be a possibility. It might have some visual impacts and property impacts.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for deeper shorelines.
			G.	Coastal wetlands	Not applicable for deeper shorelines.
Non-Structural	Accommodate		H.	Flood proofing	A possibility for some of this reach, but it would leave a few historic neighbourhoods unprotected.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	High value land would be a barrier to retreat.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	C. Special Structures
Rationale:	Because of the high property impacts of raising perimeter defences, a storm surge barrier was proposed for this reach.

Reach #:	28	Reach Name:	Vancouver – Burrard Inlet

Description: This area of Vancouver is potentially susceptible to flooding from storm surges. Currently it has been primarily developed as Port land with some commercial / recreation on the west of the reach.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No existing dike. New dike construction is a possibility but could conflict with access to water.
			B.	Widen footprint to water side	No existing dike. New dike construction is a possibility but could conflict with access to water.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for river shorelines.
			G.	Coastal wetlands	Not applicable for river shorelines.
Non-Structural	Accommodate		H.	Flood proofing	A possibility for this reach. Port land uses could be allowed to adapt to potential flood risks. Commercial/recreation land uses required to develop lot specific flood protection.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	The area is high value land and high economic value making retreat not a feasible option.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	H. Flood proofing
Rationale:	Due to the nature of the land use, flood proofing was selected as the preferred option. The area should adapt over time to increasing sea levels and still maintain the access to the water required to support economic activities.

Reach #:	29	Reach Name:	West Vancouver

Description: Most West Vancouver properties are high enough to not be impacted by flooding or only to have backyard shorelines as risk. There are a few places where the existing land is low enough that properties could be influenced by future storm surges.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No existing dike. New dike construction is a possibility. Right-of-way does not exist and would need to be acquired.
			B.	Widen footprint to water side	No existing dike.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike but could be possible where space restrictions exist.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for deeper shorelines. Some shallower areas these method could be used but not for the overall reach.
			G.	Coastal wetlands	Not applicable for deeper shorelines.
Non-Structural	Accommodate		H.	Flood proofing	A possibility for this reach since much of the shoreline is single family homes with only a portion of the shoreline properties at risk of flooding. However there are some areas storm surge flooding is larger and flood proofing may not be possible.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	The area has already been developed and retreat is not an option.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike Construction
Rationale:	While controlling flood risk though implementation of flood proofing is an alternative, a dike would provide protection for older developments and lower areas near Ambleside.

Reach #:	30 + 31	Reach Name:	District of North Vancouver / Vancouver

Description: Most North Vancouver properties are high enough to not be impacted by flooding. However, there are commercial and industrial shoreline properties that would be susceptible if sea level rises.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No existing dike. New dike construction is a possibility. Right-of-way does not exist and would need to be acquired.
			B.	Widen footprint to water side	No existing dike.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike but could be possible where space restrictions exist.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for deeper shorelines.
			G.	Coastal wetlands	Not applicable for deeper shorelines.
Non-Structural	Accommodate		H.	Flood proofing	A possibility for this reach since much of the shoreline is single family homes with only a portion of the shoreline properties at risk of flooding. However there are some areas storm surge flooding is larger and flood proofing may not be possible.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	The area has already been developed and retreat is not an option.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike Construction
Rationale:	While controlling flood risk though implementation of flood proofing is an alternative, a dike would provide protection for older developments and avoid the challenges of raising small neighbourhood pockets along the shoreline.

Reach #:	32	Reach Name:	Port Moody

Description: Most Port Moody properties are high enough to not be impacted by flooding. Where areas are low they are primarily publicly owned parks. A small pocket of development is potentially at risk from storm surges at the far east of the inlet

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No existing dike. New dike construction is a possibility.
			B.	Widen footprint to water side	No existing dike.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike but could be possible where space restrictions exist.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	Not applicable for deeper shorelines.
			G.	Coastal wetlands	Not applicable for deeper shorelines.
Non-Structural	Accommodate		H.	Flood proofing	A possibility for this reach. Because the area impacted is relatively small.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	The area has already been developed and retreat is not an option.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike Construction
Rationale:	The small area at risk could be protected by a small dike. Flood proofing is an alternative but some of the development is relatively new and likely not to be renewed in the short term.

Reach #:	33	Reach Name:	White Rock / South Surrey

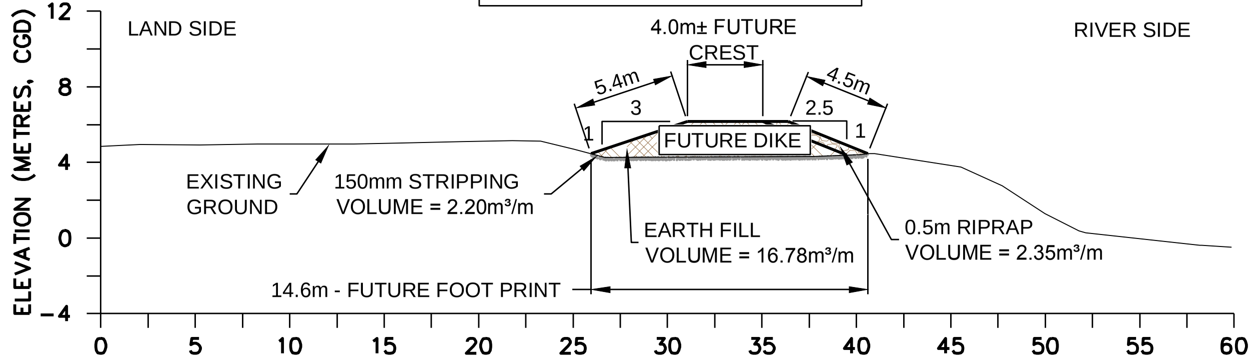
Description: The White Rock and South Surrey area is susceptible to flooding from storm surges. In most of the reach only the immediate shoreline properties or road would be affected.

Evaluation of Options

Category			Options		Application for this shoreline reach
Structural	Protect	Dikes	A.	Widen footprint to land side	No existing dike. New dike construction is a possibility. Right-of-way does not exist and would need to be acquired. It could be incorporated into the existing road/park.
			B.	Widen footprint to water side	No existing dike.
			C.	Special Structures	No special structures were considered.
		Floodwalls	D.	Permanent	Not preferred option where space exists for a dike but could be possible where space restrictions exist.
			E.	Demountable	Not preferred where a permanent structure is an option.
		Foreshore	F.	Breakwater / Barrier Islands	A breakwater or barrier island could be constructed in this area. This would allow a smaller dike along the shoreline but not eliminate the need for a dike.
			G.	Coastal wetlands	Similar to a breakwater, coastal wetlands could be constructed / enhanced to break waves and lower the required height of the dike.
Non-Structural	Accommodate		H.	Flood proofing	An option as a secondary defence but challenging to implement in historical areas.
			I.	Secondary Dikes	Not applicable for this reach. Primary dikes are not in place.
			J.	Emergency preparedness and response	Not an option as the primary form for protection. Will be a secondary protection after preferred option.
	Retreat		K.	Managed Retreat	The area has already been developed and retreat is not an option.
	Avoid		L.	Planning and Development Controls	Development has already taken place and the opportunity to not develop in the floodplain has passed.

Carried forward:	A. Dike Construction
Rationale:	While controlling flood risk though implementation of flood proofing is an alternative, a dike would provide protection for older developments and avoid the challenges of raising small neighbourhood pockets along the shoreline.

