# NORTHEAST FALSE CREEK

## Shoreline Flood Protection Performance Criteria

City of Vancouver

Infrastructure

Document Number: 673983-0000-4PER-0001

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Northeast False Creek – Shoreline Flood Protection
Performance Criteria

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|---|---|
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| PROJECT: | Northeast False Creek<br>Shoreline Flood Protection Performance Criteria |
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# 1 INTRODUCTION

## 1.1 Background

Northeast False Creek (NEFC) is situated at the head end of False Creek and is one of the largest undeveloped areas in Vancouver's downtown peninsula. False Creek is a tidal inlet vulnerable to king tides and storm surges. In the future, water levels are predicted to increase due to sea level rise, which may contribute to increased flooding in the surrounding floodplain if preventative measures are not taken.

The area currently known as Northeast False Creek holds significant meaning to the local First Nations who have stewarded the lands and waters since time immemorial. Musqueam, Squamish, and Tsleil-Waututh peoples maintain profound ties to the area and have distinct relationships with, and names for, the lands, plants, animals, and features. Their traditional knowledge of the area and ways of being vastly predate, but in many ways correspond to, Western approaches of resiliency and natural systems design that have emerged more recently.

The existing seawall along the False Creek shoreline was designed as a retaining structure to separate the land from the sea. The seawall was not specifically designed for coastal flood protection, nor was it designed for a specific level of service for flood management or for sea level rise. The current shoreline in the NEFC area has sloped revetment banks, marginal wharfs and boardwalk piers, mostly legacy items left remaining after EXPO 86, subsequent development, and the 2010 winter Olympics. Currently, the public space atop and near the seawall is enjoyed as a recreational area for cycling, walking and other activities. The future shoreline flood protection strategy is to facilitate continued public access to the waterfront and use of the structure as a recreational pathway.

In February 2018, following years of planning studies, engagement, and technical analysis and design, City Council approved the Northeast False Creek Plan ("NEFC Plan", Ref [3]) which provided a policy framework for the development of a vibrant, inclusive, sustainable, mixed-use waterfront district with a new destination waterfront park.

The NEFC Plan outlines each sub-area within the NEFC area and includes high level descriptions of the character, public spaces and built-form elements for each sub-area. Policies regarding the massing of new development and the relationship to public places and spaces, streets and adjacent context provide the framework for guiding new growth, development and public investment within NEFC over the next twenty years of implementation.

NEFC will exemplify strategies to address the risks and vulnerabilities identified in the Climate Change Adaptation Strategy (Ref [4]) such as sea level rise, stronger storm events, and hotter, drier summers. A significant increase in canopy cover, potable water conservation and green infrastructure measures will be a priority in planning for public and private realms. Engineered flood protection solutions will be integrated into the street, park and public spaces in the neighbourhood.

Coastal flood levels are predicted to rise substantially in the coming century and Vancouver is planning proactively to prevent expensive retrofits. New flood level protection will be built to meet City standards that incorporate sea level rise projections. The City sees this development as an opportunity to incorporate findings from the Resilient Vancouver Strategy (Ref [5]) into the NEFC area.

Supporting the development plans for NEFC, this Northeast False Creek Shoreline Flood Protection Performance Criteria document ("Performance Criteria") is intended to establish shoreline flood protection infrastructure approaches for the City. These approaches will reflect relevant flood protection performance criteria, the spirit of the NEFC Plan, and NEFC park planning principles.

## 1.2 Scope of Work

The Performance Criteria is intended to provide recommendations and conceptual sketches of NEFC flood protection infrastructure, to address the following:

> Design and performance criteria, and an expanded list of requirements that design engineers can use to deliver shoreline flood protection infrastructure;
> Typical dimensions or dimensional ratios for a variety of shoreline flood protection infrastructure approaches, such as height, width and crest height for options including traditional earthen berms, vertical seawalls and other forms;
> Discussions and illustrations on the opportunities and limitations for:
  - Load bearing capabilities of the variety of flood protection approaches relating to vegetated landscaping and other surface treatments for public use such as, but not limited to, benches, pedestrian paths, and bike paths;
  - Opportunities for vegetated landscaping on, behind and in front of flood protection infrastructure;
  - Spatial footprint of flood protection infrastructure at existing ground surface and subsurface extent of foundation requirements;
  - Water-side façade forms, slopes, and transition to support fish and wildlife habitat;
  - Interfaces and surface treatments of flood management infrastructure.
> Sketches of typical flood protection infrastructure and transitions with existing infrastructure on either side of the NEFC.

## 1.3 Purpose and Limitations of Document

The purpose of this document is to define the performance criteria and design standards relating to marine and coastal structures for flood protection infrastructure in NEFC. Application of these guidelines for specific projects, which include new, remediated, upgraded, or transformed waterfront structures, requires qualified engineering professionals to develop site specific designs and facilitate agency approvals.

The Performance Criteria does not alleviate the Engineer's responsibility in any way for ensuring the works are designed in accordance with all applicable codes and standards, and constructed in a cost effective and prudent manner, compliant with all applicable Federal, Provincial, and Municipal laws and regulations.

Certain sections of relevant guidelines, codes and standards, including numeric values, are summarized in this Performance Criteria for convenience. The Engineer shall consult the referenced guideline, code or standard for complete information and to verify that the information provided in this Performance Criteria is in accordance to the latest version in effect at the time of design.

Recommendations contained herein are based on the information provided and an understanding of the NEFC Plan and NEFC park planning strategies. Engineering judgement has been applied in making recommendations, as some aspects considered are unique and not explicitly codified. However, adoption of the recommendations may have implications which are not purely engineering in nature, as they may have commercial and political consequences. Accordingly, only the City can make the ultimate decisions on what is an appropriate level of infrastructure risk, based on their responsibilities, business drivers and service.

This Performance Criteria document does not review or provide recommendations for Flood Construction Levels (FCL) and Sea Dike Crest Elevations previously defined in the report developed for the City by Northwest Hydraulic 2018 (Ref [13]).

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## 1.4 Definitions

Table 1 - Definitions

| Term | Definitions |
|---|---|
| City | City of Vancouver |
| Coastal Structures | Coastal structures include a wide range of works in the coastal zone, including (but not limited to):<br>› Access facilities, such as wharves, piers and boat ramps;<br>› Shoreline protection works, such as seawalls, revetments, and beaches;<br>› Structures to dissipate wave energy or trap sediment, such as breakwaters;<br>› Pipeline, outfalls, and intakes;<br>› Aquaculture related infrastructure; and<br>› Causeways and dikes. |
| Crest | Highest point on a beach face, breakwater, seawall or wave |
| Design Life | Period of time specified by the City during which a structure is intended to remain in service. |
| Designated Flood Level (DFL) | The observed or calculated elevation for the Designated Flood and is used in the calculation of the Flood Construction Level. |
| Flood Construction Level (FCL) | Minimum elevation of the underside of a floor system, or the top of a concrete slab of a building used for habitation, business or storage of goods damageable by flood water (Ref [8]). Also the designated elevation for flood protection structures. |
| Marine Structures | Structures for which structural guidelines, codes, standards and regulations are most applicable for their design. Such structures include, but are not limited to, seawalls, bulkheads, pile-supported decks, wharves and piers. |
| Overtopping | The passage of water over the top of a coastal structure as a result of wave runup and related surge and local setup. The water may pass as a flow of water or as spray. The characteristics of overtopping are site, structure and wave specific. |
| Return Period | The average time in years between the equaling or exceeding of an event, based on historic data. Note that the inverse of the return period is approximately the probability of equaling or exceeding the event in one year (Ref [19]). |
| Sea Dike | A dike, floodwall or any other infrastructure that prevents flooding of land by the sea. As defined in the Dike Maintenance Act, “dike” means “an embankment, wall, fill, piling, pump, gate, flood box, pipe, sluice, culvert, canal, ditch, drain” (Ref [1]). |
| Sea Level Rise (SLR) | An allowance for increases in the mean elevation of the ocean associated with future climate change, including any regional effects such as crustal subsidence or uplift (Ref [1]). |
| Setback | Withdrawal or siting of a building or landfill away from the natural boundary or other reference line to maintain a floodway and to allow for potential land erosion (Ref [1]). |
| Storm Surge | A change in water level caused by the action of wind and atmospheric pressure variation on the sea surface. |
| Wave Effects | A general term describing all aspects of wave interaction with a coastal structure, including wave setup, wave run-up and overtopping. |

## 1.5 Acronyms

Table 2 - Acronyms

| Acronyms | Description |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| **ALA** | American Lifelines Alliance |
| ASCE | American Society of Civil Engineers |
| BCBC | British Columbia Building Code |
| BS | British Standard |
| CIRIA, CUR, CETMEF | European agencies sponsoring Rock Manual |
| CRZ | Critical Root Zones |
| CSA | Canadian Standard Association |
| FCL | Flood Construction Level |
| LLWLT | Lower Low Water Large Tide |
| NBC | National Building Code of Canada |
| NEFC | Northeast False Creek |
| PGA | Peak Ground Acceleration |
| PGV | Peak Ground Velocity |
| TSS | Total Suspended Solids |
| UFC | United Facilities Criteria |

## 1.6 References

The following reference documents were considered during the preparation of this Design Reference:

[1] SNC-Lavalin, 2016, Marine and Coastal Structures Design Reference.

[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. Prepared by Ausenco Sandwell for BC Ministry of Environment.

[3] City of Vancouver, 2018, Northeast False Creek Plan.

[4] City of Vancouver, 2012 & 2018, Climate Change Adaptation Strategy.

[5] City of Vancouver, 2019, Resilient Vancouver Strategy.

[6] City of Vancouver, 2019, City of Vancouver Engineering Design Manual.

[7] City of Vancouver, 2018, Coastal Adaptation Plan – Fraser River Foreshore.

[8] City of Vancouver, 2014. Flood Plain Standards and Requirements.

[9] BCBC 2018, British Columbia Building Code.

[10] Office of Housing and Construction Standards, 2020, Building Accessibility Handbook.

[11] Moffatt & Nichol, 2012, Guidelines for Universal Access to New Public Docks in False Creek.

[12] Ministry of Forests, Lands and Natural Resource Operations Flood Safety Section, June 2014, Seismic Design Guidelines for Dikes.

[13] Northwest Hydraulic Consultants Ltd., November 2018. North East False Creek - Review of Flood Construction Level, Final Report.

[14] Northwest Hydraulic Consultants Ltd., December 2014. City of Vancouver Coastal Flood Risk Assessment, Final Report.

[15] British Columbia Ministry of Transportation and Infrastructure (BC MoTI) Supplements to CAN/CSA-S6-14.

[16] WSP, July 2019, Factual Geotechnical Report.

[17] WSP, February 2020, Proposed Storm Outfall Relocation - Factual Geotechnical Report.

[18] Metro Vancouver Engineering Standards: Seismic Design Criteria.

[19] National Building Code of Canada 2015.

[20] Golder Associates Ltd. and Associated Engineering (B.C.) Ltd, July 2003. Province of British Columbia Ministry of Water, Land and Air Protection. Dike Design and Construction Guide Best Management Practices for British Columbia.

[21] BC Ministry of Environment, Lands and Parks and Fisheries and Oceans Canada, March, 1999. Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment.

Several other guidelines, reports and technical studies have been completed by the B.C. Government to assist local governments, land management authorities and engineers on Sea Level Rise adaptation strategies, land use planning and sea dike design. Many of these reference documents are available at the following website:

http://www.env.gov.bc.ca/wsd/public_safety/flood/fhm-2012/draw_report.html

Further information regarding planning related to Sea Level Rise at the City of Vancouver is available from the following website:

http://vancouver.ca/green-vancouver/sea-level-rise.aspx

# 2 DESIGN GUIDELINES, CODES, STANDARDS, REGULATIONS

## 2.1 General

The design of flood protection infrastructure for NEFC shall be undertaken with guidance from the latest revision of all relevant guidelines, codes, standards and regulations in effect at the time of design. The documents listed below are recognized as current examples of best practice for the design of coastal sea dikes.

## 2.2 Coastal

- Codes and Standards
  - BS 6349, Code of Practice for Maritime Structures.
  - City of Vancouver, September 2014, Flood Plain Standards and Requirements.
  - ISO 21650, Action from Waves and Currents on Coastal Structures.
- Design Guidelines
  - 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. Prepared by Ausenco Sandwell for BC Ministry of Environment.
  - BC Ministry of Environment, Lands and Parks, 2000, Riprap Design and Construction Guide.
  - Canadian Tide and Current Tables, Fisheries and Oceans Canada.
  - CIRIA, CUR, CETMEF, (2007). The Rock Manual. The Use of Rock in Hydraulic Engineering (2nd Edition). C683, CIRIA, London.
  - Golder Associates Ltd. and Associated Engineering (B.C.) Ltd, 2003. Province of British Columbia Ministry of Water, Land and Air Protection. Dike Design and Construction Guide Best Management Practices for British Columbia.
  - Ministry of Forests, Lands and Natural Resource Operations, British Columbia 2014.
  - Dike Maintenance Act Approval for Pipe Crossings of Dikes.
  - Northwest Hydraulic Consultants Ltd., December 2014. City of Vancouver Coastal Flood Risk Assessment, Final Report.
  - Northwest Hydraulic Consultants Ltd., November 2018. North East False Creek - Review of Flood Construction Level, Final Report.

## 2.3 Structural

- Codes and Standards
  - BCBC 2018, British Columbia Building Code.
  - CSA-A23.3:19, Design of Concrete Structures.
  - CSA-O86:19, Engineering Design in Wood.
  - CSA-S16:19, Design of Steel Structures.
  - CSA-S6:19, Canadian Highway Bridge Design Code.
  - CSA-S6.1, Commentary on CSA-S6: Canadian Highway Bridge Design Code.
  - NBC 2015, National Building Code of Canada.

- Vancouver Building By-laws 2019.

> Design Guidelines

- UFC, Design: Piers and Wharves.
- Canadian Foundation Engineering Manual.
- City of Vancouver Construction Specifications.
- ASCE 61-14, Seismic Design of Piers and Wharves.

## 2.4 Geotechnical

> Codes and Standards

- ASCE 61-14 (2014). Seismic Design of Piers and Wharves. American Society of Civil Engineers.
- CAN/CSA-S6-19, Canadian Highway Bridge Design Code, including comments from the British Columbia Ministry of Transportation and Infrastructure (BC MoTI) Supplements to CAN/CSA-S6-14 that are not incorporated in the CSA-S6-19 version.
- NBCC (2015). National Building Code of Canada. National Research Council of Canada.
- BCBC 2018, British Columbia Building Code.

> Reference and Design Guidelines

- Canadian Foundation Engineering Manual, 4th Edition, 2006.
- AASHTO LRFD Bridge Design Specifications, 8th Edition, 2017 – Section 11 Walls, Abutments and Piers.
- FHWA-IF-99-015, Geotechnical Engineering Circular No. 4 - Ground Anchors and Anchored Systems.
- NCHRP 611, Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes, and Embankments.
- APEGBC 2010, Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia.
- Dike Design and Construction Guidelines – Best Management Practices for British Columbia (July 2003).
- Seismic Design Guidelines for Dikes (June 2014).

The geotechnical structures are well-covered by directly applicable Canadian codes/standards: CAN/CSA-S6-19 and BCBC 2018, respectively. For marine structures that are not covered by domestic design standards, ASCE 61-14 can be used as the most applicable international guideline for the NEFC development. Table 3 summarizes the most-relevant types of infrastructure and relevant design standards/guidelines.

Table 3 - Relevant Standards & Guidelines for Infrastructure Design/Development

| Type of Infrastructure | Design Code and Standard |
|---|---|
| Pile supported platforms and retaining walls | CAN/CSA-S6-19 Canadian Highway Bridge Design Code, and<br>BC MoTI Bridge Standards and Procedures Manual – Supplement to CHBDC S6-14 |
| Marine structures | ASCE 61-14 Seismic Design of Piers and Wharves |
| Soil slopes | BC MoTI Bridge Standards and Procedures Manual – Supplement to CHBDC S6-14<br>APEGBC Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia.<br>Seismic Design Guidelines for Dikes |

Additional design guidelines may need to be included into the list as the project definition develops, since the above-referenced documents may not cover all possible geotechnical requirements. For instance, should ground improvement measures be required to meet static or seismic performance criteria, the references appropriate for the type of ground improvement being considered will need to be added to the reference in the list.

## 2.5 Environmental

- Regulations
  - BC Dike Maintenance Act.
  - BC Wildlife Act.
  - BC Weed Control Act.
  - BC Environmental Management Act and Regulations.
  - BC Water Sustainability Act.
  - Canada Wildlife Act.
  - Canadian Environmental Protection Act, 1999.
  - Canadian Navigable Waters Act.
  - Fisheries Act.
  - Migratory Birds Convention Act.
  - Species at Risk Act.
- Codes and Standards
  - Fisheries and Oceans Canada. Interim code of practice: culvert maintenance.
  - Fisheries and Oceans Canada. Interim code of practice: routine maintenance dredging.
  - BC Ministry of Environment – Develop with Care 2014. Environmental Guidelines for Urban and Rural Land Development in BC.
  - BC Ministry of Water, Land and Air Protection - Standards and Best Practices for Instream Works.
  - Fisheries and Oceans Canada – Policy for Applying Measures to Offset Adverse Effects on Fish and Fish Habitat Under the Fisheries Act.
  - Fisheries and Oceans Canada - Fish and Fish Habitat Protection Policy Statement.

- Guidelines
  - Canadian Council of Ministers of the Environment – Canadian Environmental Quality Guidelines, Water Quality Guidelines for the Protection of Aquatic Life, Sediment Quality Guidelines for the Protection of Aquatic Life.
  - BC Ministry of Environment – Approved and Working Water Quality Guidelines (Criteria) Reports for drinking water, irrigation, and recreation and aesthetics.
  - BC Ministry of Transportation and Infrastructure and Ministry of Forests, Lands and Natural Resource Operations – Guidelines for Use of Treated Wood In and Around Aquatic Environments and the Disposal of Treated Wood.
  - Fisheries and Oceans Canada, Guidelines to Protect Fish and Fish Habitat from Treated Wood Used in Aquatic Environments in the Pacific Region.
  - Fisheries and Oceans Canada and Ministry of Environment, Lands and Parks - Land Development Guidelines for the Protection of Aquatic Habitat.
  - Fisheries and Oceans - Canada Urban Stormwater Guidelines and Best Management Practices for Protection of Fish and Fish Habitat.
  - BC Ministry of Water, Land and Air Protection - Stormwater Planning: A Guidebook for British Columbia.
  - BC Ministry of Environment, Lands and Parks and Fisheries and Oceans Canada - Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment.

## 2.6 Health, Safety & Accessibility

- Standards
  - Vancouver Building By-law.
  - CSA-B651, Accessible Design for the Built Environment.
  - Canadian Standards Association.
  - British Columbia Building Code.
  - Occupational Safety and Health Administration.
- Regulations
  - BC Worker's Compensation Act.
  - Canada Labour Code, Part 2, Canada Occupational Safety and Health Regulations.
- Design Guidelines
  - Draft Guidelines for Universal Access to New Public Docks in False Creek.
  - City of Vancouver Engineering Design Manual.
  - Building Access Handbook.

# 3 FLOOD PROTECTION ALIGNMENT AND OPTIONS

## 3.1 Flood Protection Alignment

The flood protection infrastructure alignment proposed within NEFC is generally as indicated in Figure 1.

In the areas proposed for commercial and residential development, (namely the former Plaza of Nations site and the future Concord Pacific Development), the alignment is intended to maximise commercial operations and commuting corridors, while acting as a defence structure against flooding for the upland development. For the future and existing Creekside Park areas, (north and south of Science World) the flood protection alignment balances the requirement to protect critical upland infrastructure such as major transportation corridors (Pacific Boulevard, EXPO Line), with the cultural practices and recreational enjoyment offered by unimpeded shoreline access. A flood protection strategy for Science World is also required. That approach will be developed in coordination with Science World Owners, and part of a separate process.

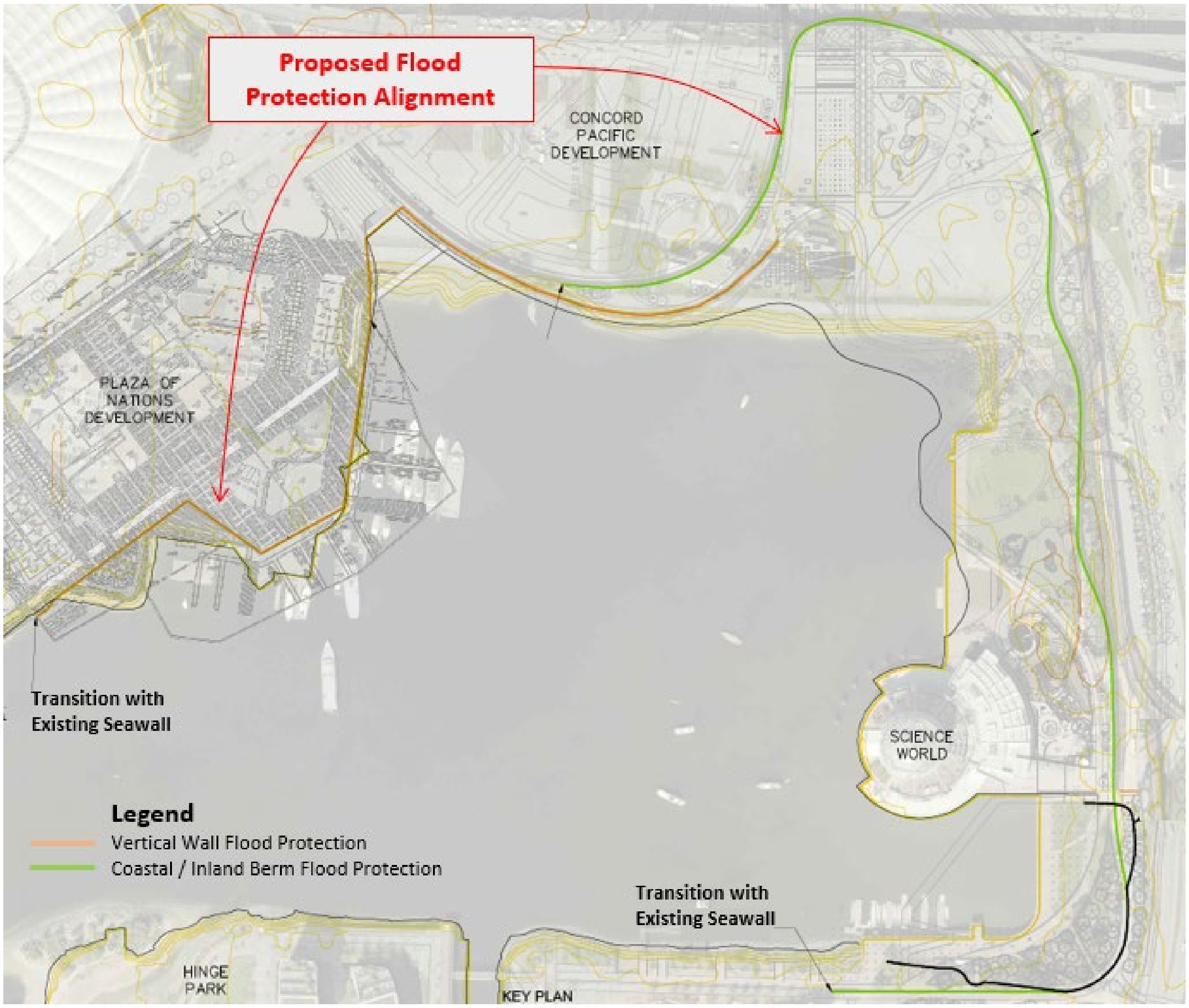


Figure 1 - Flood Protection Infrastructure Alignment within NEFC

Given the intended use of the NEFC area for both commercial / residential and park developments, the options for flood protection can generally be divided into two primary categories, namely a vertical flood wall and an engineered earthen berm.

## 3.2 Flood Protection Options for Commercial and Residential Development Areas

Functional flood protection design options for the former Plaza of Nations site and the future Concord Pacific Development indicate the use of a vertical flood wall to separate the waters of False Creek from the onshore developments. The vertical wall would commence with a transition from the existing seawall west of the Plaza of Nations site and extend along the north shoreline in front of the proposed developments. The vertical flood wall would transition to an upland berm where the Concord Pacific development area adjoins Creekside Park extension. The general extent of the vertical flood wall is indicated in Figure 2.

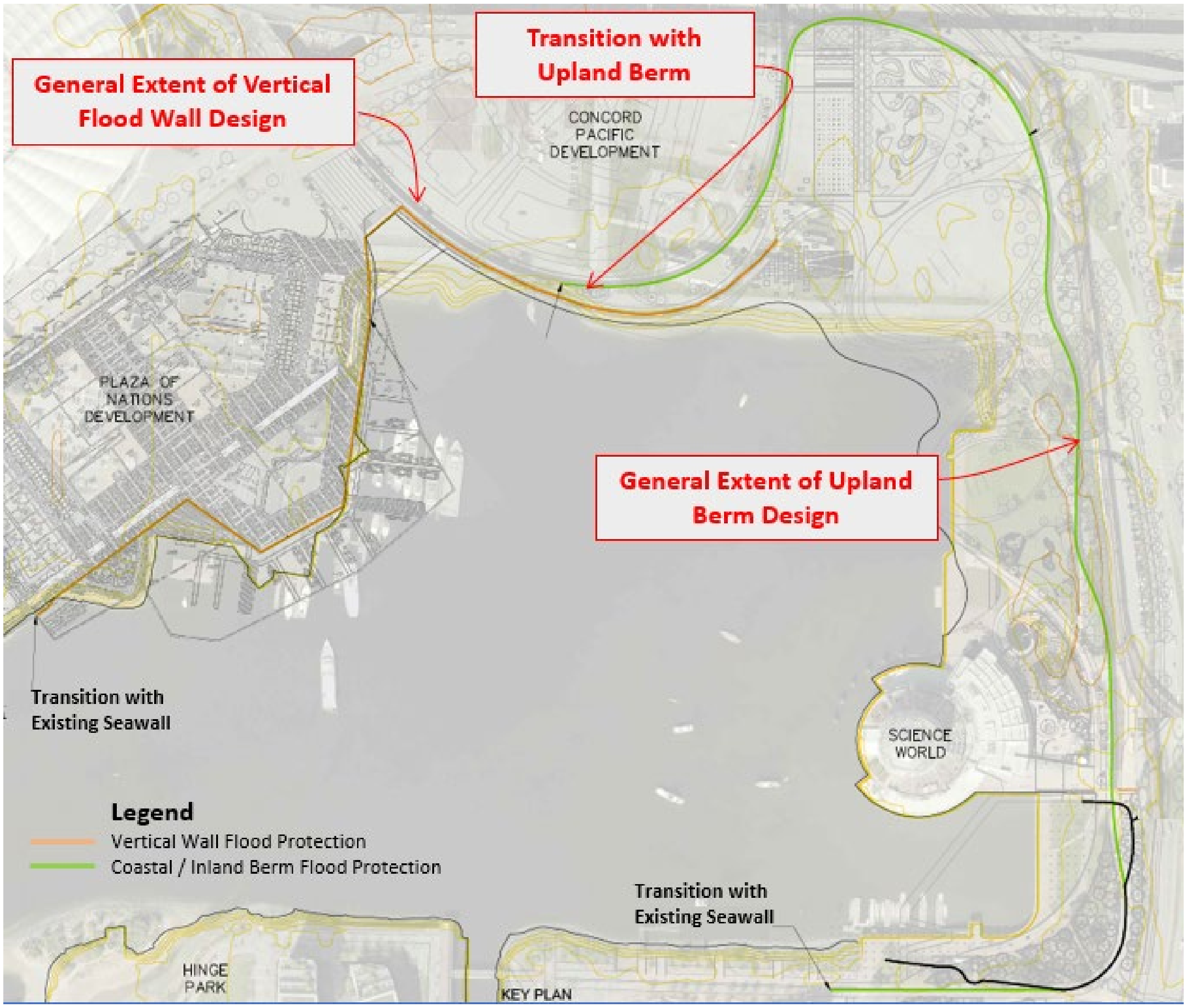


Figure 2 - General Extent of Vertical Flood Wall Design in Vicinity of Commercial Developments

### 3.2.1 Design Considerations for Vertical Flood Wall Areas

Based on the general onshore elevation of 3.5 m and a creek bed elevation of approximately -3.5 m, and considering the proposed flood control design elevation of +4.8 m, the approximate free-standing height (distance from creek bed to top of wall) for any vertical retaining structure will be approximately 8 m to 9 m.

The design options for the vertical seawall will be required to meet acceptable performance levels during both static and seismic conditions, under several different design scenarios. The seismic performance requirements will likely be linked to the infrastructure (development) located behind the wall.

The former Plaza of Nations site is proposed to be developed for commercial / residential use, with high rise buildings indicated in the conceptual designs. Life-safety performance of the vertical wall, under a 2,475-year seismic ground motion event, will be the likely design objective critical to the City. The design requirements for this type of wall and associated performance requirements are outlined in CAN/CSA S6-19. To meet these objectives, the extensive liquefaction potential of the granular fill behind the vertical wall will need to be controlled/remediated so that large deformations do not occur under the design ground motions. Given the limited space between the vertical wall and the adjacent upland building, the full seismic loading of the liquefied soil may not act on the wall.

Options for a vertical wall structure to provide adequate performance under these conditions, considering the expected design loading conditions (refer to Section 6), consist of the following:

- Anchored sheet pile wall, with or without walers;
- Soldier pile wall, with or without anchors;
- Soil-mix wall with reinforcing elements;
- Diaphragm wall with reinforcement.

Retaining walls are generally designed for seismic return periods that vary from 475 years to 2,475 years, depending on importance level and required performance (CSA/CAN S6-19). However, given that the vertical wall will be located directly in front of, and protect residential buildings, the seismic performance requirements will need to be compatible.

## 3.3 Flood Protection Options for Park Areas

Practical flood protection design options for the Creekside Park area east of the development sites indicate the use of an earthen berm (engineered soil dike) design to protect the upland areas, accommodating urban communities and transportation corridors. To maximize the effective park area and allow park users access to the shoreline to the greatest extent possible, the earthen berm design will be located upland where possible. The upland berm will integrate with public pathway and public access corridors.

Transitioning from the flood protection structures in front of the development sites, the upland berm will wrap north around the west side of Creekside Park and continue easterly, somewhat parallel to the Pacific Boulevard roadway alignment. The berm will continue south towards Science World maintaining an upland design, as the existing shoreline in this area is approximately 50 m away.

The upland berm design will need to be modified at the entrance to Science World, as the design flood construction level (FCL) will be an impediment to access the heritage site. Options may include a ramp down in elevation of the berm to meet the existing access elevation of Science World, and then ramp back up to the FCL once the access location is passed. This discrete lowering of the FCL could, if necessary, be quickly increased with temporary fill or sandbags. Another option to maintain flood protection could include maintaining the FCL across the access to Science World, and ramp down to the entrance to Science World and Quebec Street. These two options are shown conceptually in Appendix A.

Though more expensive, it could be possible to design a flood gate entrance, maintained in a retracted position until required, or a section of vertical channelling integrated into the berm design crossing the Science World entrance. When necessary the panelling incorporated into the channelling would be lowered or raised, thus sealing off flood water access to the upland infrastructure. Until the design approach is confirmed for the entrance to Science World, the transition with the adjacent earthen berms can not be finalized, thus leaving the area inland from Science World somewhat exposed to flooding.

South of Science World the berm design will be premised on future park design in this area. Land reclamation occurred in this area during the EXPO development, when a marginal wharf extending approximately 50 m seaward was constructed. This marginal wharf exists today and is reaching the end of its service life. Should this marginal wharf be removed, and the previous shoreline re-established, there will be very limited room, if at all, to build a berm structure. To remedy this, fill will be required at the shoreline to position the protection berm west of the existing shoreline. This shoreline protection berm would then extend around the southern extent of Creekside Park and wrap westward to align with the existing seawall structures in front of the Olympic Village development. The new berm would transition from the FCL 4.8 m level in this area to the elevation of the existing seawall. The transition zone, which would require the union of two earth structures, would be a simple design exercise.

The removal of the marginal wharf would reduce the existing park space considerably, and this may not be a preferred park option. An alternative to the removal of the marginal wharf would be to leave the wharf at the existing elevation and allow for occasional flooding, however, raise the pedestrian and bike pathway, and design it such that it would meet the design flood control level. A vertical flood protection wall in front of the elevated area of the marginal wharf would be required in this case. Placement of fill would be required leeside of the wall to prevent uplift pressure during the design flood. The environmental impact of fill placement and the overhanging structure would require habitat offsetting - details are presented in Section 4.5. The extent the marginal wharf extended out into False Creek could be decided based on park design. Examples of both options are provided conceptually in Appendix A.

The general extent of the upland berm design, and either the shoreline berm design or marginal wharf flood protection scheme, is indicated below in Figure 3.

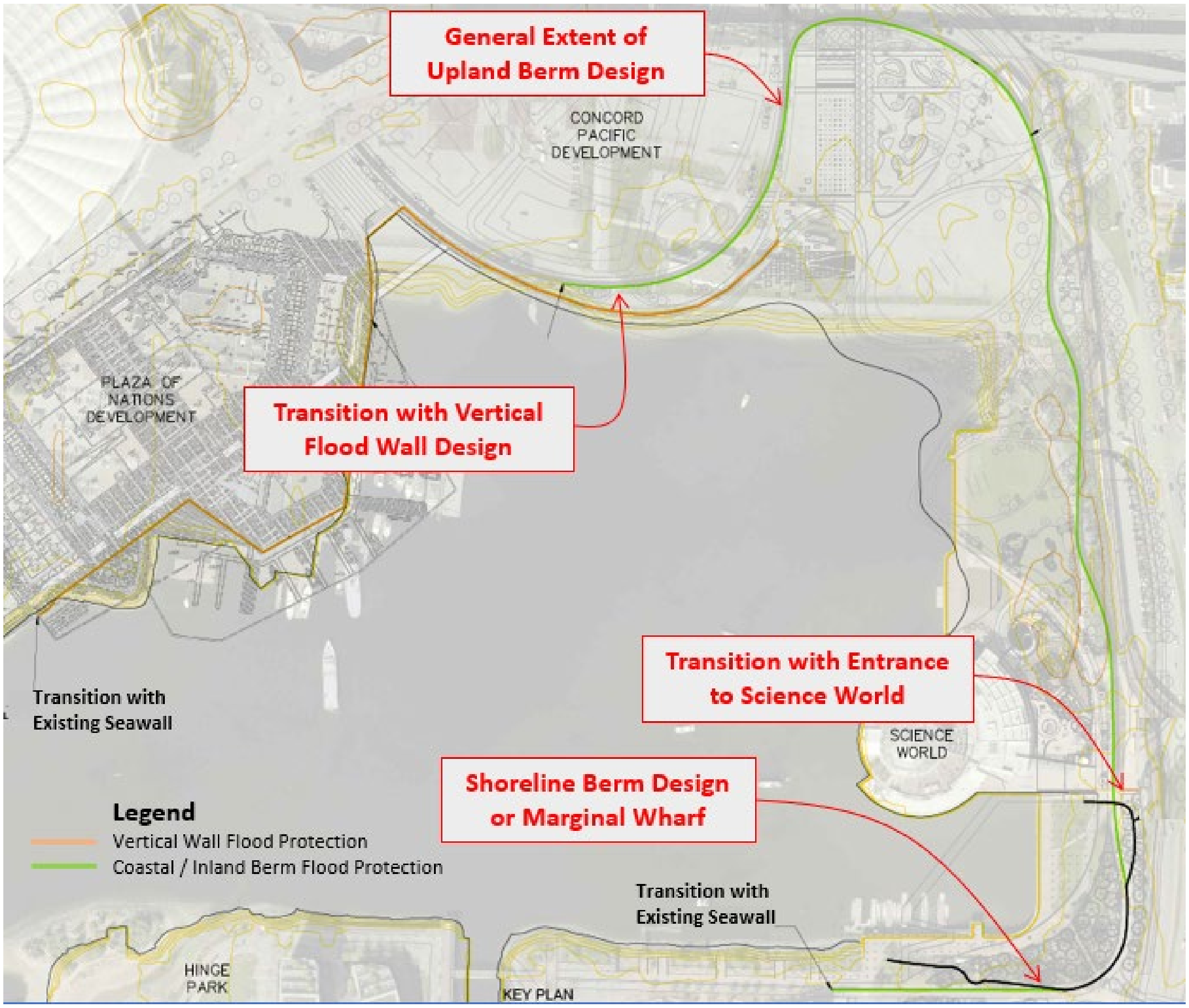


Figure 3 - General Extent of Upland and Shoreline Berm Design in Vicinity of Creekside Park

### 3.3.1 Design Considerations for Upland and Shoreline Berm Areas

Similar to the vertical seawall option, the upland and shoreline berms will be required to meet acceptable seismic performance levels during both static and seismic conditions under different design scenarios. The seismic performance requirements will also be dependant on the importance of the infrastructure being protected behind the berm.

North of the Creekside Park extension and continuing southeast to approximately the location of Prior Street, Pacific Boulevard will provide a critical transportation corridor to the new St. Paul's Hospital. The upland berm design in this area needs to be resilient to a 2,475-year seismic event, as it is intended to protect this critical infrastructure from flooding. To meet these objectives the design of the berm and/or foundations will need to consider the vertical and lateral deformation expected under the design earthquake. The combined probability event of flooding occurring with the specific earthquake return period may also influence the design basis for the berm in this area.

In its simplest form this may involve building the berm to an elevation higher than the FCL to account for expected vertical (settlement) and lateral displacement under seismic conditions, whether this is consistent with the Provincial seismic guidelines, or not. The intent of building the berm higher than the FCL is to allow for vertical settlement following a seismic event, but maintaining adequate freeboard. Analysis will be required to determine the extent of overbuilding required, but likely in the order of 300 mm. Where lateral ground movements are extensive, the foundation soils may need to be remediated (densification or reinforcement) or improved in order to limit liquefaction effects. Given that the soils in this area are heavily contaminated, consideration will need to be given to the cost implications of densification of the underlying soils versus overbuilding the berm and requiring extensive repairs following a seismic event.

Further to the south, extending past Science World and continuing to where the upland / shoreline berm joins in with the existing seawall at the Olympic Village, the seismic performance level of the flood protection system will be based on a risk-based approach. Following a risk-based seismic review, if the upland infrastructure in this area proves to be more resilient, is at a higher ground elevation and not influenced by flooding, is able to be is repairable without large consequences, or if the structures behind the berm are less critical, a lower seismic threshold may be acceptable. In the absence of information to support a risk-based approach, the flood protection infrastructure shall be designed to meet Service Limited, Repairable Damage in the 2475-year event as per CSA-S6-19.

Typically, in the Lower Mainland of British Columbia, coastal and river ‘high-consequence’ flood protection dikes are designed to seismic levels corresponding to return periods of 100, 475 and 2,475 years. Seismic performance requirements are stipulated for each seismic level. Little to no damage is expected for the 100-year event, with increasing levels of both vertical and lateral movements forming the criteria for longer return periods. For many situations, maintaining adequate freeboard and ensuring structural integrity of the compacted earth berm are the principal objectives when designing flood protection dikes.

# 4 FUNCTIONAL REQUIREMENTS

## 4.1 City of Vancouver General Functional Requirements

Shoreline flood protection infrastructure shall be designed in accordance with the City of Vancouver's design references and criteria listed in the City of Vancouver Engineering Design Manual (Ref [6]). Some of the relevant City strategies which impact the flood protection infrastructure include:

- Greenest City Action Plan;
- Integrated Rainwater Management Strategy;
- Climate Change Adaptation Strategy;
- False Creek Coastal Adaptation Plan Report;
- Urban Forest Strategy.