Appendix D
Conceptual Options Figures



1 - TYPICAL SOUTH VANCOUVER DIKE SECTION

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN DATE: JUNE 2012 DRAWING No : DIKE SECTIONS	FIGURE 1
STRUCTURAL UPGRADES SHORELINE #1 SOUTH VANCOUVER	Delcan — TRANSPORTATION • INFORMATION TECHNOLOGY • WATER	

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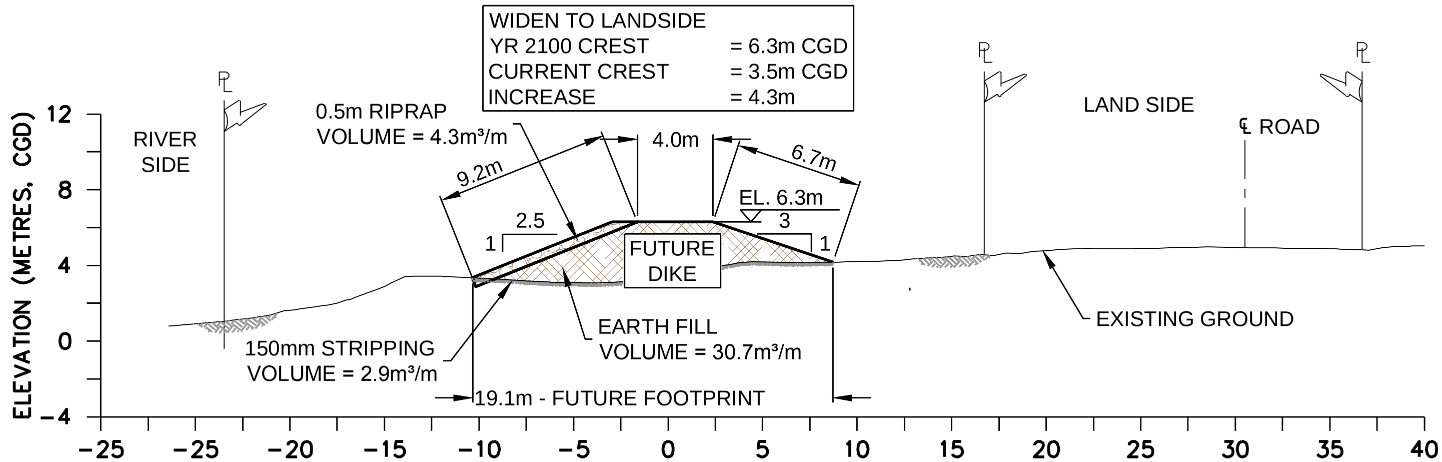

2 - TYPICAL SOUTH BURNABY DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #2 BURNABY

SCALE: AS SHOWN	FIGURE 2
DATE: JUNE 2012	
DRAWING No : DIKE SECTIONS	

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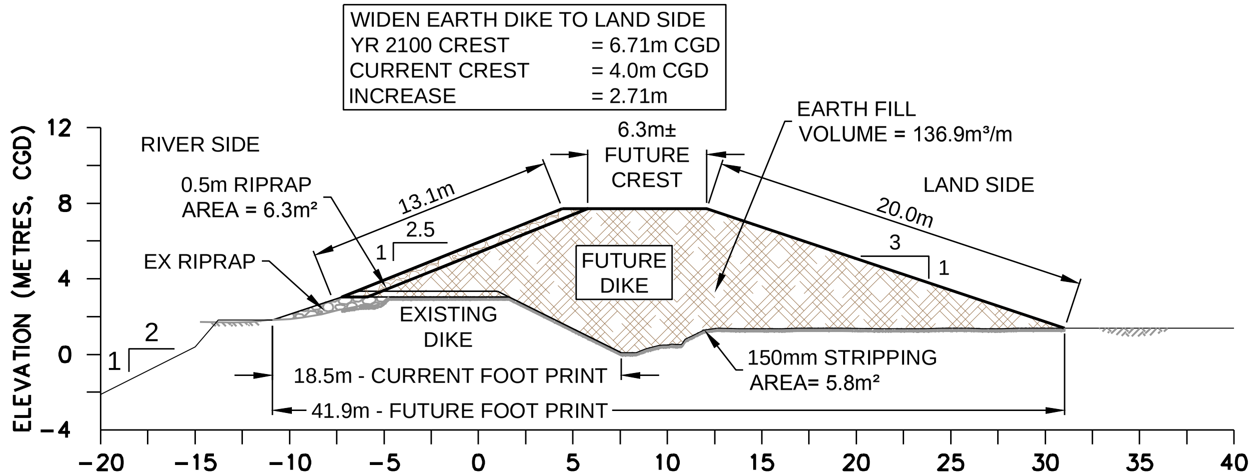

3 - TYPICAL NEW WESTMINSTER QUEENSBOROUGH DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #3 NEW WESTMINSTER
QUEENSBOROUGH DIKE SECTION

SCALE: AS SHOWN	FIGURE 3
DATE: JUNE 2012	
DRAWING No : DIKE SECTIONS	

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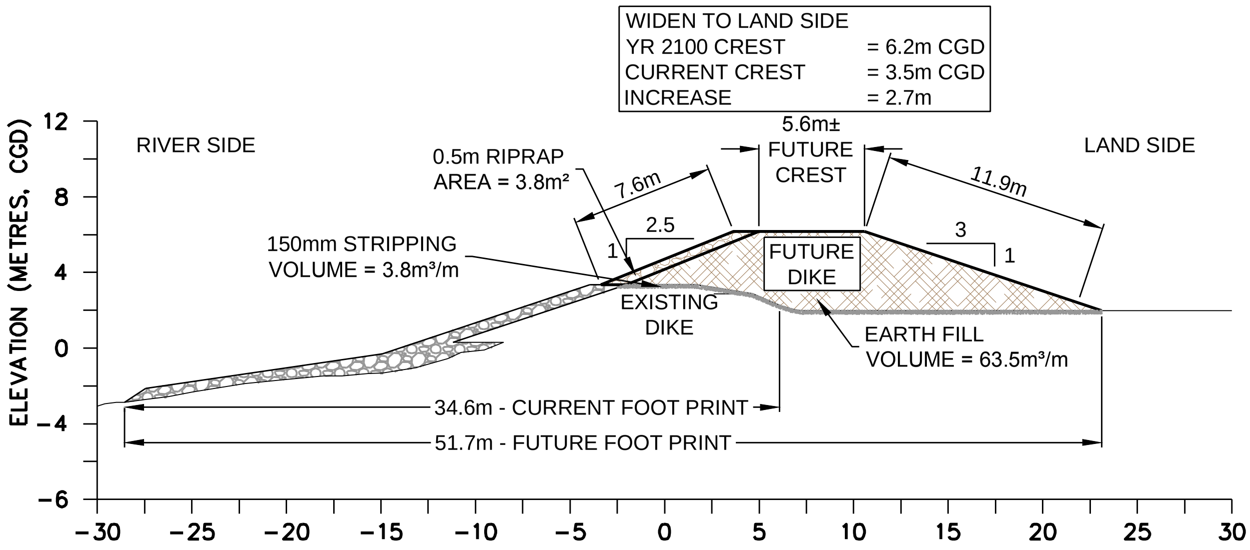

6 - TYPICAL NORTH RICHMOND URBAN AREAS DIKE SECTION

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #6 RICHMOND URBAN DIKE

SCALE: AS SHOWN
DATE: JUNE 2012
DRAWING No : DIKE SECTIONS
FIGURE 6

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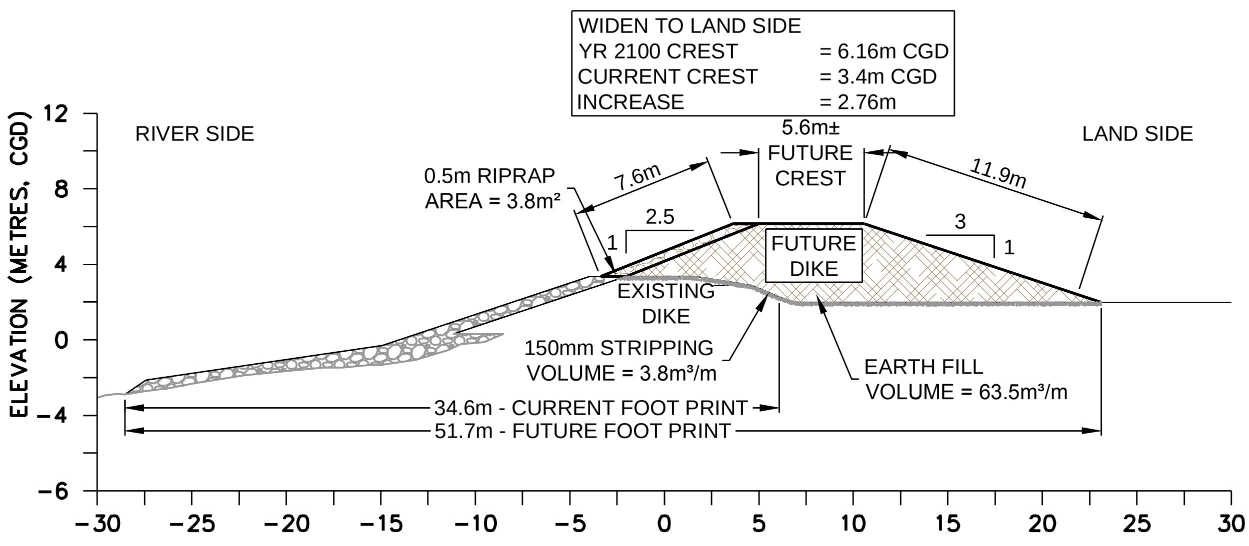

7 - TYPICAL NORTH RICHMOND LOW DENSITY AREAS DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN		FIGURE 7
	DATE: JUNE 2012		
STRUCTURAL UPGRADES SHORELINE #7 RICHMOND LOW DENSITY NORTH DIKE	DRAWING No : DIKE SECTIONS		

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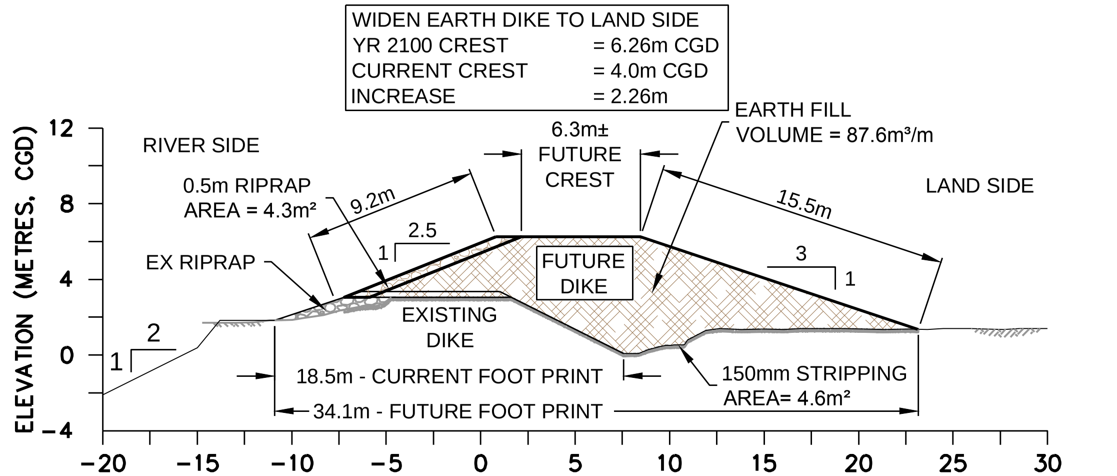

8 - TYPICAL SOUTH RICHMOND LOW DENSITY AREAS DIKE SECTION

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN	FIGURE 8
	DATE: JUNE 2012	
STRUCTURAL UPGRADES SHORELINE #8 RICHMOND LOW DENSITY SOUTH DIKE	DRAWING No : DIKE SECTIONS	

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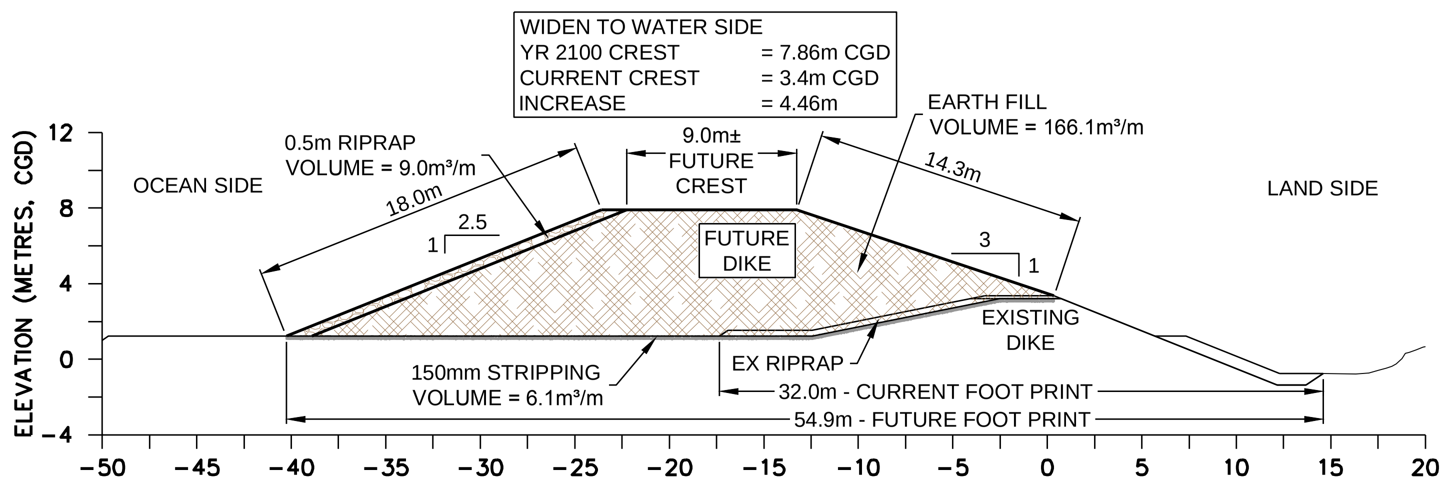

9 - TYPICAL RICHMOND WEST DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN	FIGURE
	DATE: JUNE 2012	9
STRUCTURAL UPGRADES SHORELINE #9 RICHMOND WEST DIKE	DRAWING No : DIKE SECTIONS	

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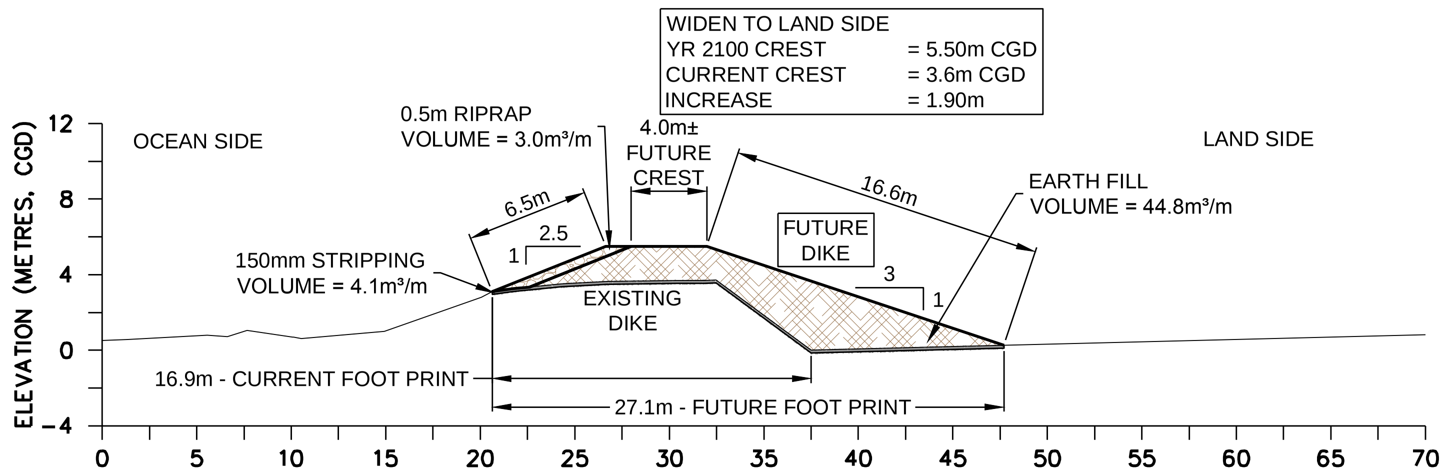

10 - TYPICAL STEVESTON DIKE SECTION

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN	FIGURE 10
	DATE: JUNE 2012	
STRUCTURAL UPGRADES SHORELINE #10 STEVESTON	DRAWING No : DIKE SECTIONS	