### 4.1.1 Public Access

For the area under consideration, the flood protection infrastructure is coincident or immediately adjacent to the planned Seaside Greenway recreational path. For this reason, access shall be provided adjacent to, or on top of, the flood protection infrastructure designed for walking and cycling. Periodic access for service vehicles shall be provided to all areas of the flood protection infrastructure. In the case of the Concord Pacific development, public and commercial vehicle access may be required if the development of the waterfront includes a public road near the shoreline.

In accordance with the City of Vancouver Engineering Design Manual (Ref [6]), NEFC shall be a highly accessible and barrier-free pedestrian environment. The design shall consider the natural surroundings and the many potential users of the space, including but not limited to, people who use wheelchairs, scooters, guide dogs, white canes, those who are deaf or hard of hearing, and those with learning disabilities. As such, as recommended in the design manual, the following Seven Principles of Universal Design shall be considered when designing the flood protection infrastructure:

- The design is useful and marketable to people with diverse abilities;
- The design accommodates a wide range of individual preferences and abilities;
- Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level;
- The design effectively communicates necessary information to the user, regardless of ambient conditions or the user's sensory abilities;
- The design minimizes hazards and the adverse consequences of accidental or unintended actions;
- The design can be used efficiently and comfortably, and with a minimum of fatigue;
- Size and Space for Approach and Use - Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

In accordance with the above, public access shall be provided to pedestrians and people with diverse abilities. Requirements should follow the City of Vancouver Engineering Design Manual (Ref [6]), BCBC 2018 (Ref [9]), and the City of Vancouver Building Accessibility Handbook (Ref [10]) guidelines. Pathways forming part of the flood protection infrastructure should consider the following:

- Permanent, firm and slip-resistant surface;
- Uninterrupted width of not less than 3000 mm, and a gradient not more than 1 in 20;

- Railings, or other barriers;
- Free from obstructions;
- Ramps shall be provided with an unobstructed level area not less than 1500 mm long by the width of the ramp, at the bottom and top ends, and at intervals.

Maximum distances between a resting spot shall be checked by the designer for the intended usage in the area, however some recommendations for distances between resting spots (Ref [10]) such as benches are as follows:

- Wheelchair users, visually impaired: 150 m;
- Mobility impaired using a stick: 50 m;
- Mobility impaired without walking aid: 100 m.

In accordance with the City of Vancouver Engineering Design Manual (Ref [6]), off-street bicycle pathways generally should be paved with asphalt. However, paving stones, sawcut concrete, or other special treatments may be considered through parks, plazas, and other context-sensitive areas, with consideration for universal accessibility. New off-street pathways should be designed with separate and intuitive walking and cycling space.

Access to public/private floats and gangways to these floats shall be designed in accordance with the recommended Guidelines for Universal Access to New Public Docks in False Creek (Ref [11]).

### 4.1.2 Operations and Maintenance Access Requirements

Public vehicle access shall be provided only in sections of development which are designed to incorporate public roads. Otherwise, no public vehicle access shall be permitted along pathways of the flood protection infrastructure.

Access for fire trucks shall be determined by adjacent land uses and emergency response requirements. In the case of the Plaza of Nations and Concord Pacific developments, access shall consider whether the developments are located immediately adjacent to waterfront structures, which would then require fire trucks utilizing the pathway for access.

Flood protection infrastructure shall be designed to allow access for replacement or maintenance of components during the design life of the structure. Future maintenance and repairs to the flood protection structure will be provided by primary access through alleyways, side streets or walkways. The designer shall confirm with the City the required distance between access points. Bollards or barriers shall be used to prevent vehicular access to pathways by the public. Vertical clearance for access to, or travelling on, the flood protection infrastructure shall follow power line dike design clearance guidelines of 5.5 m.

Access shall be designed to include the following service vehicles:

- Garbage pickup vehicle (Mini Packer 10-yard rear loader, single rear axle or similar);
- Maintenance vehicles CL-3 truck;
- Street sweepers;
- Snow plows;
- Fire trucks;
- F350 pickup or similar;
- Forklifts, manlifts of 85 ft to 100 ft;
- 5-ton flat deck with hiab crane.

All anticipated maintenance elements shall be accessible from the top of, or adjacent to, the flood protection infrastructure. In the case of utilities running through flood protection infrastructure, (if necessary) access shall be provided to areas at the intertidal zone. If access is required to the underside of flood protection infrastructure or adjacent marine structure (such as cantilever deck or suspended deck), access shall only be provided via a secured ladder.

### 4.1.3 Access to Waterfront

Access to the waterfront is achieved by providing connectivity from the pathway to the water, while achieving an aesthetically pleasing public realm area that is robust enough for the environmental conditions. Access to the waterfront shall be provided by methods such as the following:

- Sloping paths, landscape areas, and steps down from the FCL to the intertidal zone;
- Suspended platform/deck adaptive to SLR, allowing the design to be close to the water yet able to be raised over time to meet the FCL of 4.8 m;
- Gradually sloping landscape and habitat features to the intertidal zone;
- Gangways down to public/private floats.

According to City of Vancouver Coastal Adaptation Plan (Ref [7]), the following access design considerations should be considered, if appropriate:

- Consider shoreline access and trails accessibility;
- Integrate shoreline access and trails into flood management approach;
- Trails on flood management features (e.g., trails on dikes);
- Improve access to recreation (e.g., nature watching, paddling).

It is understood that access to the waterfront shall be directly from the top of the vertical seawall barrier at the Plaza of Nations and Concord Pacific developments.

### 4.1.4 Access to Float & Gangways

Floats may be either constructed of timber or concrete deck, with floatation billets underneath. The floats would be secured using mooring piles (timber or steel). Floats must be located such that they can accommodate the maximum design vessel draft at all water levels.

The following site constraints shall be considered:

- Water lot size and vessel movements;
- Height differential between fixed end of gangway and Lowest Low Water Large Tide (LLWLT);
- Limiting water depth to seabed at LLWLT.

Access to the floats would be via a steel or aluminum gangway fixed to the topside of the flood protection infrastructure. The necessary length of the gangway is governed by the elevation of the fixed upper end and the tidal range it must accommodate. As the FCL of El. +4.8 m is higher than existing, there will be an associated increase in gangway length for the gangway slope to remain reasonable. Proposed gangways shall be universally accessible (Ref [11]). A suitable gangway arrangement will need to be developed.

The factors above may require a short-fixed span to limit the gangway to a reasonable length, or a gangway system comprised of floating platforms and gangways that limits the maximum slope on any one gangway. In this case, each floating platform would be supported on piles, with pile stops at varying elevations to limit the slopes. The recently constructed Aquatic Centre public float would be an example of such a design.

## 4.2 Landscape Architecture Functional Requirements

### 4.2.1 Urban Design

Vancouver's shoreline is one of the city's defining characteristics, offering expansive views, water access, extensive recreation, habitat, and city access. The new NEFC shoreline represents an opportunity to envision the best of what city building can be, especially during a time characterized by multiple pressures on urbanization -- from climate-change, to social equity, to new emerging economies and development. The topside landscape of the shoreline protection needs to serve the long-term vision for this area: a vibrant, innovative, and resilient design.

Combining flood protection infrastructure as part of the development and landscape improvements will unlock the desirable waterfront sites, creating safe access while enhancing public enjoyment and ecological benefits. Having this infrastructure perform multiple functions is a cornerstone to a resilient shoreline. Careful design and selection of landscape elements will reinforce the ecological performance while also ensuing long term success.

The primary shoreline defense described in this document is elevating the ground plane above the flood control level. While elevating the level provides the bulk of defense, the materials, planting, furnishing, etc. all need to be considered as part of this defense, as well as the physical distance of the upland berm from the shoreline. Landscape strategies for durability and resiliency are outlined below.

### 4.2.2 Public Connectivity

The waterfront is a public space; it is a desirable space for gathering, strolling, and leisure. Vancouver's relationship to this valuable public resource has, in the past, been often concealed from the public behind private development. The NEFC basin is also host to large events, therefore the shoreline design needs to support public access, gathering and use. Sharing this common resource is critical for the health of Vancouver (wellbeing + a culture of waterfront stewardship). While developments under consideration in Parcel 6b and Parcel 6c are in different stages of design development, the following recommendations are intended to shape and guide decision-making at all design stages, for all parcels, to encourage and maximize the public nature of the waterfront. Public connectivity considerations include:

- Align visual corridors with street grid, (as throughout most of Vancouver) providing a continuous view to the water – avoid cul de sacs and streets parallel to the shoreline;
- Improve view corridors in the development, siting and arranging buildings to maximize light, air, and visual access to water from upland areas;
- Ensure the public nature of the waterfront; limit commercial uses on the shoreline; place building service access off water-facing facades of buildings;
- Reduce physical barriers to the site, such as poorly placed raised planting bed, fences, or visual obstructions such as light poles;
- Provide clear access to the shoreline: well marked and safe street crossings, including wayfinding features that considers blind or visually impaired users;
- Provide priority phasing of shoreline construction and provide public access along the shoreline before the development parcels are complete.

### 4.2.3 Water Transport

While marinas provide access to the waterfront, they also can limit public water access and space for habitat by taking up valuable shoreline. To limit the negative effects marinas can impart to the environment the following items should be considered:

> Increase amount of light accessing underlying habitat areas: use transparent surfaces such as grates or glass block; use narrow overwater structures;
> Limit the number of marina access points;
> Consider not providing service functions in this location. If service functions are necessary, conceal utility services underground and/or underneath the gangway;
> Optimize docking orientation and platform layout for maximum volume of marine traffic and minimize impact on any nearby boating or public access.

### 4.2.4 Recommendations for Surface Features

Shoreline conditions represent several challenges to landscape materials: salt spray leads to advanced corrosion, occasional flooding of items near the shoreline increases susceptibility to scouring, undermining of base, and uplift. Solid stable foundations of these items are required to resist hydrostatic, hydrodynamic and buoyant forces. Recommendations are for durable materials that can resist corrosion, erosion, saltwater, flooding, heat, cold, wind, and ultraviolet light.

In general, the NEFC area under consideration is a brownfield site and successive years of industry have left soil conditions that do not permit percolation, or the absorption of stormwater. Many of the recommendations below are landscape solutions that can help deal with surface areas that are unable to absorb stormwater, and hence tend to flood. Incorporating permeable soil areas as surface features on landscape solutions that have a propensity to flood can help to attenuate peak flow runoff.

#### 4.2.4.1 Concrete

> Concrete is recommended as a material in and above floodplain for both paving and edging as it is durable, able to withstand wave action comparably resistant to corrosion, effectively sheets water, and can be made locally.
> In areas susceptible to flooding and harsh shoreline conditions: use clean aggregate, (not recycled), ensure adequate cover protection, and epoxy-coat reinforcing.

#### 4.2.4.2 Steel

> Limit steel use to higher elevations where wave action and prolonged inundation are less likely.
> As an edging material steel is strong but subject to corrosion and detachment/underpinning in strong wave action. Avoid use in floodplain. For expansion joints, use galvanized steel. If using a self-weathering finish, either in a raised planter or furnishing, ensure catchment of dissolved rust in a gravel detail.

#### 4.2.4.3 Asphalt

> Asphalt can be used in the floodplain provided it is installed with solid base material (civil engineer to specify based on soil conditions) and edges are contained with a resilient edging material (see above) to avoid erosion and cracking.

#### 4.2.4.4 Pavers

> Precast concrete pavers in themselves are recommended and durable, only if the base is properly designed and secured with significant edging.

- Use a concrete or asphalt base; adhere with bitumen or mortar. Sand setting is not recommended for shoreline areas or in the floodplain.
- Porous pavers are not recommended for near the shoreline or in the floodplain as infiltration in this site is limited and the pores will be clogged by debris. Use porous paving further upland.

#### 4.2.4.5 Timber/Boardwalks

- As decking: wood is susceptible to rot and requires detailing to ensure drainage and to prevent uplift. Tropical hardwoods are resilient but must be sustainably sourced. Other woods may include decay-resistant local red and yellow cedar in larger member sizes. As a recommended alternate to wood planks: precast concrete planks can be used. Recycled plastic lumber is not aesthetically suited for public realm purposes and is not recommended.
- As edging material: wood not recommended in shoreline or in floodplain. Warping, damage, and subsequent undermining of pavement base due to prolonged inundation is likely.

#### 4.2.4.6 Boulders and Large Rocks

- Boulders and large rocks used for furnishing or other landscape feature are highly resilient: they are resistant to scour and generally speaking their weight will prevent unwanted movement. Boulders placed within the floodplain should be set upon a compacted base of gravel, and be subject to structural review.

#### 4.2.4.7 Logs

- Using large-diameter logs as furnishing, play elements, or other landscape feature is recommended: they weather relatively well, and their size allows for long term use before needing replacement.

#### 4.2.4.8 Other Materials

- Aluminum and high-density polyethylene are structurally weaker compared with concrete and steel.
- Avoid use of loose materials such as gravel and screenings, as these materials are susceptible to contamination during flood events. Limit gravel to naturalized areas where the public has a lesser chance of contact. Small height vegetative retaining walls may also be a design feature in areas not subject to tidal influences.

### 4.2.5 Structures + Site Amenities

There may be a need for structures (art installations, shade canopies, exterior covered areas, trellises, conditioned spaces) as part of Park and waterfront programming. Conditioned spaces or other architecture should be positioned above the floodplain. Art installations set above the floodplain should be designed to be weather resistant and robust to withstand the wear of public realm. Art installations or other supporting structures (such as canopies First Nation welcome poles) placed in the floodplain will need review by an engineer to ensure structural resiliency near the shoreline and in the floodplain. Generally, they should be situated on higher ground, and the surrounding topography should be designed to provide protections against flooding or shoreline damage.

Play is an important part of outdoor education and recreation. Traditional playgrounds – program spaces with play surfacing, equipped with proprietary play equipment, supported by furnishing and elements like water fountains – should be set outside the floodplain to protect the typically high level of investment. Use resilient materials such as galvanized steel, large format lumber, composite or concrete materials. For play program spaces set within the floodplain: design play to rely on landforms, plantings, and resilient materials and elements (see above); ensure drainage around and beneath play areas, do not use fencing,

### 4.2.6 Furniture

Furniture is an essential ingredient for a successful and vibrant public realm.

#### 4.2.6.1 Seating

Shoreline seating should incorporate a variety of seating options that are urban -scaled and suitable for the public nature of the shoreline. Seating placement should support visual connections. The public shoreline is not a place for ornate and dainty furnishing; furnishing should be robust and tough to handle the elements, high traffic, and frequent use. Steel, concrete, stone and large-format wood slat are recommended materials, as shown below in Figure 4.

Figure 4 - Robust Public Furnishing example: simple, inornate, and civic-scaled furnishing in large wood slat and concrete formats. Cornell Campus, Roosevelt Island, JCFO.

#### 4.2.6.2 Railings

- Railings and guardrails may be required along the shoreline. Low railings should be used in areas where there is no drop-off, but where frequent public access is discouraged, for example along a shoreline habitat area.
- Railings should be resilient – stainless steel is recommended, complete with a top rail profile which is smooth to the touch; wood or precast are suggested top rail materials. All railings will need to adhere to municipal code requirements.

Figure 5 - Resilient guardrail: stainless steel infill on galvanized steel structure (c/w gaskets to prevent galvanic action) topped with generous + comfortable sustainably sourced wood top. Seattle Waterfront, JCFO.

#### 4.2.6.3 Lighting

> In development of lighting of the public realm along the shoreline, minimal lighting is recommended in pursuit of dark skies. Vancouver's Outdoor Lighting Strategy should also be reviewed and considered. Light studies are required to determine if safe adequate lighting can be provided in the public realm near the shoreline (1 foot-candle is the general target). Amenity lighting may not be required beyond that provided by the street lighting and building facades. Lighting is not meant to light up the water or habitat areas and should be limited to accent lighting along furnishing and railings and street crossings. (Figure 6).

Figure 6 - Lighting along shoreline is limited to feature guardrail lighting, deferring to context and habitat. Victoria Dockside, Hong Kong, JCFO

> Electrical conduits and streetlight bases may be installed into / on the flood protection. The conduits of the floodplain lighting shall be setback a minimum of 1 m from the wall face, and be installed at a minimum depth of 1 m. If typical electric lighting is used, design upland lighting to be on separate circuits from floodplain lighting. This will allow upland lighting to remain functional should a flood event damage the electrical lines in the floodplain.

#### 4.2.6.4 Other

> To support the public and high-use nature of the shoreline, various supporting furniture such as bike racks, drinking fountains, bollards, and trash and recycling bins should be provided, however they should be limited at the waterfront edge to avoid clutter. In addition, specialty or expensive furnishing items such as fitness equipment and water-play elements need to be located upland, out of the floodplain. Elements supporting First Nation programming such as "Fire Pits" are outside the domain of this document and need further specific case-by-case review.

### 4.2.7 Planting

The shoreline systems (vertical seawall and upland berm) described in this document are not discrete systems; they are complex systems, interacting with surface and subsurface infrastructure, defining much of the shoreline ecology and public realm landscape architecture. Indeed, the vertical seawall forms the very interface between land and water, while the upland berm system is integrally part of parkland tissue. This performance criteria document therefore features expansive recommendations for addressing water's edge habitat creation, planting, and the shaping of the public realm.

Planting is one part of public realm improvement and habitat creation (see Section 4.5). This document is not meant to be a comprehensive planting selection document, rather, it highlights strategies that compliment a shoreline structure. Both shoreline flood protection systems must be multifunctional: they will be installed at considerable cost and take up considerable footprint in premier urban waterfront sites; they cannot simply be barren engineering structures. They will simultaneously support habitat, public open space, and park space. Planting, as a critical part of habitat creation, improvement to public open space and park space will be integrated near and on both shoreline systems.

False Creek is a marine inlet in the Salish sea, and in the past was host to an incredibly dynamic shoreline environment, providing a huge range of critical structures and process from aquatic to upland zones, sustaining a diversity of ecosystems, habitats, and species. Vancouver relies on its shoreline for its identity, health, and welfare of its waterfront communities. Figure 7 identifies shoreline zones for an idealized shoreline section.

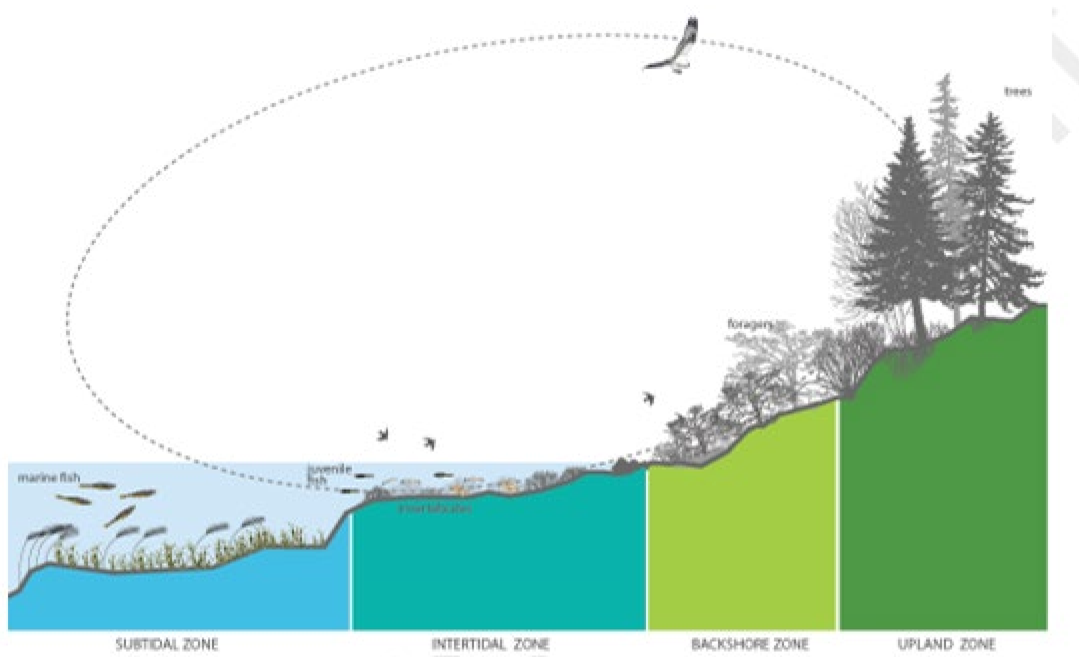


Figure 7 - Ideogram representing an ideal shoreline section, interactive and complete with all shoreline zones.