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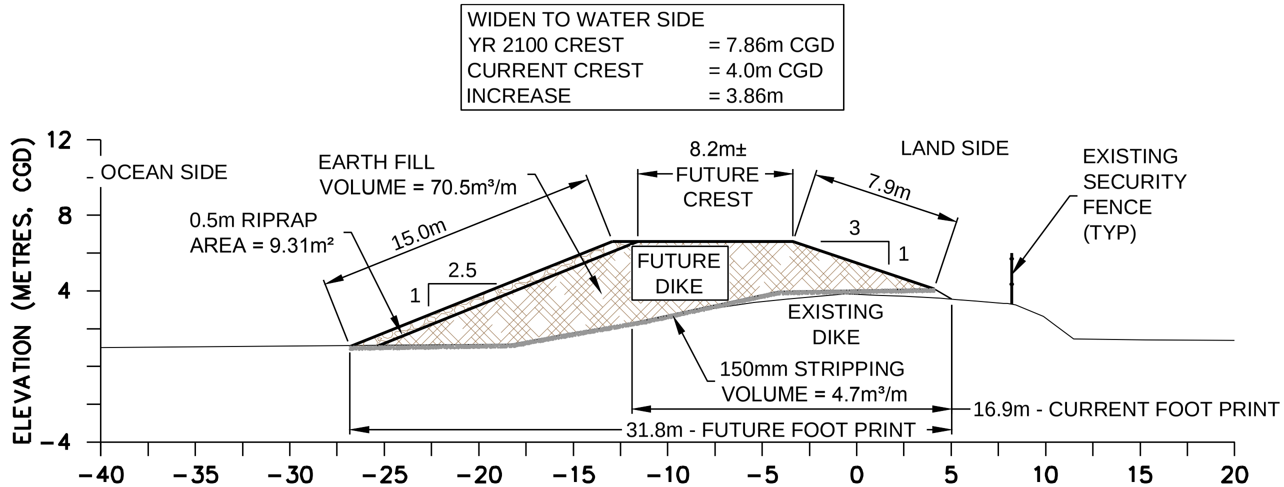

11 - TYPICAL SEA ISLAND DIKE SECTION - OCEAN

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #11A YVR SEA ISLAND
OCEAN

SCALE: AS SHOWN	FIGURE
DATE: JUNE 2012	11A
DRAWING No : DIKE SECTIONS	

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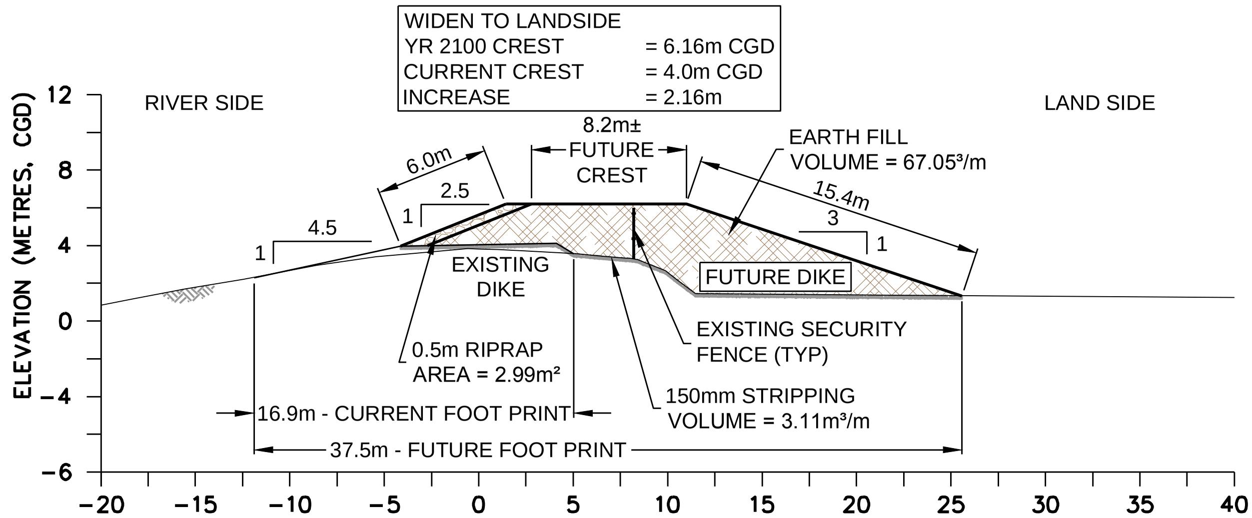

11B - TYPICAL SEA ISLAND DIKE SECTION - RIVER

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #11B YVR SEA ISLAND
RIVER

SCALE:	AS SHOWN
DATE:	JUNE 2012
DRAWING No :	DIKE SECTIONS
FIGURE	11B

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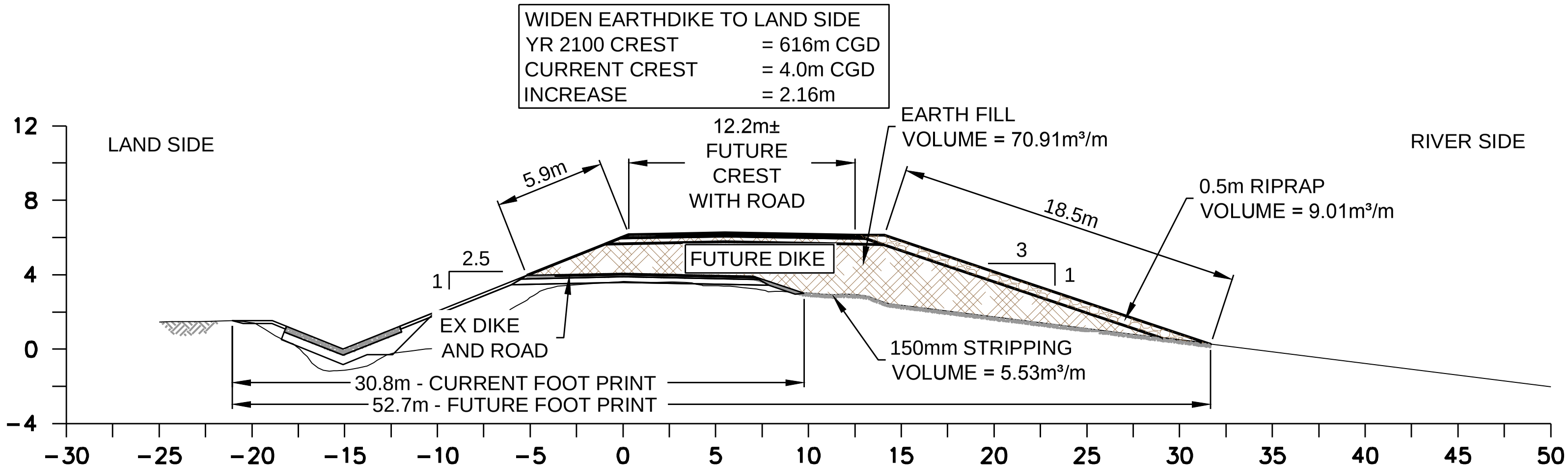

12 - TYPICAL SURREY TILBURY SUNBURY DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #12 TILBURY/SUNBURY
(SURREY)

SCALE: AS SHOWN
DATE: JUNE 2012
DRAWING No : DIKE SECTIONS
FIGURE 12

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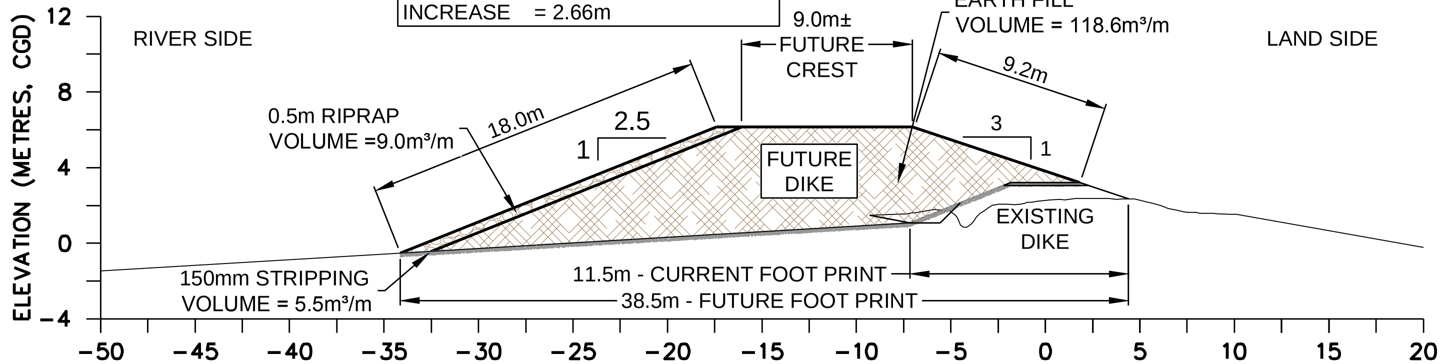

13 - TYPICAL LADNER DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #13 LADNER

SCALE: AS SHOWN		FIGURE
DATE: JUNE 2012		13
DRAWING No : DIKE SECTIONS		

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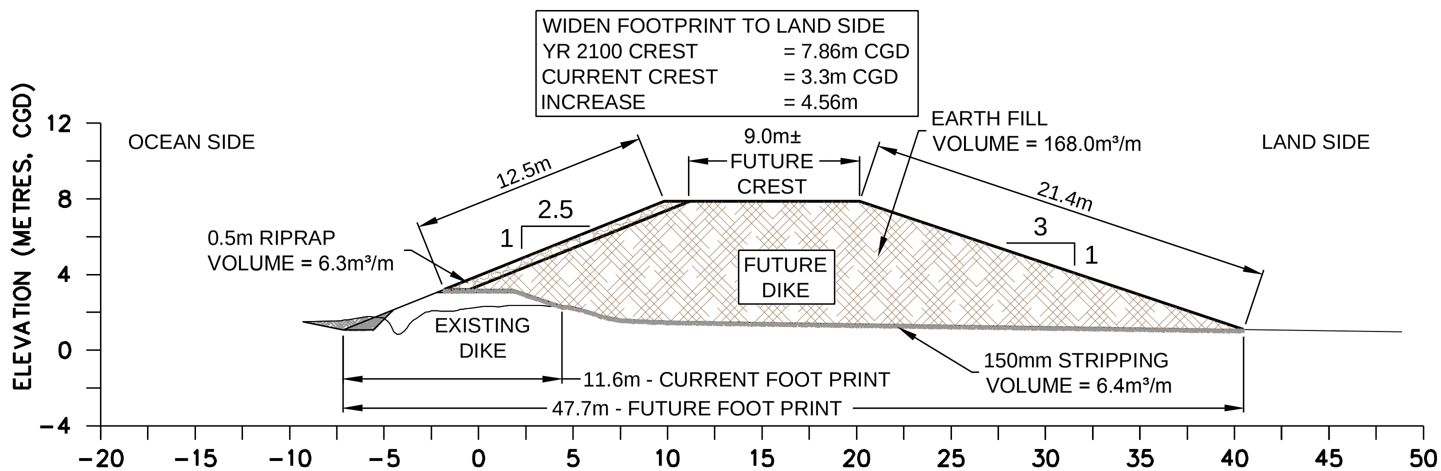
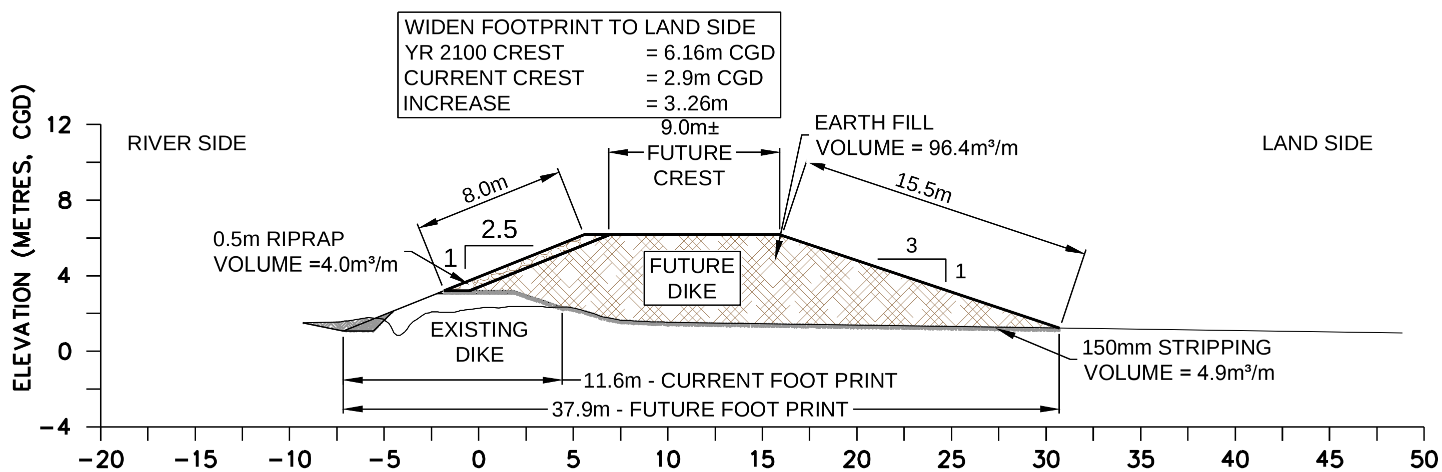


14 - TYPICAL WESTHAM ISLAND SEA DIKE SECTION



14B - TYPICAL WESTHAM ISLAND RIVER DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #14A WESTHAM ISLAND

SCALE: AS SHOWN
DATE: JUNE 2012
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FIGURE 14

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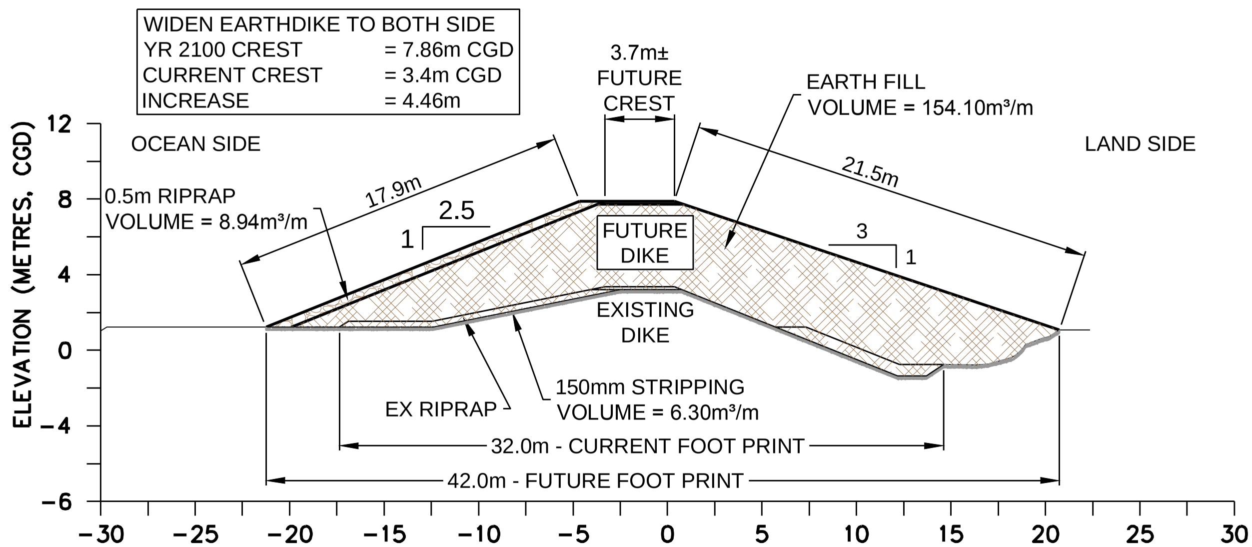

15 - TYPICAL DELTA WEST DIKE SECTION

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN DATE: JUNE 2012	FIGURE 15
STRUCTURAL UPGRADES SHORELINE #15 DELTA WEST DIKE	DRAWING No : DIKE SECTIONS	

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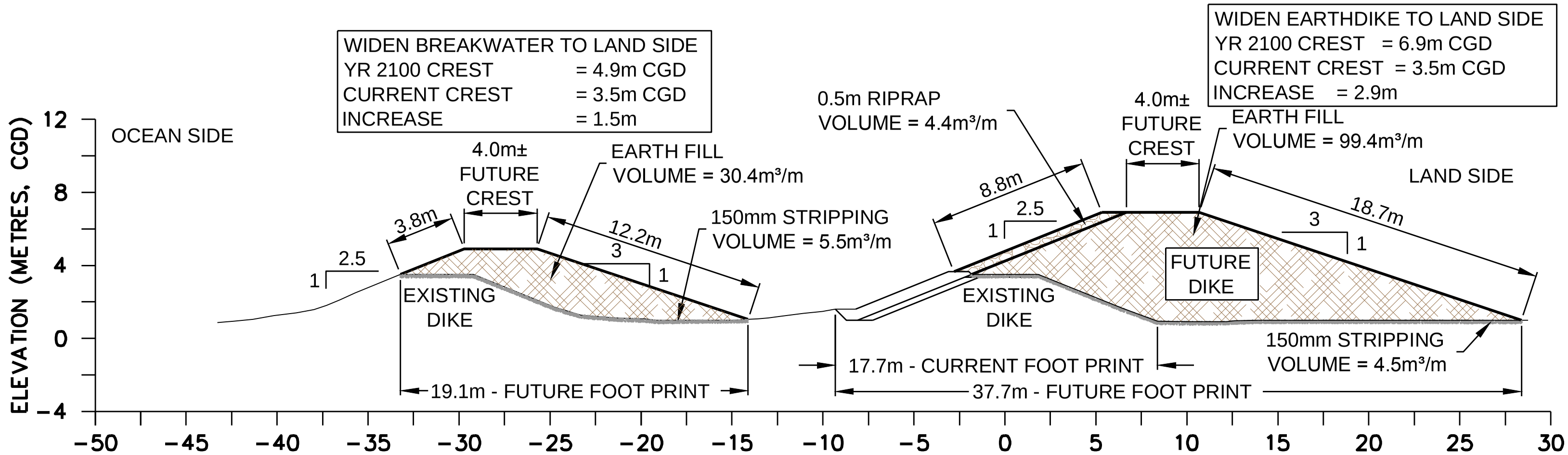