The False Creek shoreline area has been drastically urbanized, and original ecological conditions cannot be recreated. Shoreline interventions, such as the flood protection systems, can only create elements along the shoreline that enhance the capacity of the False Creek ecosystem, to provide ecological functions for marine life typical of the southwest coast of British Columbia. In broad terms, the shoreline system spans aquatic and upland zones, with intertidal and backshore areas making up the middle gradient. Planting selection needs to correspond to these zones, to not only be fitting to their particular zone, but also to properly host animal species and play a part of the larger ecosystem. See Table 4 below for a sample of planting species, organized by shoreline zone, that support select indicator animal species (developed as part of the park design development).

Table 4 - Planting Species, organized by shoreline zone

| Zone | Habitat Name | Plant Species | | Indicator Animal Species |
|---|---|---|---|---|
| Aquatic | **Kelp Reef**<br>*The interstitial spaces between stacked rocks provide protection for small fish. Boulders are colonized by kelp and other seaweed that larger fish use for protection from predator. The reef protects the eelgrass meadow from highwaves.* | Wireweed<br>Sugar Kelp | *Sargassum munitnum*<br>*Saccharina latissima* | Sea anemones<br>Starfish<br>Sea worms<br>Mussels<br>Barnacles |
| Subtidal: | **Eelgrass meadow (-4m)**<br>*Eelgrass is home to a great diversity of species. TThe herring spawn will attach tothe eelgrass drawing birds to feed on eggs and small fish. Eelgrass habitat has great educational potential and is the highest value marine habitat in False Creek.* | Eelgrass | *Zostera marina* | Clams<br>Juvenile and adult Dungeness crabs<br>Herring (larval, juvenile and adult herring<br>Juvenile salmon, Shiner and Pile perch<br>Shore birds (heron, ducks) |
| Intertidal: | **Intertidal Cobble / Boulder Field (-3.5 to 0m)**<br>*The intertidal beach occurs on the upper tidal range. Many animals are buried in the sediment, including clams and many types of worms.* | Rockweed<br>Filamentous algae<br>Encrusting algae<br>Small algae | *Fucus gardneri* | Shore crabs , Starfish<br>Fish (blennies, sculpins shiner, pile perch, juvenifish, juvenile salmon + larval herring)<br>Shore birds |
| Backshore: | **High Marsh/Dune (1.5 to 3.5m)**<br>*The highmarsh / dune habitat is made up of drought and salt tolerant plant species. Flowering dune plants support native pollinators throughout the summer.* | Dunegrass<br>Ambrosia<br>Gum flower<br>Beach pea | *Leymus mollis*<br>*Ambrosia chamissonis*<br>*Grindelia integrifolia*<br>*Lathyrus japonica* | Voles<br>Small perching birds inclusing sparrows<br>Butterflies<br>Bees |
| Upland: | **Upland Forest**<br>*Upland forest will increase the canopy cover in the neighborhood and include a diversity of native tree species that prefer generous soil volume and create the framework for native under-story species. The upland forest is a native habitat that supports foraging and nesting birds. Flowering native shrubs support native pollinators.* | Douglas fir<br>Western redcedar<br>Pacific dogwood<br>Bitter cherry<br>Blueberries<br>Salal<br>Oregon grape<br>Beaked hazelnut<br>Sword fern | *Pseudotsuga menziesii*<br>*Thuja plicata*<br>*Cornus nutallii*<br>*Prunus emarginata*<br>*Vaccinium spp.*<br>*Gaultheria shallon*<br>*Mahonia nervosa*<br>*Corylus cornuta*<br>*Polystichum munitum* | Douglas squirrel<br>Shrews<br>Small owls<br>Perching birds: towhees, thrushes,<br>Stellar's jays, crows<br>Carabid beetles |
| | **Grassland Thicket**<br>*The grassland thicket is adapted to hot temperatures in summer. Mass plantings will attract bees, butterflies andhummingbirds to enjoy the flowers. Plants flower earlier in the season providing early forage for pollinators. Birds can also nest in the long grass.* | Native hawthorne<br>Saskatoon<br>Beaked hazelnut<br>Wood's rose<br>Baldhip rose<br>Sitka brome<br>Larkspur<br>Yarrow | *Crataegus douglasii*<br>Amelanchier alnifolia<br>*Corylus cornuta*<br>*Rosa woodsii*<br>*Rosa gymnocarpa*<br>*Bromus sitchensis*<br>*Delphinium dissectum*<br>*Achillea millefolium* | Voles and moles<br>Perching birds: sparrows, juncos, finches, varied thrushes<br>Hummingbirds<br>Bees<br>Butterflies |

Generally speaking, goals for successful plantings for and near shoreline structures should consider:

- Playing a functioning role in the active shoreline ecosystem by hosting other species;
- Supporting native, rare, and biodiverse ecosystems through planting and management;
- Not interfering with shoreline structures;

- Reduce water use;
- Have the potential to filter run-off;
- Reduce erosion in flood events.

Planting design recommendations for and near shoreline structures include:

- Design planting beds to be few and large, filled with dense plantings, with small plant palettes arranged in swaths. Grouped plantings are encouraged due to the benefits of trees in close proximity. These benefits include increased shading, less evapotranspiration, less soil compaction, greater shared soil volume, and less reflective heat absorbed by a single tree. A grouped planting can be achieved in several types of sites: a "greenstreet", such as a median or traffic triangle, with opportunity for a large planting bed; a continuous tree pit, where two or more trees are planted in a single trench in the sidewalk (at least 10 m long); or a raised planting bed as within a plaza or alongside a pedestrian passageway.
- Small beds, with large spaces with complex planting plans are subject to failure and risk being choked out by weeds. Plant large areas of hardy shrubs over small perennials. Select plants that do not require extensive irrigation to reduce site complexity.
- Select native species and support threatened and migratory species to enhance habitat robustness and biodiversity. Plantings, especially those in the floodplain should be designed to be flooded or washed over, with minimal repair and replacement cost.
- Irrigation in floodplain areas, if used, should use quick coupler valves and hydrants – in-ground irrigation should be reserved to upland areas.
- Plants selected should be tolerant of shoreline context. Ensure that plantings can withstand harsh coastal conditions, floods, storms, drought, wind, and salt spray. Planted species should be tolerant of salt, sediments, high seasonal water flow, and, in areas with sandy soil, drought. Fortunately, the robust palette of coastal plant communities listed above have evolved to thrive under these harsh conditions.
- Natural turf, while not being great for supporting habitat, is great for a variety of flexible recreational and passive uses and holds up great in the floodplain as it handles inundation well. The designer of the shoreline features shall ensure positive drainage to ensure recovery after flooding. Prevent soil erosion with proper edging and maintenance. The planting season should be carefully determined to encourage sufficient root development prior to the plant dormancy season in order to give the plant the optimal chance of success.

### 4.2.8 Trees

Trees are an essential component of the outdoor public realm: they provide shading, and comfort, habitat for shoreline and migratory birds, and are effective stormwater tools. Trees will inevitably be included in a shoreline design.

The following are some recommendations for tree planting for shoreline structures and near the shoreline:

- Vegetation management and planting on shoreline protections structure shall conform to the "Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment (MELP, DFO, 1999) – refer to Ref [21].
- Trees should be located to provide shade, particularly on pavement, seating, and play areas. Shade will provide comfort to users, as well as keep surfaces cool to reduce the urban heat island effect.

- Tree pits should be as large as possible to allow for ample growing space for tree roots and crown. Optimal tree pit size would be 1.5 m by 4 m, with continuous tree pits whenever possible. Tree pits shall be continuous wherever group plantings are involved. Tree pits need to be properly located to not interfere with shoreline protection structures.
- Trees located within the 15 m setback of the vertical seawall will be installed in properly sized enclosed containment (e.g. enclosed pits or large pots), or unless designed such that they do not affect the integrity of the flood protections structures. Designers may suggest alternatives for tree and shrub planting, provided the recommendations are based on a thorough design review. Design alternatives shall be subject to approval by the City.
- Trees planted near the shoreline should be installed with a salt barrier; a geotextile composite product, non-woven, thermally laminated either side to a drainage core, enabling permeable capillary break and barrier to salt.
- All designs should carefully consider the critical root zones (CRZ) of existing trees.
  - Shrubs should not be planted within CRZ;
  - Avoid running utility lines through CRZ.
- Tree plantings are not recommended on the flood protection earthen berm crest. In these circumstances it is recommended to contain trees or shrubs within an enclosed containment (e.g. enclosed pit or large pot). Designers may suggest alternatives for tree and shrub planting, provided the recommendations are based on a thorough design review. Design alternatives shall be subject to approval by the City.
- See Section 4.5.4 for recommendations on planting near earthen berms.

## 4.3 Surface and Sub-Surface Drainage

### 4.3.1 Rainwater Management / Green Infrastructure

Typical surface and subsurface drainage management techniques for vertical wall and earthen berm flood protection designs will direct water off or away from the structure, either directly through swales or storm drains at the edge of the berm or behind the wall, or over the wall and into the adjacent water body. Regardless of drainage method the design will need to consider storm events with possible overland flow to ensure the drainage system is not overwhelmed. For vertical walls, the drainage design shall consider the collection and safe conveyance of water that could pond on the land-side of the seawall / floodwall during wave overtopping events.

Redevelopment of NEFC streets, parks, and private land, and incorporating flood protection infrastructure, also provides opportunities to include green infrastructure measures to protect watershed and improve water quality. The appropriate applications of green infrastructure should attempt to mimic the natural water cycle at the development, targeting small storm events to infiltrate rainwater to maintain a water balance. Appropriate green infrastructure should be selected based on subsurface conditions and capacity to infiltrate. In areas with no infiltration capacity, strategies should focus on detention.

In accordance with the City of Vancouver Engineering Design Manual (Ref [6]), green infrastructure design targets shall achieve both volume reduction and water quality as follows:

> Volume Reduction
  - Retain the first 24 mm of rainfall, (50% of the 6 month - 24-hour return period storm) 70% of the average annual rainfall volume through onsite infiltration and evapotranspiration or rainwater reuse.
> Water Quality
  - Treat the first 48 mm of rainfall, (6 month - 24-hour return period storm) 90% of the average annual rainfall volume) to remove 80% of Total Suspended Solids (TSS).

Green infrastructure should be implemented to collect, store and treat runoff from the upland berm drainage and the seawall drainage at the design phase of the infrastructure development and include:

> Rain Garden
  - Rain Gardens are landscape features designed to store and treat stormwater runoff from hard surface areas such as roofs, roads and parking lots by promoting infiltration and evapotranspiration.
> Vegetated Swales
  - Grassed ditches are commonly used in highways and roads. They can provide both stormwater conveyance and treatment for pollutant removal by filtration through grass and infiltration through soil.
> Infiltration Trenches
  - Infiltration trenches are shallow excavations with rubble or stone that create temporary subsurface storage of stormwater runoff, thereby enhancing the natural capacity of the ground to store water. Infiltration trenches allow water to exfiltrate into the surrounding soils from the bottom and sides of the trench.
> Absorbent landscapes
  - Include either natural or manmade landscapes that act like a sponge to soak up and slowly release rainfall.

Green infrastructure used on site should achieve both stormwater volume reductions and water quality improvements. Oil and grit separator systems are also an effective water treatment facility that can be installed to treat stormwater if necessary, prior to discharging to False Creek.

Implementation of Green Infrastructure should be integrated in the site drainage design and park landscape design practice, such as using vegetated swale instead of underground sewers, as long as the space is available, and creating rain garden, absorbent landscapes, and/or infiltration trench in landscape area wherever possible. The locations and type of Green Infrastructure to be used shall be evaluated during the design phase based on, soil type, underground water table, overall landscape layout, and flood protection structure location.

Similarly, there are plenty of opportunities to provide Green Infrastructure near the vertical seawall and surrounding earthen berms, such as a permeable promenade behind the seawall, planters placed in the rest areas, bio-swales and infiltration trenches on each side of earthen berms, and grassed slopes on the earthen berms. The location of such Green Infrastructure will need to be reviewed very carefully from the context of where it is being located.

In general, Green Infrastructure should be located above the flood control level to minimize damage in the event the area is subject to flooding. In the park areas flooding to that extent may not occur for several years. Designers may suggest alternatives for Green Infrastructure provided the recommendations are based on a thorough design review. Design alternatives shall be subject to approval by the City

## 4.4 Service Utilities

Service utilities in this section refer to City owned infrastructure and / or third-party utilities, such as Fortis and BC Hydro. In general, it is preferable to avoid utility crossings through water retention structures. Utilities which require crossings should consider the recommendations below. The utility design should ensure that hydraulic pathways across the flood retention structures are not formed.

### 4.4.1 Vertical Wall Service Utilities

The main utility presently being considered along the section of the vertical flood protection wall is the Abbott stormwater outfall that will discharge into False Creek approximately between the Plaza of Nations (Site 6B) and Concord Pacific (Site 6C), near Georgia Plaza. No other outfalls to service individual site stormwater will be allowed by the City and must therefor connect into the City stormwater system instead. The City of Vancouver design guidelines shall be followed, and good engineering practice applied, in the design of outfalls and utilities crossing the flood wall.

The Abbott 3 m by 3 m box culvert will be installed at a depth of approximately 5 m below ground level. In False Creek, a 20 m length will be exposed with an interim 1.8 m diameter corrugated steel pipe section at the end, protected by rip-rap. The interim outfall pipe is to be modified/removed upon shoreline development. Within False Creek, due to the required over-excavation for placement of bedding material, it is likely that the box culvert will be placed on hard till, as the soil cover is minimal.

The vertical flood protection wall is to be installed after the stormwater outfall is in place. It will be important that the exact location of the box culvert is identified prior to commencing construction in the vicinity of the outfall. Once the preferred vertical flood wall option is selected, ensuring an impervious seal between the wall structure and the box culvert should not be overly problematic, although it may increase the construction costs.

For the case where the flood protection wall is to consist of rigid structural elements such as driven sheet piles or soldier piles, the structural elements can be placed as close as possible to the sides and top of the culvert, with the space between the two grouted to ensure no preferential flow. Where the flood protection wall is to be constructed using soil mixing, or bored diaphragm or soldier piles, excavation in immediate contact with the box culvert should be possible. Subsequent concrete/grout placement will ensure a seal between the wall and the culvert.

Other utilities in the area will likely be placed at shallow depth. Where necessary, panels can be cut into the vertical wall where utilities need to pass through the wall. However, many of the utilities will be required for infrastructure behind the vertical wall and the need to provide access through the wall is expected to be limited.

### 4.4.2 Earthen Berm Service Utilities

Utilities that service the park would include water, storm sewer, sanitary sewer, electrical duct, or groundwater perforated pipes. In general, utility crossings should be avoided through water retention structures such as earthen berms. Incorporating utilities parallel to the berm alignment is not a major concern provided the design and construction procedures ensure that hydraulic pathways across the width of the earth structure are not formed. In terms of location, provided the utility does not compromise stability of the downstream slope, there is generally no restriction on how close these can be placed.

Where utilities cross the berm alignment, these are commonly embedded at some depth beneath the earth structure itself and generally do not impact the berm. The prime objective is to ensure that no preferential seepage pathways are facilitated from the upstream to the downstream side. Depending on the size and shape of the utility crossing, different options can be implemented to avoid preferential seepage across the earth berm. Possible options are considered in the Dike Design and Construction Guide ((Ref [20])).

In many instances, utility crossings are required for maintaining onshore drainage. Throughout the Lower Mainland there exist many coastal and river dikes where culverts have been installed at pump stations used to maintain water levels in the drainage ditches behind dike systems. Generally, culverts are installed in the foundation soils underlying the berm and measures are taken to avoid the creation of preferential seepage pathways. Apart from good design, careful construction is paramount to the adequate functioning of any system that needs to traverse a dike structure.

Critical to the design of any utility crossing a berm is the adequate sealing of the structure-soil interface to ensure that preferential seepage does not occur. The design of the contact between the soil and the rigid utility should also consider the possible settlement of the berm over time so that cracks/voids do not open between the two. In this respect, the use of geomembranes to effectively seal potential seepage pathways is an effective approach employed where utilities need to cross dike structures. Seepage collars and clay plugs have also been considered in the past provided they account for expected future ground movements. However, current design practices in BC avoid the use of seepage collars, instead placing granular filters around the downstream section of the pipe to safely manage seepage. Many of the design and construction guidelines for dikes include options for constructing this type of interface. Flood protection utility crossings must be designed by a Qualified Professional Engineer.

## 4.5 Habitat Creation

The NEFC shoreline area was once a rich and diverse shoreline area, featuring countless freshwater streams coursing through coniferous forest and tidal flats, abundant with clams, oysters, mussels, and crabs providing food and habitat for migratory birds on the Pacific Flyway, stewarded by Musqueam, Squamish and Tsleil-Waututh peoples since time immemorial. Shoreline ecosystems are critical habitats for fish of cultural, ecological and economic significance as they are nurseries for juvenile fish, critical parts of larger ecosystems, attracting whales such as orcas and dolphins, while the dense coniferous forest was home to bears, elk, cougars, and deer. Today, the area is host to a dense urban environment, which has significantly decreased habitat offerings: the shoreline has been hardened and simplified through successive years of urbanization and industrialization, affecting the ecology of nearshore systems by restructuring, eliminating and shading shallow waters. The water quality of False Creek is degraded, consistently exceeding BC water quality objectives in the warmer months.

**It is necessary to improve shoreline conditions and restore some form of nearshore ecosystem functionality. Any new development in this area has a responsibility and a role to play in improving shoreline conditions and the water quality in False Creek**.

Figure 8 - Image of Shoreline area of False Creek flats, depicting conditions prior to industrialization and urbanization: rich habitat, shoreline area with marine grasses (Vancouver Archives)

Figure 9 - Image of contemporary shoreline area of False Creek, depicting barren shoreline conditions left after years of successive industrialization and shoreline urbanization: devoid of substantial habitat and deteriorating water quality (image JCFO)

In addition to providing sea level rise defense, the goal of shoreline structures and development need to include improving water quality and increasing overall natural habitat.  Design plans need to describe how these goals are to be reached.  Impacts to, or reductions in, these habitats should be avoided, minimized, or mitigated through design and construction. Guidelines for water and sediment quality criteria and minimizing habitat impacts can be found in Section 2.5.

Larger and continuous habitats provide greater quality, facilitate wildlife species movement, encourage pollinator species, and enable native species colonization of formerly void areas. The linear quality of the sea level rise defense presents a major opportunity for creating a long continuous aquatic, intertidal and upland habitat.

> For the linear shoreline barrier and along the horizontal surface of the berm: this is an opportunity to build a long continuous habitat system: plant regular swaths of upland pollinator-friendly plants.
> Existing habitat: increase the quality and robustness of existing habitat by extending it and continuing it; for example, the legacy forest "planted triangle" can be reinforced and connected by planting salt marsh plants in lower-lying flood plain and salt-tolerant native coastal shrubs and trees upper floodplain along the shoreline in the Plaza of Nations site.
> In addition to creating connections horizontally, upland areas can be connected vertically to intertidal habitats through a more naturalized slope – approximating gradual slopes will enable this connectivity

The shoreline protection design shall comply with considerations and principles provided by the Coastal Adaptation Plan guideline (Ref [7]). Habitat is sensitive and fragile, and is generally incompatible with the anticipated heavy human activities and traffic in this area – cyclists, pedestrians, pets, marine traffic, etc. Protect habitat with design barriers and buffers where needed to separate sensitive ecosystems from human activities, such as elevated walkways. Provide a buffer between areas of high vessel traffic and submerged aquatic vegetation. Limit structures over water (cantilevered decks, floating docks, and piers) and wetlands or other vulnerable habitats. Restrict access to sensitive habitat and ecosystems with placement of railings on adjacent sections of boardwalk.