16 - TYPICAL TSAWWASSEN FIRST NATION DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #16 TSAWWASSEN
FIRST NATION

SCALE: AS SHOWN
DATE: JUNE 2012
DRAWING No : DIKE SECTIONS
FIGURE 16

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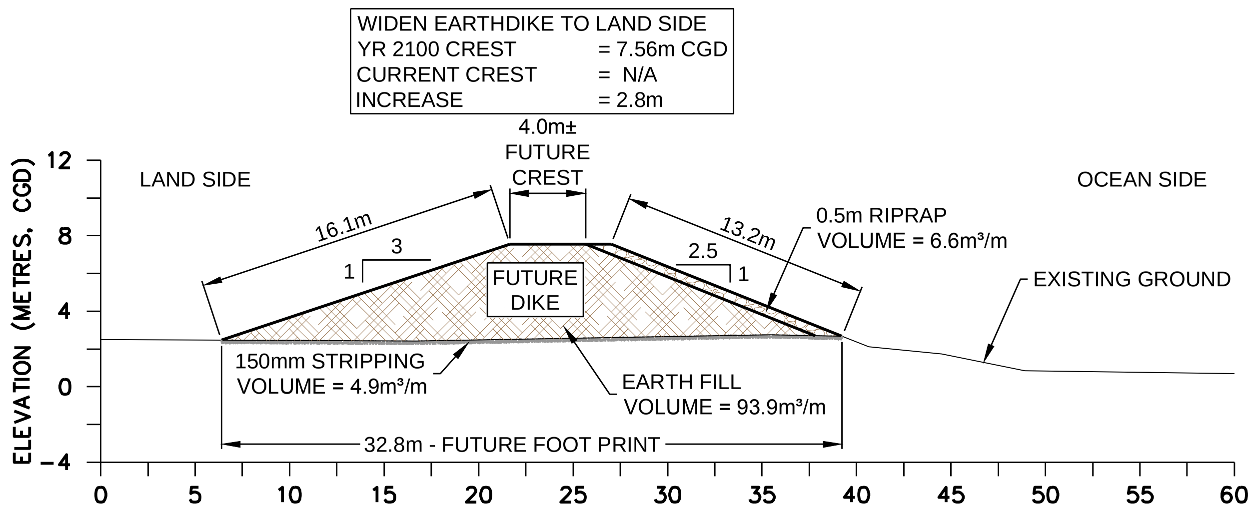

18 - TYPICAL BOUNDARY BAY VILLAGE
BEACH GROVE & BOUNDARY BAY REGIONAL PARK DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #18 19 & 20 BOUNDARY BAY VILLAGE, BEACH GROVE & BOUNDARY BAY REGIONAL PARK

SCALE: AS SHOWN		FIGURE
DATE: JUNE 2012		18–20
DRAWING No : DIKE SECTIONS		

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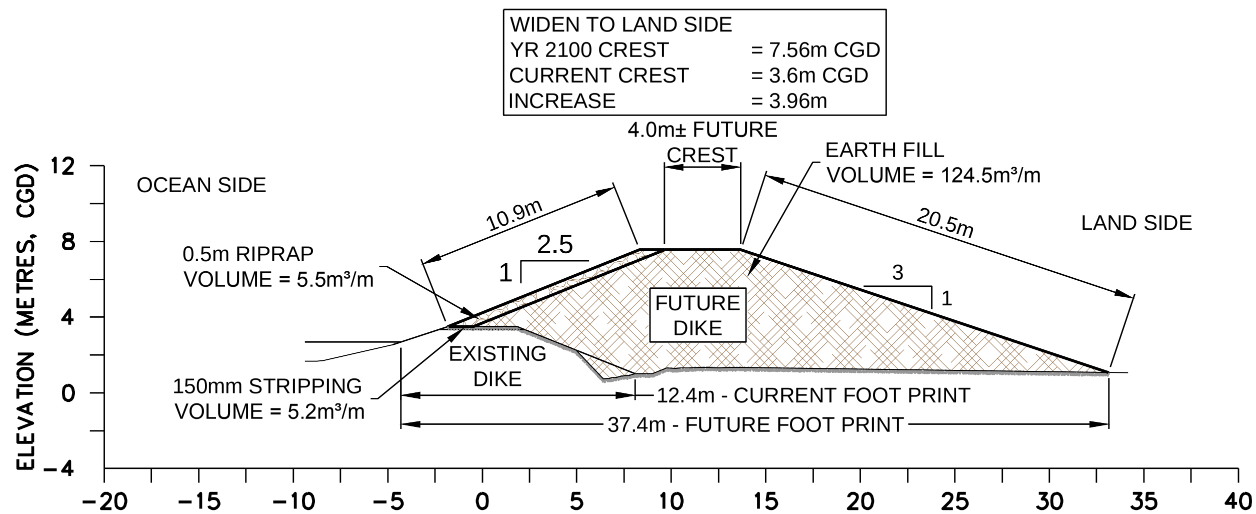

21 - TYPICAL BOUNDARY BAY DIKE SECTION

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #21 BOUNDARY BAY

SCALE:	AS SHOWN
DATE:	JUNE 2012
DRAWING No :	DIKE SECTIONS
FIGURE	21

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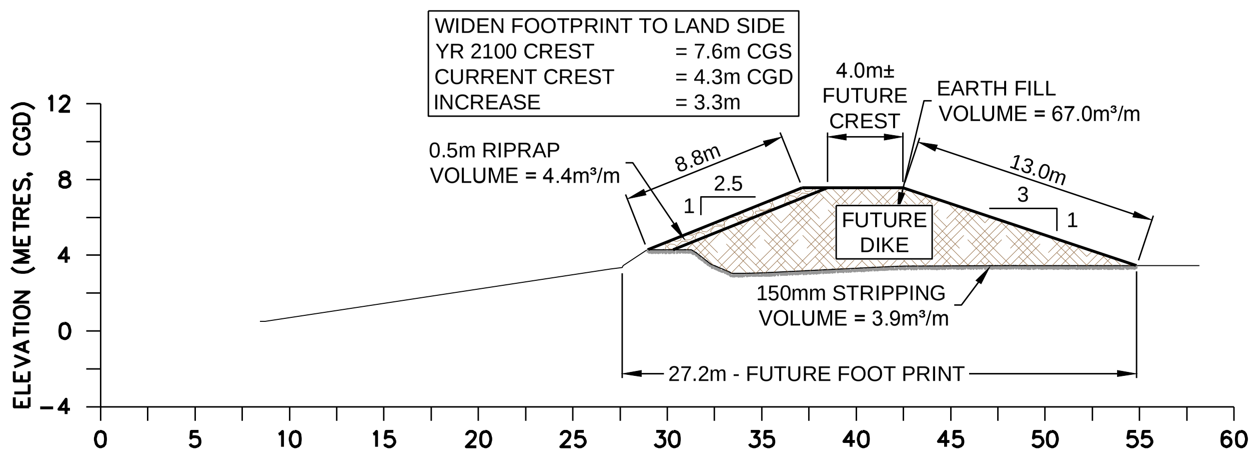

22 - TYPICAL SURREY FRASER DIKE SECTION

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN DATE: JUNE 2012 DRAWING No : DIKE SECTIONS	FIGURE 22
STRUCTURAL UPGRADES SHORELINE #22 SURREY FRASER	Delcan	SUITE 2300, METROTOWER I 4710 KINGSWAY, BURNABY, B.C. CANADA V5H 4M2 TEL: 604-438-5300 FAX: 604-438-5350

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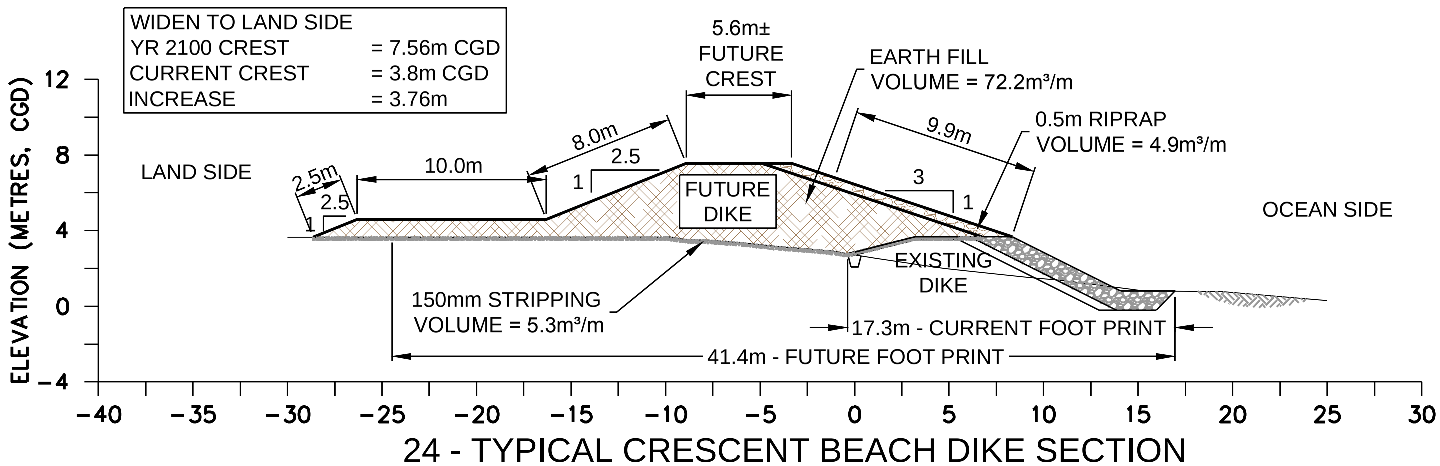

24 - TYPICAL CRESCENT BEACH DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #24 CRESCENT BEACH

SCALE: AS SHOWN
DATE: JUNE 2012
DRAWING No : DIKE SECTIONS
FIGURE 24

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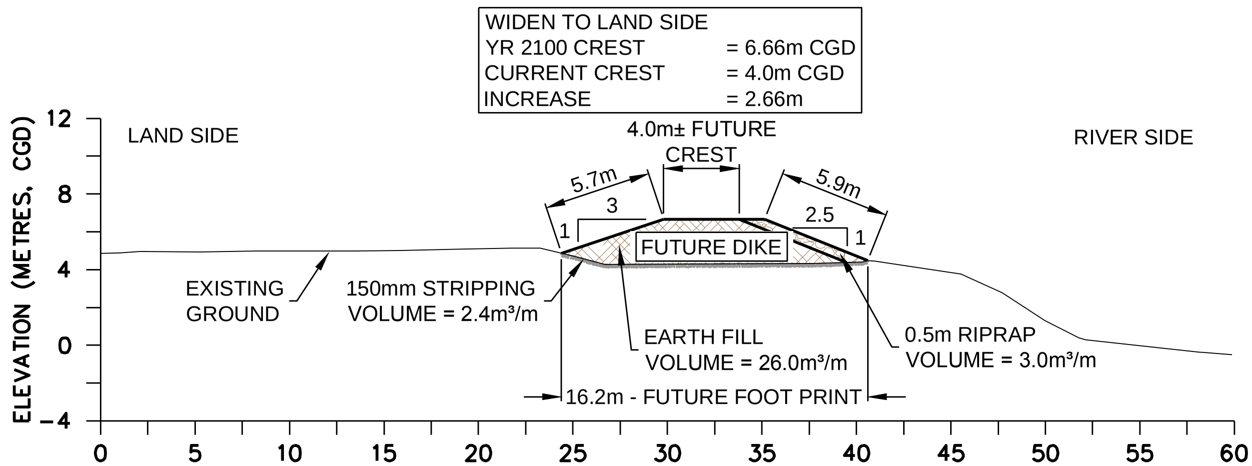

25 - TYPICAL ANNACIS ISLAND DIKE SECTION

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN DATE: JUNE 2012 DRAWING No : DIKE SECTIONS	FIGURE 25
STRUCTURAL UPGRADES SHORELINE #25 DELTA–ANNACIS ISLAND	Delcan	

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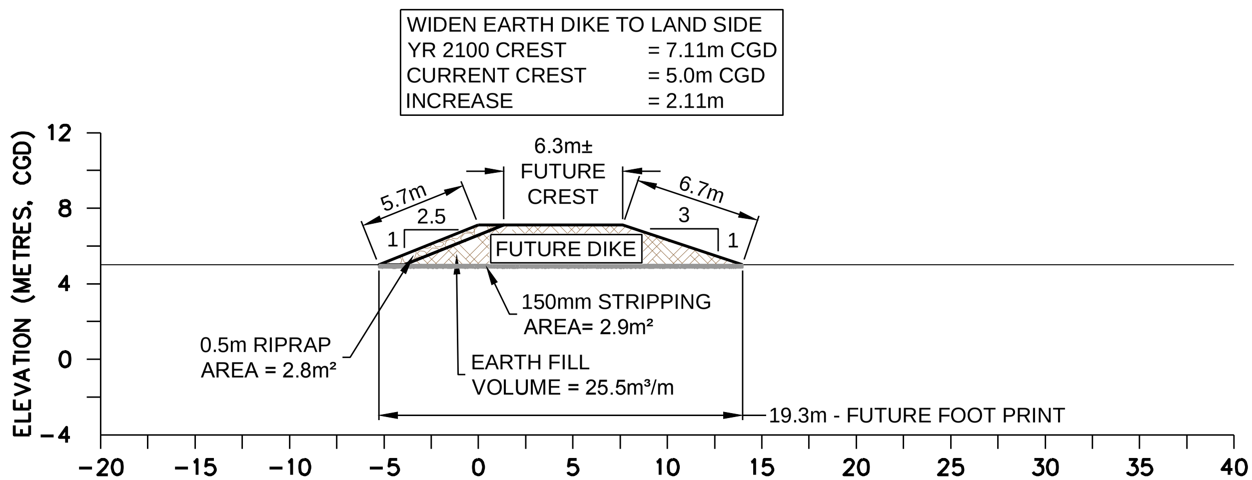

26 - TYPICAL KITSILANO AND ENGLISH BAY DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #26 KITSILANO AND
ENGLISH BAY

SCALE: AS SHOWN	FIGURE 26
DATE: JUNE 2012	
DRAWING No : DIKE SECTIONS	

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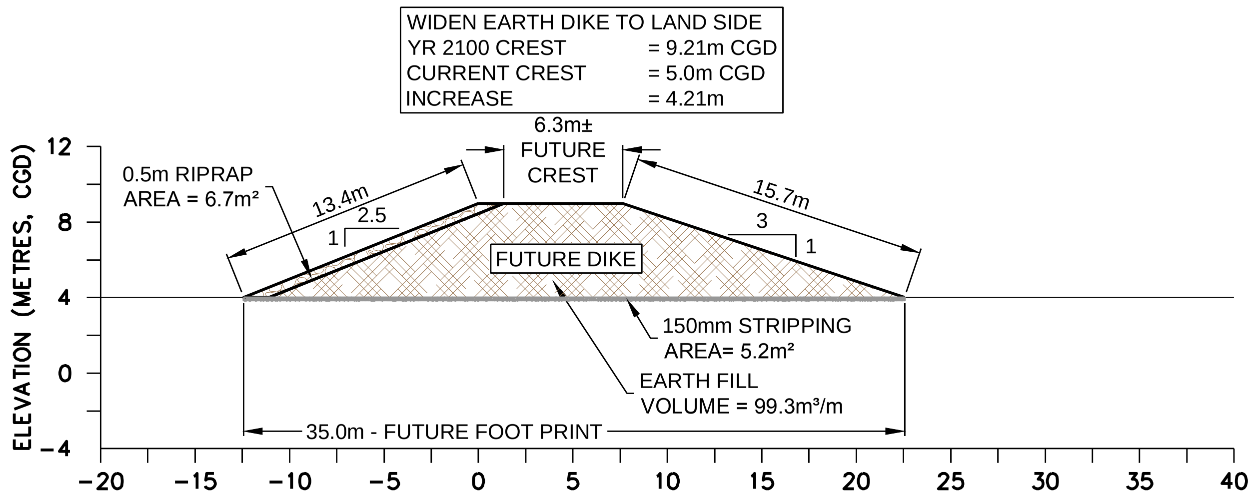