### 4.5.1 Waterside Façade Forms

A vertical flood wall form of protection is incredibly spatially efficient for creating space for urban environments, but it is also extremely different from a complex natural shoreline, with its smooth surfaces and abrupt water zonation and uniform water depth. The design should consider enhancing the vertical seawall's capacity to support diverse habitat. This could include wall features which provide roughness, crevices, and overhangs. Access to light, and surface roughness (small-scale variations in the height of a surface) and crevices are important habitat features, especially as refuges from physical disturbance for invertebrates such as mussels, chitons, limpets, and snails. The design of waterside façade forms will require the expertise of environmental specialists to ensure the infrastructure is conducive and compatible to both aquatic and terrestrial life.

Ecological capacity on a vertical seawall can be introduced in a variety of ways and scales: surface roughness and complexity; enhancing the immediate seawall toe or seabed, ensuring light access to the nearshore, and by introducing a number of features along the length of the shoreline with beaches or other large intermittent seabed features. These strategies are all demonstrated in the Seattle seawall project by MKA engineers (implementation) and JCFO (landscape + urban design). Seattle's Central Elliott Bay Seawall Replacement Project (EBSRP) is a massive urban infrastructure project which addresses current issues of sea level rise, ecology and aquatic habitat rehabilitation while in the center of a large port city. The EBSRP replaced 3,700 linear feet of derelict seawall with a new state-of-the-art, seismic-resistant seawall that is seamlessly integrated with an unprecedented salmon migration corridor, an enhanced tidal marine environment, and an updated pedestrian promenade.

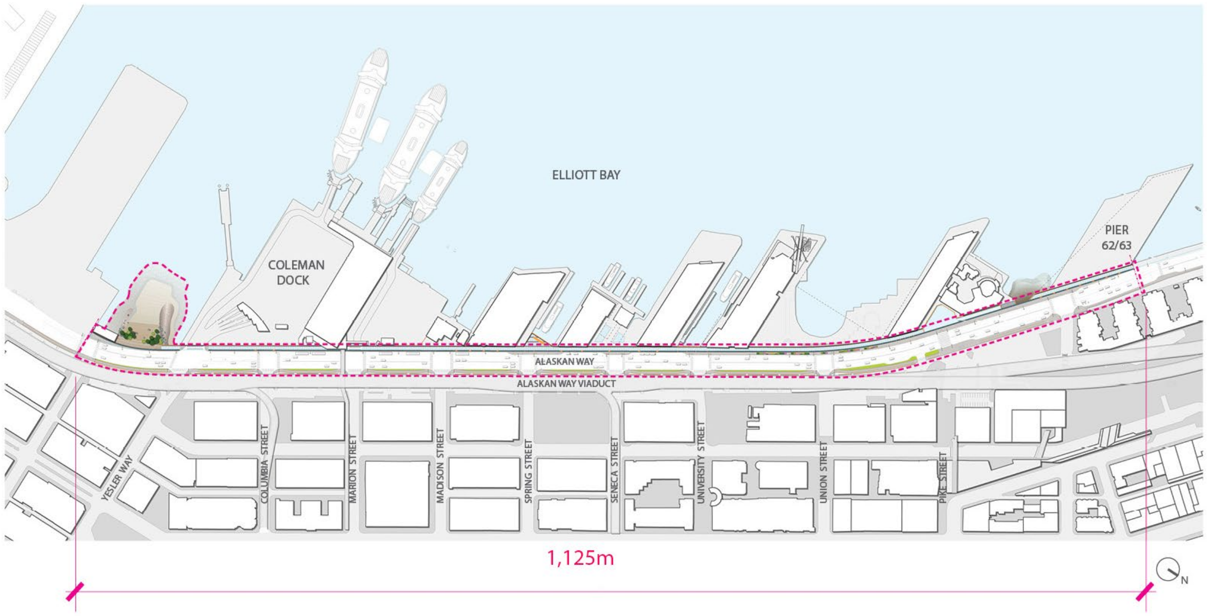


Figure 10 - The EBSRP project: over 1 km of seawall replacement in downtown in Seattle with a high level of focus on habitat creation.

The EBSRP is unique among public realm projects due to the high level of collaboration between landscape architecture, civil/structural/marine engineering, infrastructure specialists, and aquatic habitat specialists. Innovative habitat creation is paired with integrated public realm design, which both contribute to the health of marine life while positively engaging the public in understanding all issues at stake. The result is a new model for infrastructure investment that benefits the city, the public, and the ecosystem.

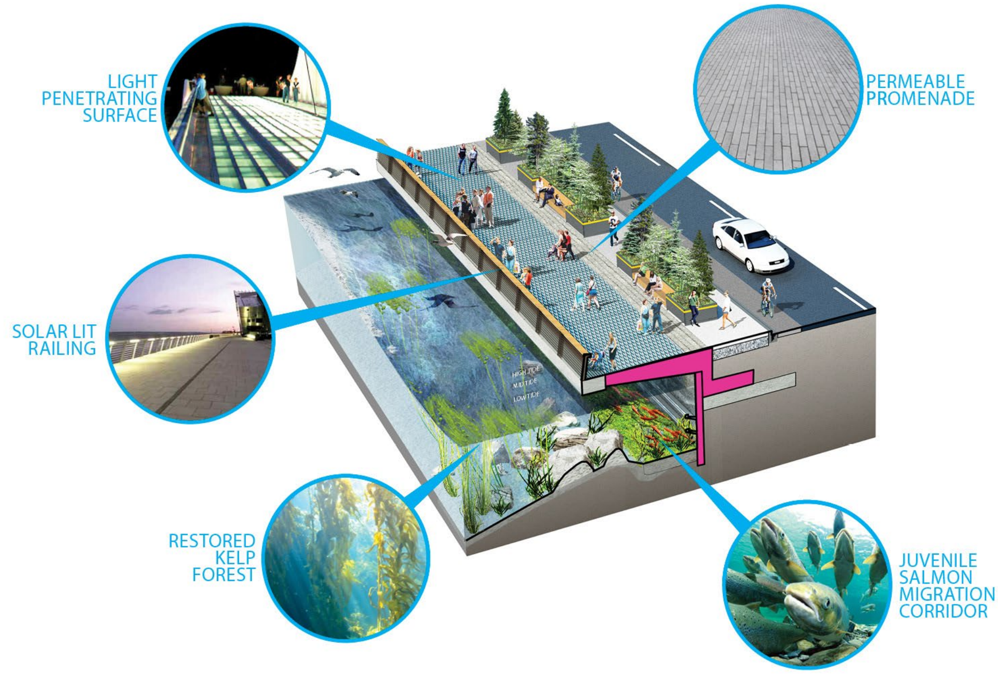


Figure 11 - The simple infrastructural improvement (seawall) is leveraged as a complete project, with integrated marine habitat, an expanded pedestrian realm, and plantings.

Generally speaking, overhanging or cantilevered structures shade the nearshore, creating problems for creating habitat. The EBSRP project used seabed improvements along the length of the seawall, at the toe to provide elevational gradients, access to light, and complexity of shoreline, creating a linear habitat corridor. Here, along the developed waterfront, fish have sufficient access to prey, reproductive areas and shallow refuges from predators. This area was ensured light through a transparent pedestrian surface. As shown below, the seabed treatment varied along the length of the intervention, and in one instance included a complete "habitat beach" with full spectrum of rocky intertidal zonation. Criteria for seabed improvements include:

> Improve seabed access to light and nearshore zonation by raising seabed floor.

> Create difference and variety along the length of the seabed floor with various seabed enhancements.

> Improve seabed access to light by minimizing overhanging structures. If overhanging or other over-water structures must be used, minimize size and shape to ensure light penetration, Incorporate perforations with glass block or with metal grating.

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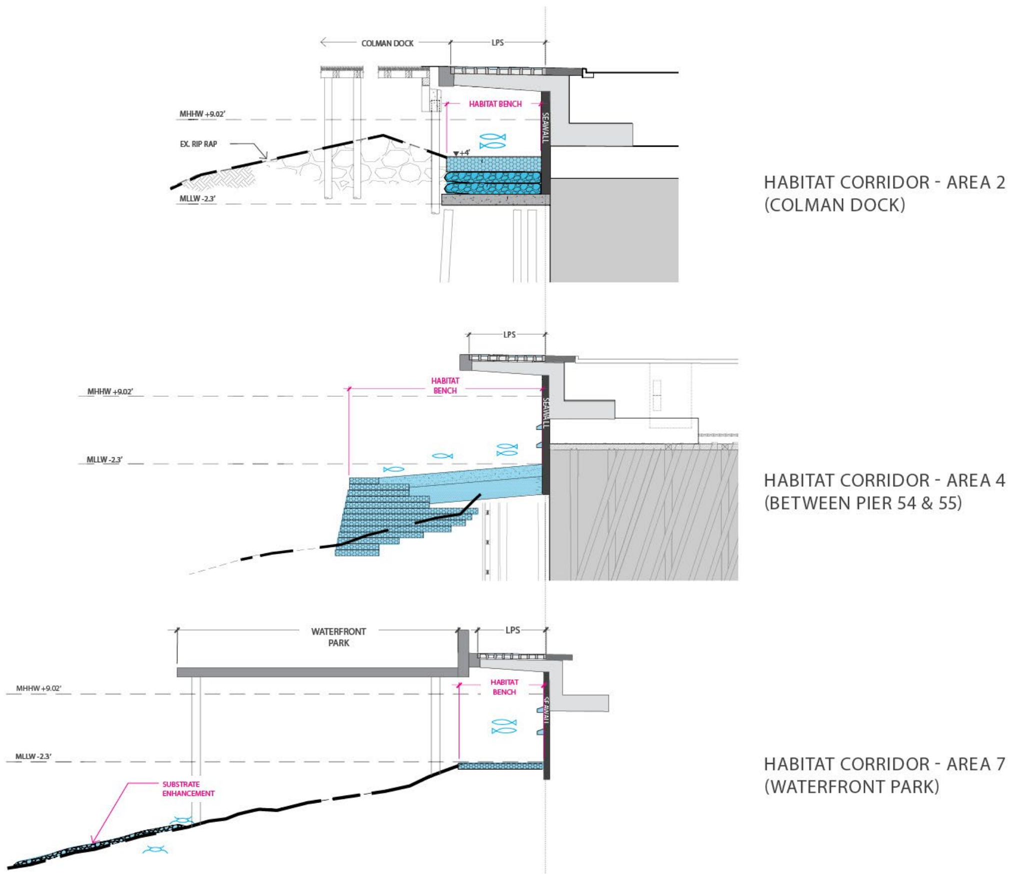


Figure 12 - The seawall included improvements along the seabed along a range of shoreline conditions, re-establishing a salmon migration route by offering light and water depth conditions that mimic a natural shoreline and deter predators.

Studies show that seawall texture and relief, mimicing shoreline “roughness” and interstitial spaces of varied size and shape are effective at hosting life. Roughness can be achieved with the use of form liners or molds. In the case of the EBSRP, a two-inch thick relief, in conjuntion with shelves was chosen after years of field studies. Additionally, structural features can provide more heterogeneity and habitat-supporting complexity. Shelves or habitat and reef modules can be added to the face of these panels to create overhangs and more relief. In locations where the seawall face is exposed and visible to the public, special attention is warranted to create a unique visual display of habitat and sea level rise: in the EBSRP, three types of seawall face were developed using form liners.

Figure 13 - The textured the seawall with marine mattresses forming the re-established salmon migration route, the "shelves" on the left, the cantilevered "Light-Penetrating-Surface" above, (and temporary construction barrier on right). Where the seawall is exposed to views, the textured seawall provides datums for various tide levels. Cantilevered pedestrian surface above.

Criteria for creating habitat on seawall face include:

- Create rough, textured, surfaces or varied sizes of rock that create interstitial spaces of varied size and shape; that has at least 5 cm of depth;
- For the vertical flood wall composition, concrete composition for saltwater conditions is required. Also, materials preserved with potentially toxic substances, such as chromated copper arsenate, creosote, or others that can leach into the aquatic environment, are to be avoided. Use edge materials that have a chemical composition, alkalinity, toxicity, pH, and other features that support the native biological community and attachment of characteristic marine organisms;
- Other in-water structures (pier piles, bulkheads) should be also be considered as above: do not use treated wood; use roughened concrete to allow adhering of encrusting organisms;
- Create visual interest for areas that are exposed to the public.

Figure 14 - Desired results: algae and invertebrates colonizing the vertical seawall panels with shelves and textured surfaces; salmon fry using the lit and raised seabed floor. Seattle Waterfront Seawall, JCFO + MKA.

### 4.5.2 Water Side Slopes and Transitions to Support Fish & Wildlife

Berms are typically located close to the shoreline, resulting in loss of habitat in intertidal and nearshore areas. For the NEFC project area, the alignment of the upland berm has been set back well from the waterfront, leaving substantial area for incorporation of habitat on waterside transitions: options for incorporating habitat in bench form are listed below.

NEFC shoreline modifications, similar to other development areas within False Creek, may require authorization under paragraph 35(2)(b) of the *Fisheries Act* for residual temporary and permanent changes to fish habitat resulting from construction of marine infrastructure (sheet pile, outfalls and other foreshore works). Once final design has been agreed upon and the effects to fish habitat can be quantified, it will be necessary to balance any negative effects through habitat offsetting (compensation work).

Compensation works in other areas of False Creek have included the following:

- Intertidal marsh benches;
- Intertidal rock slopes;
- Subtidal rock slopes;
- Intertidal cobble beaches;
- Marine backshore vegetation;
- Salt marshes.

Compensation area design considerations include the use of water retaining ecological features to increase diversity of habitat and maintain some intertidal plateaux, such as tide pools or salt marshes. The incorporation of nature-based features, such as tiered reinforced edges with native plantings, oysters, mussels, salt marsh grasses provide multiple benefits. Tiers can be made of rip-rap revetments, combined with live stakes as bank stabilization. These nature-based features can reduce impacts from smaller, more frequent storms and gradual erosion.

Often, the absorptive qualities of a park area are diminished due to development. Therefore, use of green infrastructure within parks is recommended for management and detention of water from small precipitation events generated from landside storm water runoff. The waterside slope of the shoreline protection should pitch forward towards False Creek and allow storm water to discharge via surface runoff. Special considerations for locating structures near the water's edge, but resistant to flooding, will be required.

For the upland flood protection berm, given the distance from the water's edge, there is the opportunity to locate other resilient park-spaces on the water side of the barrier. These spaces may include turf grass areas, informal open spaces such as boulder fields or nature-based play elements, and paths/circulation to access the water. While these spaces are a form of "retreat" and may flood on the most extreme flood conditions, they should be designed as resilient as possible to bounce back after a flood.

### 4.5.3 Landside Façade Forms

Since the shoreline promenade is a low pollution generating surface, design shoreline surfaces to sheet drain directly to open water without the use of a drainage system.

If a pollution-generating surface (street) adjoins the shoreline surface in a seamless / curbless fashion, locate a crown at the transition of these surfaces to ensure street stormwater is properly diverted and collected by municipal systems.

Habitat incorporation on the landside of a seawall is limited to the topside surface: trees and surface planting. Ensure raised planters and curbs do not allow water from collecting behind the elevated surface. Careful design is required to avoid damage to the surface structures as well as the shoreline protection structures. Trees located within the 15 m setback of the vertical seawall should be installed in properly sized enclosed containment (e.g. large pot), as identified in Section 4.2.8.

### 4.5.4 Landside Transitions

The landward slope of the upland flood protection barrier will need to slope down to meet the adjacent grades of Pacific Boulevard to the north, tie into the slope of the Dunsmuir connection on the north, and the grades of Quebec street to the east. Slopes that tie into streets, supporting park circulation should slope at 5% or less. Slopes that are not meant to facilitate pedestrian flow or access, or feature planting can be built at 20% or less. Given the existing grades along the upland berm alignment, slopes should be minimal. For this reason, habitat can be incorporated on the upland berm side slopes, and in fact would contribute to integrity of the berm, offering protection from erosion. See Table 5 below, for a series of recommended shrubs that are compatible with upland berms.

Table 5 - Native Shrub Species for Use on Dike Slopes

| Species | Form and Size | Rooting Character |
|---|---|---|
| *Cornus stolonifera*<br>red osier dogwood | shrub to 6.0 m in height | shallow, spreading; strong adventitious rooting |
| *Corylus cornuta*<br>beaked hazelnut | shrub to 4.0 m in height | extensive, branching |
| *Holodiscus discolor*<br>oceanspray | shrub to 4.0 m in height | shallow, spreading |
| *Gaultheria shallon*<br>salal | shrub to 3.0 m in height | shallow, spreading |
| *Physocarpus capitatus*<br>Pacific ninebark | shrub to 4.0 m in height | shallow, spreading |
| *Rosa spp.*<br>wild rose | sparse to dense shrubs to 1.5 m in height | poorly developed |

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| | | |
|---|---|---|
| *Rubus parviflorus*<br>thimbleberry | shrub to 3.0 m in height | shallow, fibrous, extensive |
| *Rubus spectabilis*<br>salmonberry | shrub to 4.0 m in height | shallow, fibrous, extensive;<br>reclining stems often set roots |
| *Sambucus racemosa*<br>red elderberry | shrub to 7.0 m in height<br>fibrous, | strong adventitious roots |
| *Spiraea douglasii*<br>hardhack | dense shrub to 2.5 m in height | fibrous, extensive |
| *Symphoricarpos albus*<br>snowberry | dense shrub to 1.5 m in height | extensive, branching, fibrous;<br>spread from rootstocks |

*(Shoreline Structures Environmental Design; Environment Canada)*

- As identified in *Shoreline Structures Environmental Design* by Environment Canada, more intensive and complex habitat can be incorporated into berms in a "pocket" format, with dedicated soil volumes that are not part of the dike structure. As long as adequate and dedicated soil volumes can be positioned which do not affect the integrity of the flood protection structure, more substantial plantings can be planted near and on the upland berm.
- Trees can safely be planted in areas surrounding the berm; the generous parkland areas on each side of the berm provide ample opportunity for this. Similarly, green infrastructure (catchment/detainment gardens) can be implemented along the park perimeter to capture surface runoff. Designers may suggest alternatives for plantings near and on the berm and associated Green Infrastructure provided the recommendations are based on a thorough design review. Design alternatives shall be subject to approval by the City.
- Design concerns associated with Habitat "pockets" on berm structures would include:
    - Roots penetrating beyond the soil pocket and affecting the integrity of the underlying berm slope;
    - General overgrowth of the pocket through lack of maintenance practices;

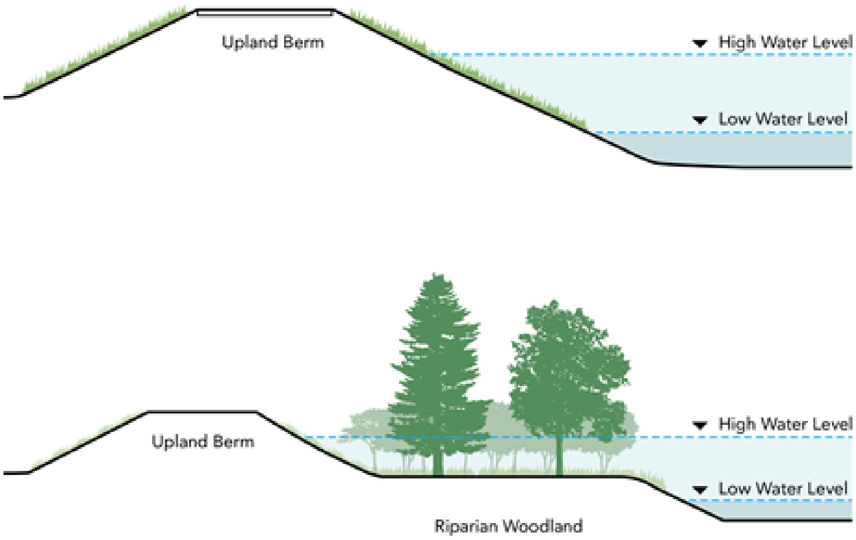


Figure 15 – Top image: showing standard, and undesirable arrangement of a berm located immediately next to water, with no substantial planting. Bottom image robust tree planting can be accommodated beyond "setback" areas, or areas adjacent to berm structures. (Shoreline Structures Environmental Design; Environment Canada)

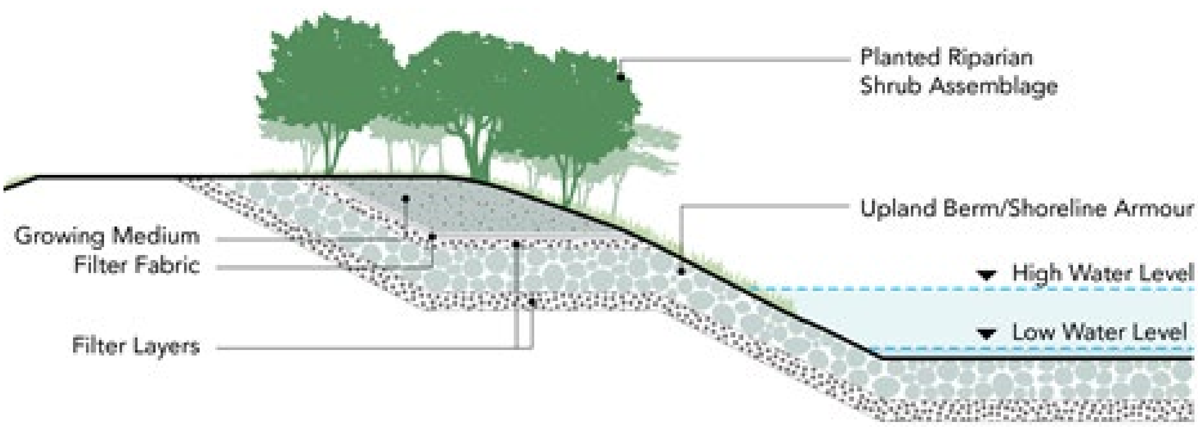


Figure 16 - Habitat "pockets" including shrub assemblages, can be accommodated on berm structures, given adequate soil provision above structural assembly. (Shoreline Structures Environmental Design; Environment Canada)

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## 4.6 Safeguarding Measures

The shoreline protection structure design shall conform to design for safety and public health attribute and principles provided by Coastal Adaptation Plan guideline (Ref [7]).

All areas with unrestricted access shall be designed to appropriate safety standards for public areas, including but not limited to:

> Railings at level differences, and vehicle barriers where appropriate;
> Elimination of trip hazards in accessible areas;
> Emergency egress from the water (e.g. stairs / ladders) for "man overboard" situations;
> Where practical, through design, public access should be prevented from enclosed areas, such as under suspended decks.  Avoid dry areas under deck at all tide levels;
> Appropriate lighting for areas accessible at night;
> Multiple options for access and egress during emergency events (check codes).

# 5 DESIGN CONSIDERATIONS

## 5.1 Design Life

### 5.1.1 Expected Design Life

The design life of new flood protection infrastructure and waterfront structures in NEFC shall be as follows:

- Coastal / flood protection infrastructure: 75 years[1];
- Primary components of marine structures which do not act as flood protection infrastructure (i.e. suspended decks, abutments, steps): 50 years;
- Miscellaneous steel components: guardrails, handrails, ladders: 20 years;
- Chains, wire rope and associated hardware: 20 years.

The design life for a repair to an existing waterfront structure shall be 10 years, unless otherwise stipulated by the City.

### 5.1.2 Durability

The design of the structural forms, materials and details shall ensure the serviceability of the structure during its design life. The properties and performance of the selected materials shall be specified, while considering the design loads and the environmental conditions expected during the design life of the structure. The design shall consider the environmental conditions existing, or likely to exist, during the design life of the structure, and shall determine potential mechanisms of deterioration of the structure. Site investigations may be required in order to determine the influence of poor (corrosive) soils, groundwater, local runoff water, seawater, etc.

Concrete elements shall use cover and mix designs appropriate to the exposure conditions expected. Steel elements shall use suitable corrosion allowance and coating specifications to achieve the intended design life.

### 5.1.3 Scour, Washout & Accretion

Waves, tidal currents and vessel traffic induced currents can cause scour to occur on the seabed adjacent to shoreline protection. The scour depth should be taken into consideration during the design life of the structure and scour protection should be provided as necessary. Scour can result in loss of support for structural footings, resulting in movement, cracking and failure. Conversely, deposition of material can have adverse impacts for operation and maintenance of marine facilities.

Design of shoreline flood protection structures shall take account of the potential for scour, washout, and / or accretion at the site by considering the site sediment / bed material regime and expected water flow above and below ground level. Consideration should be given to possible benefits of aquatic planting, rocky habitat on mitigating the effects of scouring.

## 5.2 Flood Construction Level

This Performance Criteria considers the current FCL defined for the City by Northwest Hydraulics (NHC) in 2018 (Ref. [13]). The study used the joint probability approach to calculate designated flood levels (DFL)

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[1] Based on current CSA standards

directly by applying extreme value analysis to the hindcast of static water level at each shoreline zone. The FCL was obtained by including an acceptable freeboard (0.6 m) and an allowance for subsidence (0.2 m) to the DFL.

The City considers the SLR allowance of 1.0 m as the current design condition. The City has adopted an adaptive SLR allowance of 2.0 m for future design conditions. Flood protection structures and construction levels should consider the current design conditions and be adaptable to the future conditions. Table 6 indicates the FCL adopted by the City for flood protection design (both vertical flood protection structures and upland / shoreline flood protection berms) in NEFC.

Table 6 - FCL for Northeast False Creek (Current (Ref. [13]) and Future Design Conditions)

| Design Conditions | Year | SLR | Storm Event | DFL (m, GD) | Freeboard (m) | Subsidence Allowance (m) | FCL (m, GD) |
|---|---|---|---|---|---|---|---|
| Current | 2100 | 1.0 | 500 | 4.0 | 0.6 | 0.2 | 4.8 |
| Future | Adaptive * | 2.0 | 500 | 5.0 | 0.6 | --- | 5.6 |

*adopted by City

## 5.3 Seismic Design

### 5.3.1 Introduction – Geotechnical Conditions

False Creek, including the NEFC area, consists primarily of land recovered during the industrial development of the area. The present shoreline throughout the area has been developed by the placement of non-engineered fills behind vertical retaining structures, or earth and rip-rap protected slopes, to provide land above the tidal ranges within False Creek. Much of the borehole information (Ref [16]) available for the development of this report is located along Pacific Boulevard, along Georgia Street, and then along part of Quebec Street - some 150 m or more from the shoreline around False Creek. Limited information closer to the shoreline – for example, at the proposed Abbott Street stormwater outfall (Ref [17]) – indicates a similar sequence of soils, with the depth to till at up to about 16 m.

From the information available at the time of this report, the creek bed is covered by very soft mud of limited thickness before dense till and/or bedrock is encountered. Where the shoreline has been raised, non-engineered fill usually comprises granular soils to general depths of about 10 m below existing ground level, underlain by silt and clay. Thin peat horizons are also present in locations below the silt/clay and above till and is an in-place marker between natural soil and fill. The shallow silt/clay layer(s) are generally considered to be fill, but below depths of about 7 m to 8 m, the fine-grained soils appear to be natural and deposited in-place. The granular soils vary from sands to gravels, with sand and gravel mixtures being probably the most widespread deposit. The granular soils are generally loose to compact with localized dense to very dense horizons. Fines contents of the granular soils also vary widely. As would be expected for non-engineered fill, the granular layers contain wood and wood debris, cobbles and boulders, and general construction debris (brick, concrete, slag, plastic, asphalt, metal, etc.).

The water table levels within the area are somewhat uncertain. In many of the boreholes, established water levels were not recorded. However, it is generally considered that the ground water level onshore would be tied into the varying tidal levels within False Creek.

To the south of BC Place, along Pacific Boulevard, till is encountered at about 10 m depth. Northeast along Pacific Boulevard, the upper soil layers to depths of 6 m to 8 m consist of loose to compact granular fill with interlayered silt and clay with variable debris. From 6 m to 10 m depth, the soils are finer grained consisting of soft to firm silts and clays with peat and organics with strengths increasing to firm or even stiff near the top of till. While the general depth to the till is about 10 m, localized high points at about 8 m depth are also noted. To the northeast, the till drops to depths of about 13 m.

At the boundary between the Plaza of Nations site and Concord Pacific, drilling for the Abbott Street stormwater outfall (Ref [17]) indicates that the depth to till increases from 12 m to about 16 m towards False Creek, and that the water table is at a depth of 3 m to 4 m below ground level.

At the intersection of Pacific Boulevard and West Georgia, the available borehole information (Ref [16]) follows the boulevard along a W-E alignment. The predominant soil type in the upper 8 m to 9 m of the profile is granular with a mixture of sand and gravel and sand with varying fines contents. A marker layer of peat and organics is present at the base of the granular (at about 8 m to 9.5 m) which overlies the underlying silts and clays that reach depths of more than about 15 m. In most of the holes, the depth to till was not defined. At the intersection of Carrall Street and the Georgia Viaduct, till was encountered at a depth of 14 m; some 125 m to the west, the till was found at 9.5 m depth.

South along Quebec Street, little information is available. Boreholes 17-23 to 17-26 and 17-35 are indicated in the area (Ref [16]), but the borehole logs were not provided. Boreholes 16-31, 16-32 and 16-34 are all shallow holes that only provide surficial information (down to about 5 m max.).

The above descriptions should be considered as general in nature and based on an overview of available boreholes offset from the proposed flood protection alignment. For detailed design, additional site-specific geotechnical information should be obtained.

### 5.3.2 Seismic Design Considerations

Four predominant standards/guidelines should be considered to cover the seismic design for the main flood protection infrastructure:

- CAN/CSA-S6-19;
- BCBC 2018;
- ASCE 61-14;
- Seismic Design Guidelines for Dikes.

Coastal dikes in British Columbia are commonly designed in accordance with Provincial Guidelines: Seismic Design Guidelines for Dikes (2014)[2]. The earthen berm design shall follow a variation of these guidelines as appropriate for the intended use in NEFC. Vertical seawall structures will provide flood protection, and are structures associated with bridges (bridge-type structures) which have vehicle and pedestrian uses. These structures should be designed following the recommendations provided in CAN/CSA-S6-19. In addition to CSA-S6-19, any associated marine structures should be designed with the recommendations provided in ASCE 61-14 for seismic design. Furthermore, structures associated with buildings should be designed following the recommendations provided in NBCC 2015 and BCBC 2018.

For seismic structural design, the governing code is as follows, based on the appropriate seismic inputs (as currently defined by NBCC 2020):

[2] This guideline is presently under review and a revised guideline is expected for 2021.

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Table 7 – Seismic Standards/Guidelines

| Infrastructure Type | Seismic Structural Standard |
|---|---|
| Earthen Berms | Seismic Design Guidelines for Dikes |
| Bridge-Type Structures (i.e. Vertical Seawall) | CAN/CSA-S6-19 |
| Marine Structures (i.e. Adjoining Marine Structures) | ASCE 61-14 |
| Buildings | BCBC 2018 |

When the performance of any structure affects the performance of another adjacent structure, the most stringent design standard and required performance criteria should apply.

The infrastructure importance categories, performance levels, and damage descriptions are outlined in the standards. The general framework of the seismic performance is also consistent between the different standards. The seismic performance criteria defined in CAN/CSA-S6-19 and BC MoTI Supplement (Ref [15]) are used to provide the performance and damage levels for the different infrastructure elements at NEFC. The structural performance criteria and damage levels are summarized in Table 8 for bridge-type structures, but similar performance requirements can be defined for other geotechnical structures, such as pile-supported platforms or retaining walls.

For bridge-type structures (similarly for pile-supported platforms or retaining walls), the performance criteria and damage levels are summarized below in Table 8 and Table 9 (from CAN/CSA S6-19).

Table 8 - Performance Criteria and Damage Levels (CAN/CSA S6-19)

| Performance Criteria | Damage Levels |
|---|---|
| **Immediate:**<br>Bridge-type structures shall be fully serviceable for normal traffic and repair work does not cause any service disruption. | **Minimal Damage:**<br>Foundation movements shall be limited to only slight misalignment of the spans or settlement of some piers or approaches that does not interfere with normal traffic, provided that no repairs are required. |
| **Limited:**<br>Bridge-type structure shall be usable for emergency traffic and be repairable without requiring closure. If damaged, normal service shall be restored within a month. | **Repairable Damage:**<br>Ground deformations shall be mitigated such that permanent foundation offsets are small and repair objectives specified for the structure can be met. Foundation offsets shall be limited such that repairs can bring the structure back to the original operational capacity. |
| **Service Disruption:**<br>The bridge-type structure shall be usable for emergency traffic after inspection. The bridge-type structure shall be repairable. Repairs to restore the bridge-type structure to full service might require closure. | **Extensive Damage:**<br>Foundation lateral and vertical movements must be limited such that the bridge-type structure can be used by emergency traffic. Foundation offsets shall be limited such that repairs can bring the structure back to the original operational capacity. |
| **Life Safety:**<br>The structure shall not collapse, and it shall be possible to evacuate the bridge-type structure safely. | **Probable Replacement:**<br>Foundation movements shall not lead to collapse of the superstructure nor prevent evacuation. |

Note: Refer to CAN/CSA-S6-19 and BC MoTI Supplement to CHBDC S6-14 for the structural damage considerations.

Table 9 – Seismic Performance and Damage Levels for Bridge-Type Structures (CAN/CSA S6-19)

| Probability of Exceedance (Earthquake Return Period) | New Structure (Lifeline) | | New Structure (Major Route) | | New Structure (Other) | |
|---|---|---|---|---|---|---|
| | Service | Damage | Service | Damage | Service | Damage |
| 10% in 50 year (1:475) | Immediate | None | Immediate | Minimal | Limited | Repairable |
| 2% in 50 year (1:2475) | Limited | Repairable | Disruption | Extensive | Life Safety | Probable Replacement |

For flood protection retaining walls, the seismic design should comply with the Limited Service Disruption condition during the 2475-year ground motions (as per “Lifeline” structures). As such the permanent lateral wall deformations shall be consistent with the service and damage level performance requirements for bridge-type ‘lifeline’ structures (BC MoTI Supplement).

The major risks for vertical seawall structures are considered to be liquefaction-induced lateral spread and operational/safety consequences. Structural remediation and/or ground improvement will probably be required to control the structural movements and/or lateral (soil) spread in order to meet the seismic performance requirements. For structures placed away from the shoreline, the risk of lateral spread may be limited.

NEFC flood protection vertical seawall options and associated structures include options for sheet piles and soldier piles. If these options are preferred, they will generally be founded in the till layer at a depth of approximately 16 m below ground level. Wharf and deck structures are likely to be supported on piles, which will probably penetrate the very dense till-like material or bedrock. It is recommended that these types of marine structures should also comply with the performance requirements in ASCE 61-14, assuming that NBCC (2020) is the appropriate seismic design code (since ASCE 61-14 refers to ASCE 7-10).

Similar to the vertical seawall structures, the major risks for adjoining marine structures are considered to be liquefaction and associated lateral spread. Based on the geotechnical review, the liquefaction induced lateral movements will impact the proposed marine structure in the vicinity of the wall (at Georgia Wharf). Structural and/or ground improvement will likely be required to control the liquefaction and lateral spread in order to meet the seismic performance requirements.

In accordance with the Seismic Design Guidelines for Dikes (Ref [12]), the performance requirements for coastal dikes under the seismic loading conditions are defined for three earthquake levels:

- EQL-1: 100-yr return period ground motions
- EQL-2: 475-yr return period ground motions
- EQL-3: 2,475-yr return period ground motions

The design guidelines recommend that for a 100-year earthquake event (EQL-1) the vertical and horizontal displacements at the crest of the dike should be less than 30 mm. For the 475-year event (EQL-2), the vertical and horizontal displacements are limited to 150 mm and 300 mm, respectively, while for the 2,475-year event (EQL-3), the respective vertical and horizontal displacements should be less than 500 mm and 900 mm.

The earthen berm shall be designed in accordance with the provincial guidelines for a 2,475-year event at the interface with Pacific Boulevard which is to be a post-disaster structure. In this case, in the event of combined events of earthquake and flooding, the earthen berm shall maintain flood protection (minimum freeboard) even with the respective vertical and horizontal displacements endured during the seismic event.

The post-disaster route performance criteria of Repairable Damage will be attained within these levels of displacements. The route may need minor (immediate) maintenance (placement of fill in areas of pronounced total/differential settlement); however, the route shall still be accessible.

The seismic geotechnical risks related to the NEFC infrastructure include liquefaction, lateral spread, inertial loading and post-seismic vertical settlement. In addition, the operation and safety for each infrastructure element should be considered for the overall design objectives.

For geotechnical earthquake design, foundation deformations should be estimated to assess the structural performance and determine if additional structural measures and/or ground improvement is required to meet the performance requirements for the design earthquake under consideration.

The basis for the recommended seismic performance criteria is summarized below:

- It is understood that Pacific Boulevard will be a post-disaster structure with access to the new hospital being required.
- The NEFC infrastructure importance level is Lifeline/Repairable Damage based on the relevant codes and standards
- Whatever the basis for the design of the flood protection structures, there should be no impact on other structures that have the same or higher classifications.
- For any future NEFC developments, the minimum code performance requirements should be the basis for design, unless otherwise stipulated by the City.

### 5.3.3 Liquefaction of Soils

Liquefaction is the process by which the sediments below the water table temporarily lose strength as a result of the application of earthquake-induced cyclic shear stresses. As a result of pore pressure increase and eventual liquefaction, the soils behave as a viscous liquid rather than soil. Liquefaction can lead to slope instability, lateral spreading of ground, settlement, increased lateral loads on retaining walls and piles, and loss of foundation support.

Preliminary assessment on liquefaction susceptibility, i.e. the ability of the soil to liquefy when subjected to an applied stress, can be carried out through existing literature, and maps, for example the GeoMap Vancouver, or the Liquefaction Susceptibility map included in the Seismic Design Guidelines for Dikes (Ref [12]).

Generally, because of the granular nature of the sediments overlying the till found in NEFC, the potential for soil liquefaction should be investigated. The Commentary on the Canadian Highway Bridge Design Code, and the Seismic Design Guidelines for Dikes (Ref [12]), describe several methodologies to determine the potential for soil liquefaction under a seismic event of a certain magnitude. Where necessary, the design of flood protection infrastructure shall allow for the effects of liquefaction.

As discussed above, the generalized soil profile in the NEFC area consists of up to 10 m of loose to compact sand and gravel followed by silt and clay before encountering till-like material over bedrock. The upper granular soils are likely susceptible to liquefaction to varying degrees under the design earthquakes that have return periods that vary from 100 years to 2,475 years. The underlying silts and clays are probably more susceptible to strength loss during seismic shaking rather than liquefaction, although low plasticity silts (PI $<7$ and possibly for $7<PI<12$) are considered potentially liquefiable. Under the 100-year return period ground motions, extensive liquefaction is not considered likely, except for isolated pockets throughout the fill. As the return period increases, the extent of liquefaction will increase until at the 975 / 2475-year ground motions, the granular layer(s) will likely liquefy throughout the entire depth. Even for the 475-year earthquake ground motions, liquefaction may be extensive.

Liquefaction of granular soils implies a significant loss in strength which then can give rise to instability and large deformations. The loss in strength is due to the increase of pore pressure and an associated reduction in effective stress in the granular soil. After the earthquake, these excess pore pressures will dissipate and the associated changes in volume will give rise to settlement. For water retaining earth structures such as the proposed earthen berms, this may cause longitudinal and transverse cracking and loss of freeboard. Liquefaction of soils behind a retaining wall will give rise to a large pressure increase on the back of the wall and potential failure. The differential soil and water loading across a retention structure may cause failure since the strength of the foundations soils decreases as the earthquake ground motions develop and induce liquefaction.