29 - TYPICAL WEST VANCOUVER DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #29 WEST VANCOUVER

SCALE: AS SHOWN		FIGURE 29
DATE: JUNE 2012		
DRAWING No : DIKE SECTIONS		

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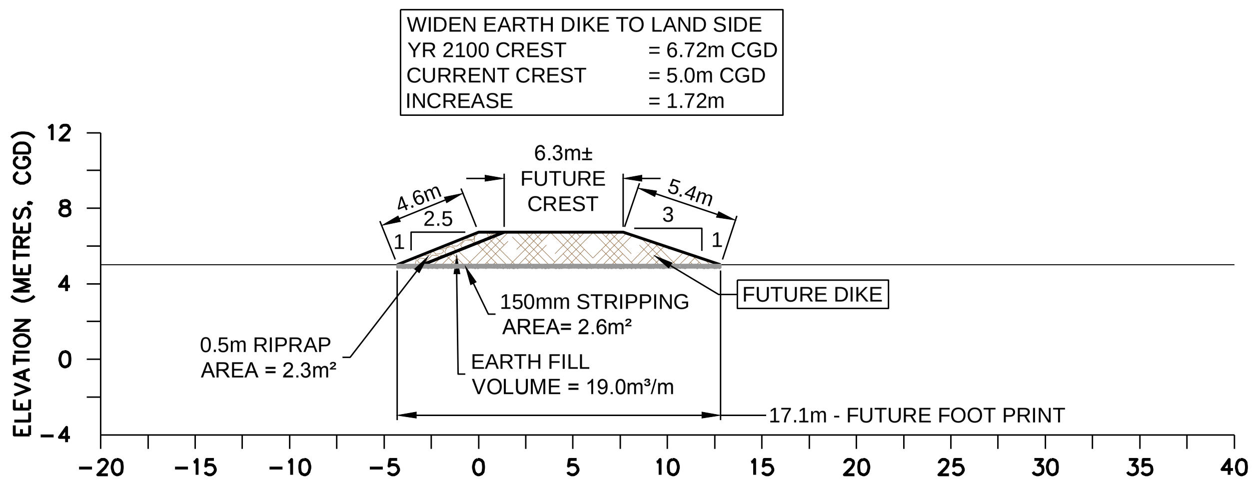

30 - TYPICAL DISTRICT OF NORTH VANCOUVER DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #30 DISTRICT OF
NORTH VANCOUVER

SCALE: AS SHOWN	FIGURE 30
DATE: JUNE 2012	
DRAWING No : DIKE SECTIONS	

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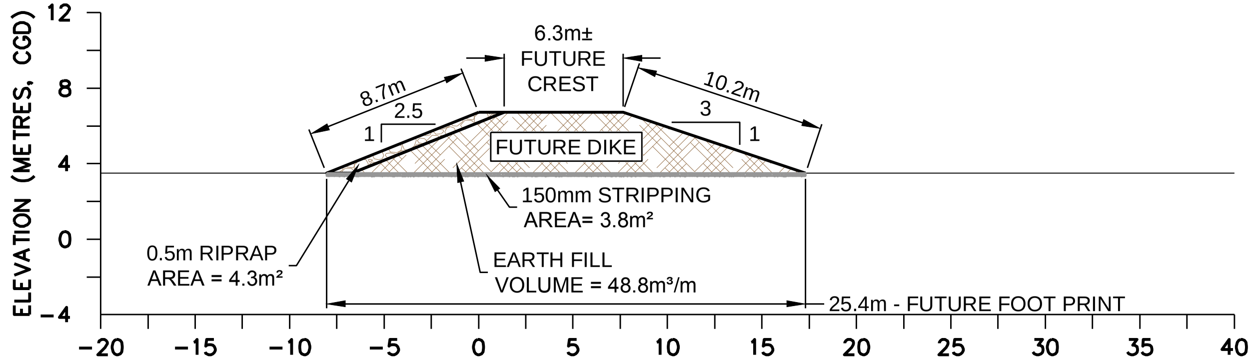

31 - TYPICAL CITY OF NORTH VANCOUVER DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION: SEA DIKES & ALTERNATIVE STRATEGIES	SCALE: AS SHOWN DATE: JUNE 2012	FIGURE 31
STRUCTURAL UPGRADES SHORELINE #31 CITY OF NORTH VANCOUVER	DRAWING No : DIKE SECTIONS	

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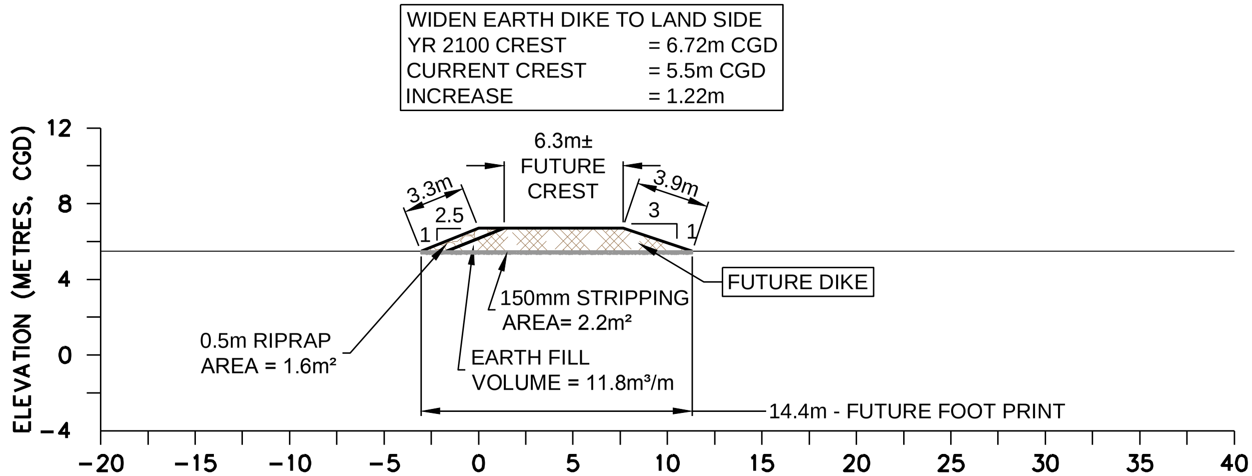

32 - TYPICAL PORT MOODY DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #32 PORT MOODY

SCALE: AS SHOWN		FIGURE 32
DATE: JUNE 2012		
DRAWING No : DIKE SECTIONS		

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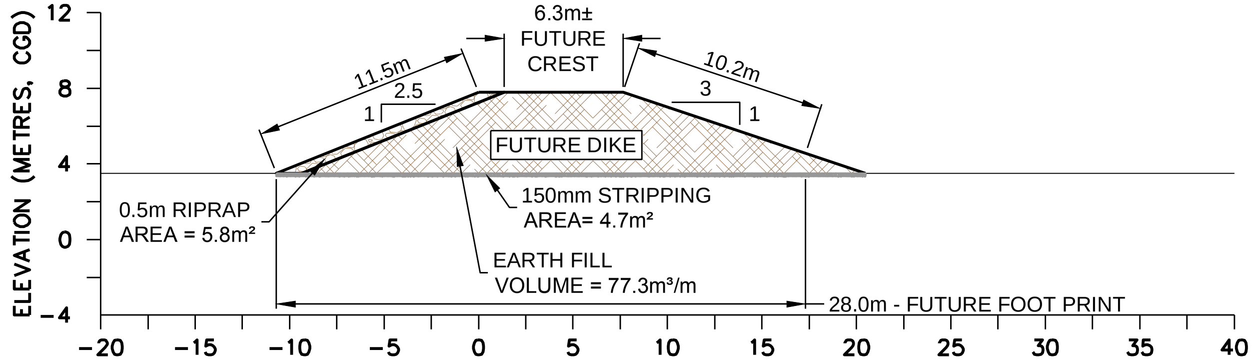

33 - TYPICAL WHITE ROCK / SOUTH SURREY DIKE SECTION

BRITISH COLUMBIA

COST OF ADAPTATION:
SEA DIKES & ALTERNATIVE STRATEGIES

STRUCTURAL UPGRADES
SHORELINE #33 WHITE ROCK
SOUTH SURREY

SCALE: AS SHOWN
DATE: JUNE 2012
DRAWING No : DIKE SECTIONS
FIGURE 33

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