### 5.3.4 Vertical Flood Protection Seawall Design Approaches

Bridge-type structures and their components shall be designed to meet seismic requirements in accordance with the Canadian Highway Bridge Design Code and Commentary, for an importance category of "Lifeline Bridges" and assuming equivalence to a "Regular Bridge" (see Section 5.3.2).

The applicable design approach recognized within CSA-S6, 2019:

> Performance-Based Design: a design philosophy based upon meeting specific structural, functional, and service performance criteria under a specified seismic hazard. Three (3) earthquake return periods are to be investigated: 475-year, 975-year and 2475-year. Structures shall meet the minimum performance levels and criteria of Table 4.15 and Table 4.16 of CSA-S6, 2019, respectively. For an importance category equivalent to "Lifeline Bridges", the performance levels and general performance criteria to obtain the specified performance levels are summarized in Table 10 below.

Table 10 - Performance Levels and Criteria for Lifeline Bridges (CSA-S6, 2019)

| Probability | Service Level | Service Criteria | Damage Level | Damage Criteria |
|---|---|---|---|---|
| 1/475 years or 10% in 50 years | Service Immediate | Structure shall be fully serviceable for normal traffic. | None | - |
| 1/975 years or 5% in 50 years | Service Immediate | Structure shall be fully serviceable for normal traffic and repair work does not cause any service disruption. | Minimal | Structure shall remain essentially elastic with minor damage that does not affect the performance level of the structure. |
| 1/2475 years or 2% in 50 years | Service Limited | Structure shall be usable for emergency traffic, if applicable.<br>Structure shall be repairable without closure.<br>If structure damaged, normal service shall be restored within a month. | Repairable | There may be some inelastic behaviour and moderate damage may occur, however, primary members shall not need to be replaced, shall be repairable in place, and shall be capable of supporting the dead load plus full live load. |

A multitude of options are possible for the design and construction of seawall flood protection structures. However, given the particular site characteristics, the options are limited by feasibility of construction. The seawall options will likely be retaining walls constructed from the shore and will separate either the existing or future extent of False Creek from the onshore developed area. The construction of traditional gravity-type retaining walls is not considered a feasible option. More likely the retaining wall along the waterfront will be constructed using some form of vertical structure embedded into the underlying competent soils.

For a shoreline elevation equal to the FCL of El. +4.8 m, a creek bed elevation of around El. -3.5 m, the free-standing height of the wall will be about 8.3 m. Based on the free-standing height being about one-third of the sheet pile length, a typical sheet pile length would be about 24 m. This would mean driving the sheets up to 12 m or more into the underlying till-like material. More likely would be the need to install the sheets about 5 m to 8 m into the till with at least one row of anchors, maybe more. A soldier pile wall may be another option at this location. As mentioned above, the possible wall types along the Plaza of Nations and the Concord Pacific waterfront could consist of the following relatively common structural options:

- Anchored sheet pile wall, with or without whalers;
- Soldier pile wall, with or without anchors;
- Soil-mix wall with reinforcing elements;
- Diaphragm wall with reinforcement.

Whichever option selected would need to be designed for the static and environmental loading conditions, including seismic. Important in the seismic design considerations would be the potential loading from the potentially-liquefiable soil behind the structure, in addition to the inertial loading. Soil-structure interaction analyses would be required as it is likely that the retained granular soils will liquefy early during the 2475-year ground motions, and possibly even at lower earthquake return periods.

The design loading on the wall will depend to some degree on the proposed development plans at the Plaza of Nations site. The present preliminary layouts indicate a 15 m wide access area (setback) behind the wall location before reaching the building envelope. The buildings are likely to have multi-level underground parking/facilities. During excavation for the underground parking, the soil between the vertical flood wall and the buildings could be improved to avoid strength loss and additional loading on the back of the wall. The loading on the wall will depend on how the development is to be designed and may benefit from coordinated discussions between the City and the developer.

#### 5.3.4.1 Adjacent Marine Infrastructure (Deck on Piles)

Additional marine infrastructure, such as a patio or deck, may be constructed in front of the retaining wall in the proximity of the commercial developments. The infrastructure would need to be designed in a way which does not prevent the vertical flood wall from being inspected.

It is likely that any structure would have a piled foundation. The sediment cover at the nearshore area is understood to be limited to several meters of soft soil, underlain by till/bedrock. The piles will probably need to be embedded several diameters into the till/rock to provide adequate vertical and lateral resistance for both the static and seismic design requirements.

An alternate option for any proposed wharf deck would be to cantilever it off the retaining wall[3]. The feasibility of this option would depend on the required width of the deck and surface loading requirements.

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[3] Will depend on ownership. If the proposed infrastructure is not owned by the City, agreements would need to be reached to have private infrastructure attached to public infrastructure.

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### 5.3.5 Upland Flood Protection – Conventional Earthen Berms

Coastal structures should consider a design in accordance with the Seismic Design Guidelines for Dikes (Ref [12]), which provide guidelines for seismic stability and integrity of high consequence dikes in southwestern British Columbia and Vancouver Island.

Similar to seismic design of highway bridges, the seismic design of dikes has evolved in recent years to include Performance-Based Design criteria, which considers the damage associated to differing earthquake levels. The Seismic Design Guidelines for Dikes (Ref [12]) defines three performance categories associated to three earthquake return periods: namely 100-year, 475-year and 2475-year. High Consequence Dikes are to meet the requirements shown in Table 2 of the Seismic Design Guidelines (Ref [12]), which are summarized below in Table 11.

Table 11 - Performance Level and Criteria for Dikes

| Performance Category | Probability | Damage Level | Damage Criteria | Maximum Allowable Vertical Displacement | Maximum Allowable Horizontal Displacement |
|---|---|---|---|---|---|
| A | 1/100 years or 10% in 50 years | Not significant | No significant damage to the dike body. Post-seismic flood protection ability is not compromised. | Small (<0.03 m) | Small (0.03 m) |
| B | 1/475 years or 5% in 50 years | Repairable | Some repairable damage to the dike body. Post-seismic flood protection ability is not compromised. | 0.15 m | 0.3 m |
| C | 1/2475 years or 2% in 50 years | Significant | Significant damage to the dike body. Post-seismic flood protection ability is possibly compromised. | 0.5 m | 0.9 m |

At the east end of the Concord Pacific development, the vertical flood protection seawall moves inland and transitions to an earthen berm. The transition from the vertical wall to a surface earth retention structure will require detailed design considerations that will be predicated on the specific ground conditions along the transition. If the transition is between a vertical or horizontal "hard face" and soil, separation along that interface due to future ground movements will likely give rise to preferential seepage pathways. This can be handled in several ways, such as employing geomembranes, self-sealing additives or by designing the interface to accept the expected differential/relative movements. The flood protection berm structure itself will be a relatively simple and straightforward design, comprising upstream and downstream slopes that will ensure adequate static stability. Typically, upstream and downstream slopes of the berm are 2H:1V and 3H:1V, but this can vary based on geotechnical analyses. Static factors of safety against sliding failure for these slopes will be around 1.5. The seismic design requirements are generally expected to be in-line with those provided in the Seismic Design Guidelines for Dikes (Ref [12]). Rather than a specific stability condition for the seismic loading, the berms will be expected to meet the seismic performance requirements outlined above in Section 5.3.2 according to the classification of the berm. Close to the Concord Pacific property boundary, the berm performance will have to be compatible with that required for the vertical wall. As the dike moves north and converts into an upland berm, the berm will need to protect Pacific Boulevard which is a transportation corridor to the future St. Paul's hospital. Lifeline performance of the upland berm, under a 2,475-year seismic ground motion event, will be the likely design objective critical to the City. To meet these objectives the design of the berm and/or foundations will need to consider the vertical and lateral deformation expected under the design earthquake in order for the post-disaster Pacific Boulevard lifeline corridor to function satisfactorily following a 2,475-year seismic event.

In its simplest form for vertical movements, this may involve building the berm to an elevation higher than FCL to account for expected settlement under seismic conditions. Where lateral ground movements are extensive, the foundation soils may need to be remediated (densification or reinforcement) or improved in order to limit liquefaction effects.

During the design stage of the upland berm, for conditions requiring ground improvements or otherwise, the impact on the foundations of the adjacent Expo line will need to be considered carefully.

The shoreline itself will be formed by a soil slope protected with rip-rap and may take the form of a designed rocky shoreline and select plantings conducive to the berm face. The soils below the slope will be potentially liquefiable thus likely inducing a flow failure condition at the shoreline. The slope failure will move back into the slope and impact the flat area of Creekside Park. However, there is generally a limit to the extent that a failure can develop before the slope becomes stable and the retrogressive failure will eventually stabilize. With the inland berm more than a couple of hundred meters from the shoreline it is unlikely that the slopes of the upland berm will suffer extensive lateral ground movements. Post-seismic settlement of the dike (and loss of freeboard) will occur after initial liquefaction, but this can be considered in the design. The required freeboard can be maintained by building the crest to a higher elevation to compensate for the expected post-seismic settlement. Additional height would be determined during the final design but would likely be in the range 300 mm – 500 mm in order to maintain required freeboard after a seismic event.

Dikes are generally designed to consider the following conditions:

- Stability of side slopes under static, environmental and seismic conditions;
- Control of seepage both under and through the embankment for equilibrium conditions and the potential case of rapid drawdown;
- Short- and long-term settlement of the earth structure;
- Selection of compacted materials to form the body of the dike and provide the required performance.

The crest width of the dike depends on proposed function. For this structure, the dike will be integrated into a recreation area with access for pedestrians and cyclists. A crest width of 4 m is generally considered a minimum width for maintenance considerations, though the crest width of the berm within Creekside Park will likely be wider to accommodate the recreational components proposed.

### 5.3.6 Ground Improvement Options

The granular foundation soils within the NEFC development area are generally loose to compact and are thought to be potentially liquefiable under the seismic design requirements for the development. At the 2,475-year earthquake level, and probably the 975-year and even possibly at the 475-year return period, extensive liquefaction may occur. It is also likely that some softening/degradation of the underlying clays/silts may also occur. These effects could be handled directly with structural solutions, although these may be very costly. Geotechnical options to avoid the negative impacts from the seismic loading can also be considered.

The first ground improvement option would be one of excavating (and replacing, if necessary) the potentially liquefiable soils. While this may appear to be a major effort[4], if the buildings are to provide underground facilities such as parking, excavating the additional volume of soil between the building and the waterfront retaining wall may be a cost-effective option. The removal of the soil would reduce the foundation loading, allowing optimization of the foundation support requirements and may lead to a partially or even fully compensated foundation.

If the soils are to be left in place and treated, densification is probably the most cost-effective alternative. This could be achieved by vibro-compaction or vibro-replacement; the later involving the installation of stone columns throughout the granular profile. Dynamic compaction could also be an option over the central area of the site provided the grid was sufficiently distanced from the retaining wall (and other adjacent structures) so as not to cause damage (due to vibrations or ground movements). One potential drawback of these methods would be the need to handle potentially contaminated ground water and soil as a product of the densification work. However, this may be a more cost-effective option than more expensive ground improvement methods, such as soil mixing. Stone columns could also be extended into the underlying silt layer(s) should this be necessary for an adequate design. However, care should be exercised when employing stone columns beneath water retention structures such as earth dikes. The formation of vertical high permeability zones in the foundation could lead to potential seepage or even piping problems that would need to be considered at the design stage. Alternative methods (soil mixing, timber piles, etc.) other than stone columns may be more appropriate below dikes.

### 5.3.7 Site Services

Failure of buried services during seismic events is primarily caused by large permanent soil displacements and can also be caused by buoyancy due to liquefaction.

Each buried service target performance under seismic conditions is related to its intended function and importance. For example, pipelines that provide water for fire suppression serve a more important function for post-seismic response than those provided for irrigation water. In this manner, the approach to seismic design of buried services is similar to that described for structures, with the seismic importance assigned to each service resulting in a recommended design seismic event. The approach for services differs from that for infrastructure in that there is less formal consideration of a “spectrum of damage”, and there is generally no safety/risk to life consideration.

American Lifelines Alliance guidelines (ALA) and Metro Vancouver Seismic Design Criteria (Ref [18]) classify pipes into four functions related to their importance for post-seismic response and recovery, as well as the minimum performance reliability following an earthquake, as per Table 12 and Table 13, respectively:

[4] The possibility of highly contaminated soils in the NEFC area must also be considered, as there will be regulatory and economic implications of an excavate / replace approach.

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Table 12 - Pipe Function Classes (ALA -Table 3-1)

| Pipe Function Class | Seismic Importance | Description |
|---|---|---|
| I | Very Low to None | Pipelines that represent very low hazard to human life in the event of failure. Not needed for post-earthquake system performance, response, or recovery. Widespread damage resulting in long restoration times (weeks or longer) will not materially harm the economic well-being of the community. |
| II | Ordinary, Normal | Normal and ordinary pipeline use, common pipelines in most water systems. All pipes not identified as Function I, III, or IV. |
| III | Critical | Critical pipelines serving large numbers of customers and present significant economic impact to the community or a substantial hazard to human life and property in the event of failure. |
| IV | Essential | Essential pipelines required for post-earthquake response and recovery and intended to remain functional and operational during and following a design earthquake. |

Pipelines in Pipe Function Class I can be constructed using “standard” design, where “standard” means that all non-seismic load conditions must be considered, but seismic effects are not considered.

Table 13 - Earthquake Hazard Return Period for Each Pipe Function Class (ALA -Table 3-2)

| Pipe Function Class | Probability of Exceedance P in 50 years | Return Period T (years) |
|---|---|---|
| I | 100% | Undefined. |
| II | 10% | 475 |
| III | 5% | 975 |
| IV | 2% | 2,475 |

# 6 DESIGN LOADING

## 6.1 Dead Loads

Dead loads consist of the effective weight of all fixed structural elements, including wearing surface, earth cover and utilities, having either a dry weight (in air) and / or a buoyant weight (if submerged in water). For the earthen berm option, all foundation loads should consider the weight of the material used to construct the berm using suitably compacted materials. The phreatic surface should be determined across the berm in order to determine total and effective stress both within the berm itself and in the foundation.

In the absence of more precise information, the unit material weights specified in Table 3.4 of CSA-S6, 2014 shall be used in calculating dead loads.

In the absence of more precise information, a superimposed dead load of 2.4 kPa of surface treatments shall be assumed. Specific allowances may be required for superimposed dead loads such as material storage or stockpiles.

Specific allowances shall be made to accommodate future dead loads due to raising of the FCL to 5.6 m.

## 6.2 Live Loads

Live loads consist of movable and moving loads imposed on structures due to use and occupancy. These will consist of cyclic, impulsive, random, static and long-term cyclic types of loads. The following live loads shall be considered as appropriate and shall be confirmed with the City prior to detailed design phase:

> Pedestrian: all flood protection structures shall be designed for a pedestrian load of 7.2 kPa. (Ref. [1])

> Garbage pickup: all flood protection structures shall be designed for a Mini Packer 10 yard rear loader, single rear axle with the characteristics presented in Table 14.

Table 14 - Garbage Pickup Vehicle Characteristics

| Vehicle Weight (lbs) | Axle Load (lbs) | | Wheel Base (inch) |
|---|---|---|---|
| | Front Axle | Single Rear Axle | |
| 19,500 | 6,581 | 12,919 | 138 |

As well, all flood protection structures shall be designed for the Waste Collection Vehicle as shown in Figure 17 with a total weight of 8,845 kg (86.7 kN) and a vehicle body width of 3.5 m.

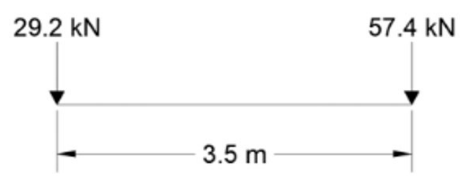



Figure 17 – City of Vancouver Waste Collection Vehicle

> Maintenance vehicle: all waterfront structures shall be designed to allow for maintenance to adjacent building facades and be designed for a maintenance vehicle as per loading information in S6- Section 3.8.11 and a CL-3-625 design vehicle as per CSA-S6-19 (for loading and unloading). As well, waterfront structures shall be designed to allow manlifts of 85 ft to 100 ft, and a 5-ton flat deck with a hiab crane which services the existing ground water treatment plant.

> Street sweeper: all waterfront structures shall be designed to allow a mid-sized street sweeper weighing 11,500 kg (112.8 kN) and a full-sized street sweeper weighing 14,500 kg (142.2 kN). The vehicle body width for both sweeper sizes is 2.2. m. Design shall be for the worst case of these two vehicles.

> Snow clearance vehicle: all waterfront structures shall be designed to allow a C992 snow clearance vehicle with a weight of 4,760 kg (74.2 kN) and a width of 1.65 m and a 1-ton jitney with a weight of 7,570 kg (74.2 kN) and a width of 2.92 m. Design shall be for the worst case of these two vehicles.

> Fire access: requirement for access of fire trucks shall be determined by adjacent land uses and emergency response requirements. For example, fire access needs to be considered where developments are located immediately adjacent to waterfront structures and fire trucks utilize pathway for access. The characteristics presented in Table 15 shall apply:

Table 15 - Fire Truck Characteristics

| Vehicle | Axle Load (kN) | | Wheel Base (m) |
|---|---|---|---|
| | Front Axle Actual GVW (kN) | Rear Axle Actual GVW (kN) | |
| Single Fire Engine | 86.9 | 118.0 | 4.928 |
| Single Rescue Engine | 85.5 | 127.8 | 4.928 |
| Tandem 105” Ladder | 97.2 | 249.1 | 7.620 |
| Tandem Heavy Rescue | 99.2 | 149.1 | 6.550 |

> The Single Fire Engine and Single Rescue Engine include a single rear axle while the Tandem 105” Ladder and Tandem Heavy Rescue include a tandem rear axle.

> In addition to the global fire truck loading above, local components shall be designed for a local pressure of 500 kPa from a fire truck outrigger over the contact area of the outrigger when the apparatus is loaded to its maximum in-service weight and the aerial device is carrying its rated capacity in every position permitted by the manufacturer as per NFPA standard 1901.

> In addition to the fire vehicles listed above NEFC shall be designed for a new fire truck currently in production. The fire truck has a rated maximum GVW of 102.3 kN for the front axle and 275.9 kN for the rear axle with a wheelbase of 6.220 m. Design shall be based on the actual GVW once it is available.

> For specific live load (e.g. crane pad loads during lifting), appropriate design criteria shall be derived to suit the circumstances.

> To determine foundation stability, a nominal live load for traffic should be included in all stability calculations. Typically, a uniform surface loading of 16 kPa across the berm crest is assumed for stability assessments. For settlement calculations, some percentage of the traffic load is used in the analysis.

> For the vertical retaining wall, surface loads should also be considered in terms of lateral load effects on the back of the wall.

## 6.3 Soil and Differential Water Loads

Soil and differential water loads consist of loads that affect the stability of earth-retaining structures. The design water head difference across a retaining structure shall be based on the tidal water levels and information regarding the groundwater regime at the site. Where no information exists, the design head difference across the structure is generally taken as the greater of one (1) meter or one-third (1/3) of the retained height. For dikes in tidal areas the stability of the retaining structure under rapid drawdown should also be checked. The range in water levels for these extreme events can be related to the highest expected flood level with an almost instantaneous drawdown to low water level, with established water levels for the flood within the body of the dike being maintained.

## 6.4 Wind Loads

Wind loads on structures shall be calculated in accordance with Clause 3.10 of CSA-S6, 2014 (Ref. [15]) and shall be based on the Hourly Mean Wind Pressures at Vancouver for the relevant Return Period indicated in Table 16.

Table 16 - Hourly Mean Wind Pressure

| 10-year Return Period | 25-year Return Period | 50-year Return Period | 100-year Return Period |
|---|---|---|---|
| 360 Pa | 430 Pa | 480 Pa | 530 Pa |

## 6.5 Environmental Loads

Environmental loads consist of statically applied long-term loads such as waves and currents.

### 6.5.1 Wave Climate

#### 6.5.1.1 Wind waves

A nearshore wave modelling assessment was conducted by Northwest Hydraulic in 2014 (Ref. [14]) for areas from the Strait of Georgia to English Bay. NEFC is generally sheltered. The extreme significant wave height was predicted to be 0.2 m at NEFC. The estimated wave effects calculated by NHC were 0.3 m along the shorelines of NEFC considering riprap with a design slope of 2H:1V.

#### 6.5.1.2 Vessel induced waves and tidal currents

Considering that the NEFC area has vessel traffic, loads from vessel induced waves and currents must be considered on the shoreline protection design. Waves and currents generated by boats vary according to the distance, vessel speed and power. These loads must be calculated for each specific development and vessel traffic.

The tidal currents shall be compared to vessel generated currents to determine the governing currents for the design purposes.

## 6.6 Seismic Loads

Seismic loads consist of shear forces applied during the design earthquake event, and lateral soil movements due to liquefaction, if applicable. Kinematic loading due to soil liquefaction are considered in Section 5.3.3.

Seismic forces on the flood protection vertical walls shall be calculated in accordance with the CAN/CSA-S6-19 for an importance category of “Lifeline Bridges” and assuming equivalence to a “Regular Bridge”, unless specified otherwise.

# 7 FORM AND DIMENSIONS

## 7.1 General

According to the City setback requirements (Ref. [6]), no building, structural support, or fill shall be constructed or located within 15 m of the natural boundary of False Creek, or 7.5 m from any structure erected for flood protection or seepage control. At the proposed Plaza of Nations and Concord Pacific developments, a 15 m setback from the vertical flood protection seawall is established. Similarly, for the earthen berm, the width will be designated by the City, and likely in the range of 10 m to 12 m to accommodate the public activities the top of the berm will host (pedestrian paths, bicycle lanes, etc.), and ensure the berm slopes are not compromised. Setbacks are established to maintain the long-term structural stability of the flood protection works, and to allow for future maintenance and repairs.

In locations or situations where the City has reviewed and agreed that these setback requirements can not be achieved, alternate setback options can be proposed and may be approved by the City.

To allow a future height allowance without demolishing the structure when FCL construction levels rise from 4.8 m to 5.6 m, the following options for development are possible, following consultation with the City:

- Raise the upland berm crest elevation which will result in loss of berm crest width, keeping the same alignments and slopes
- Use the areas adjacent to the berm to increase the crest height and keep the same crest width and slope.
- Steepen the slope to increase the crest height and keep the berm width. A slope stability analysis must be performed if this option is selected

For the vertical seawall at the proposed Plaza of Nations and Concord Pacific developments, Developers must design the flood protection wall to be adaptable to the higher FCL. Developers must understand the implication of the raised wall in relation to the adjacent setback area.

The level of risk depends on the sensitivity of the land use, with the two main considerations being safety to the public and risk of damage to property. While FCL's are well defined for buildings/developments, it should be considered whether the pathway, or in the case of the proposed Concord Pacific development, a public street will require additional coastal flood protection. Specifically, whether the pathway and road itself will require raising or whether the seawall barrier allowance is sufficient to protect against wave overtopping/flooding, even though this may be less desirable aesthetically (line of sights, access to waterfront, etc.).

## 7.2 Vertical Flood Protection Seawall Options

The following vertical flood protection seawall options are considered to potentially provide adequate solutions under the existing conditions and design loading:

- Anchored sheet pile wall;
- Soldier pile wall;
- Soil-mix wall with reinforcing elements;
- Diaphragm wall with reinforcement.

The above options are meant to provide examples of options which could meet the required performance criteria in this document. This is not a comprehensive list of options.

### 7.2.1 Slopes, Grades and Elevations

- Top of vertical flood protection seawall shall be at the FCL 4.8 m elevation, with the ability to be raised effectively to 5.6 m when the City imposes higher FCL requirements.
- Pavement areas and transitions to FCL 4.8 m shall have a maximum grade of (Ref [10]):
    - 1:20 without handrail,
    - 1:12 with handrail.
- Gangway grades shall be limited to a slope ratio of 1:12.
- Retaining heights of the vertical seawall options are dependant upon the depth to seabed at specific locations and potential scour protection/habitat creation elements placed in front of the wall. Generally, it is expected that the vertical retaining structural shall have an approximate retaining height of 8 m to 10 m. Future allowance for raising the seawall to elevation 5.6 m could impact the retaining height.
- Marine structures shall be designed to comply with the performance requirements indicated in CSA-S6-19.

### 7.2.2 Physical Constraints

#### 7.2.2.1 Adjacent Infrastructure Limitations

Vertical seawall options are favoured at the proposed Plaza of Nations and Concord Pacific developments, as the width required for a conventional flood protection berm is not conducive with the public realm requirements based on the proposed building layouts. A 15 m setback from the flood protection seawall would only be possible, based on current design concepts, with a vertical wall approach. The vertical seawall design options must consider access to proposed waterfront marinas or floating structures.

### 7.2.3 Habitat Improvements

Habitat offsetting may be required to balance the potential negative effects resulting from new construction of marine infrastructure. These compensation works will increase fish habitat and diversity of habitat. In the case of a vertical flood protection seawall, these can be intertidal plateaux such as tide pools, intertidal marsh bench, intertidal rock slopes, intertidal cobble beach, which can also act as scour protection measure in the front of the wall. The types and extent of habitat improvements will be developed through consultation with Fisheries and Oceans Canada as described in further detail in Section 4.5.1.

## 7.3 Upland Flood Protection – Conventional Earthen Berms

### 7.3.1 Slopes, Grades, Materials and Elevations

Conventional earthen berms will be constructed in adherence with the Dike Design and Construction Guidelines – Best Management Practices for British Columbia (Ref [20]). In addition, berm design should reflect the design principles outlined in Coastal Adaptation Plan report (Ref [7]).

The following additional criteria should be met to facilitate the specific requirements for the NEFC area:

- The crest elevation shall be 4.8 m in accordance with the FCL (Section 5.2).

- In the floodplain area, the park development considers a slope from the toe of the dike to the shoreline promenade at an elevation of 3.8 m.
- The landward slope of the upland berm is required to slope down to an elevation of 4.0 m in the vicinity of Pacific Boulevard to the north.
- The landward slope of the upland berm, to tie into the Dunsmuir connection to the north and Quebec Street to the east, shall be 5% or less to account for the park circulation.
- The upland flood protection berm will descend from a FCL of height of 4.8 m to tie into the Science World entrance at approximately 3.5 m. Examples of how this could be achieved are discussed in Section 3.3, and shown in Appendix A.
- The shoreline protection earthen berm slope must adhere with Dike Design Guidelines – Best Management Practices for British Columbia (Ref [20]). According to this guideline the dike slope varies depending on the site-specific situation of soils, dike height, and dike construction materials. Generally, the dike slopes of 3H:1V or flatter is recommended.
- The berm material must adhere to Dike Design Guidelines – Best Management Practices for British Columbia (Ref [20]). The required berm material shall be designed based on design guidelines to resist the loads from design flooding event or require little maintenance after it.
- The seaward slope of the upland berm should be less than 20% or less to feature park planting.
- For the transition section, at the vicinity of the Science World, two options are presented and shown in Appendix A:
  - Option 1 considers raising the existing ground elevation from approximately 3.5 m to the FCL height of 4.8 m. The ramp surface material shall be a firm and slip-resistant surface. The ramp gradient shall be 1:20 to facilitate wheelchair access. Ramps steeper than 1:12 are restricted as it makes accessibility hard for person in wheelchair (Ref [10]). The ramp down from the upland berm to the entrance of Science World is recommended 1:20. The ramp down from the upland berm to Quebec street to reach the elevation of approximately 3.2 m shall be limited to 1:12.
  - Option 2 considers a ramp down in elevation of the berm to meet the existing access elevation of Science World, and then ramp back up to the FCL once the access location is passed. The ramp slope of 1:20 recommended as a safer and more reliable slope (Ref [10]).

## 7.3.2 Physical Constraints

### 7.3.2.1 Adjacent Infrastructure Limitations

The City requires that enough space will be available to build and maintain the upland berm. The following considerations should be considered for adjacent infrastructure:

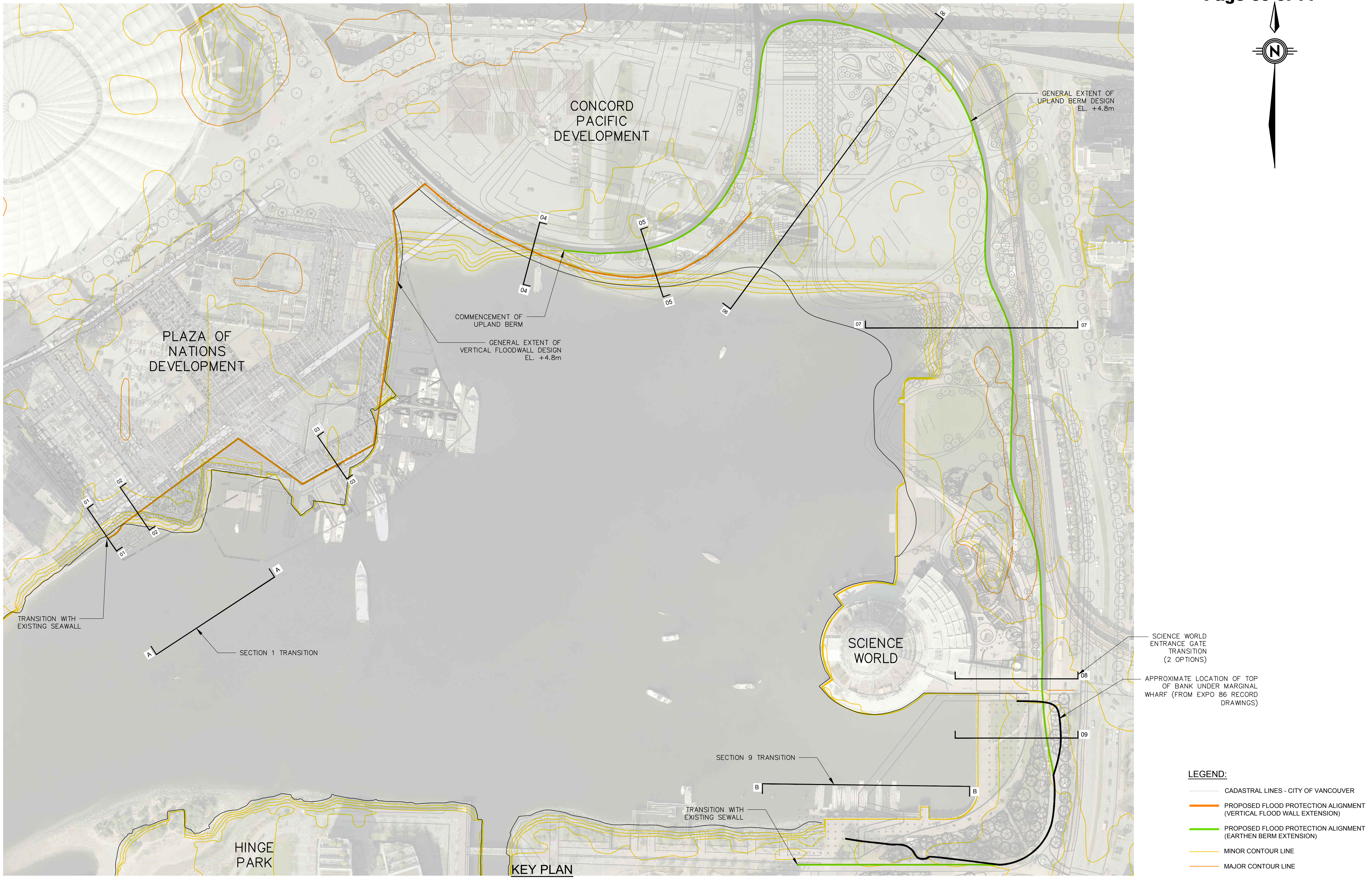
- A stormwater outfall currently exists to the south of Science World. The future redevelopment of the park suggests the removal of the marginal wharf south of Science World, whereby the existing outfall will be exposed, with cause aesthetic concerns. According to the Northwest Hydraulic Report in 2014 (Ref. [14]) a planning level estimate was performed to identify the pumping capacity needed to prevent flooding in the False Creek study basin for the 25-year design storm. Northwest Hydraulic, 2014 (Ref. [14]) also recommended that the stormwater storage provided in the basin would be incorporated into the new pump station in the form of a wet well or forebay. The future flood protection berm in the vicinity of the existing stormwater outfall will likely need to incorporate a pump station design to discharge future stormwater into False Creek, in a similar manner as the pump stations on the dikes in Richmond operate.

> The upland berm should be designed to provide a minimum width to accommodate a pathway for cyclist and pedestrians. The minimum required width of 10 m to 12 m is considered for the upland berm crest width.

### 7.3.3 Habitat Improvements

Construction of the flood protection berms will generally lead to the implementation of mitigation works, such as plantings or habitat features, in order to offset disturbance of existing habitats or vegetation. In the case of upland areas, biodiversity and habitat improvement can create a quality habitat for birds foraging, resting, perching, nesting.

# APPENDIX A – CONCEPT DESIGNS

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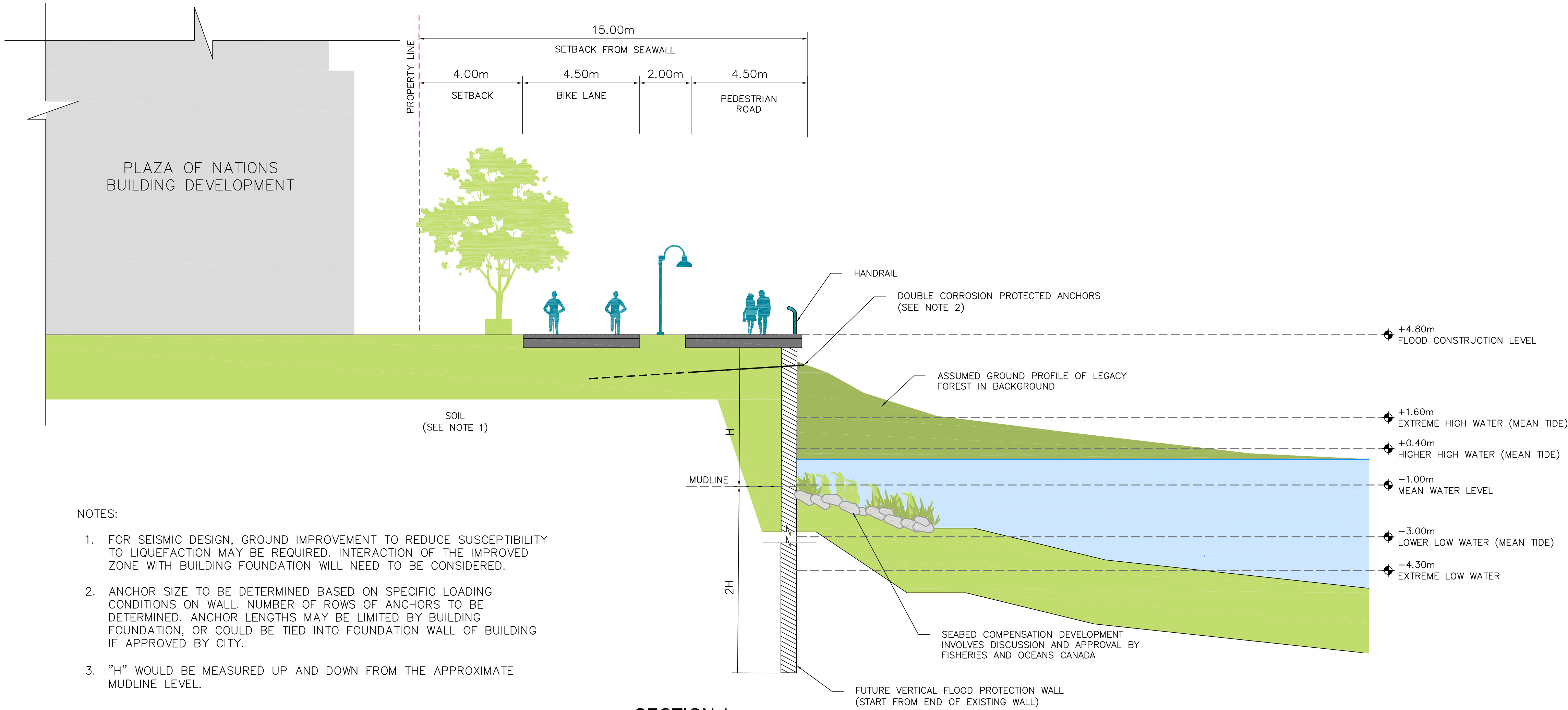


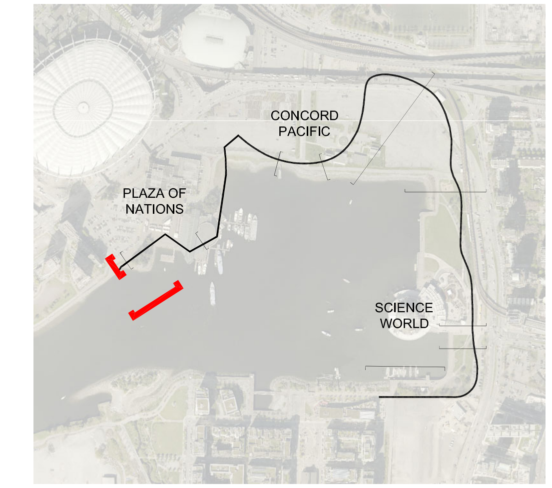


## KEY PLAN

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2. ANCHOR SIZE TO BE DETERMINED BASED ON SPECIFIC LOADING CONDITIONS ON WALL. NUMBER OF ROWS OF ANCHORS TO BE DETERMINED. ANCHOR LENGTHS MAY BE LIMITED BY BUILDING FOUNDATION, OR COULD BE TIED INTO FOUNDATION WALL OF BUILDING IF APPROVED BY CITY.
3. "H" WOULD BE MEASURED UP AND DOWN FROM THE APPROXIMATE MUDLINE LEVEL.

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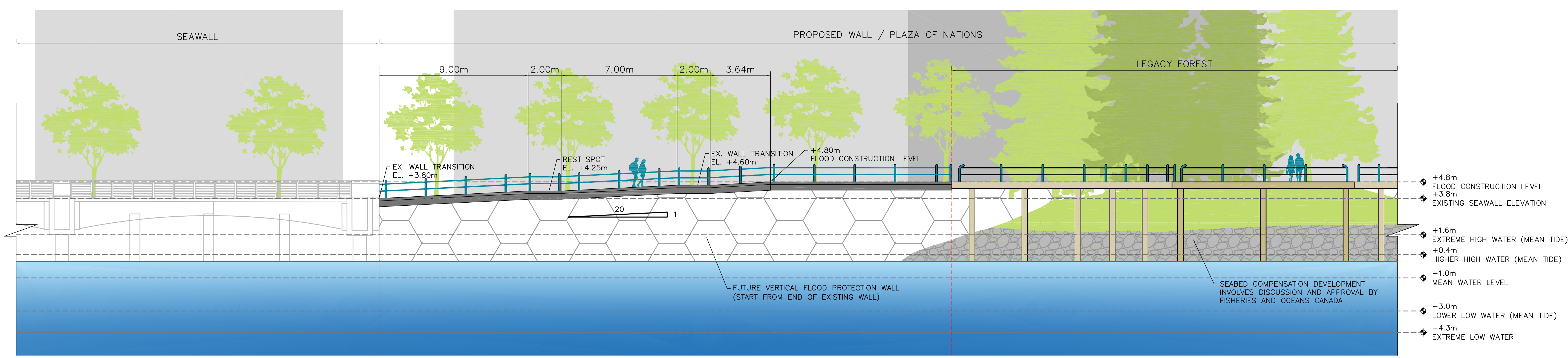


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SECTION 01

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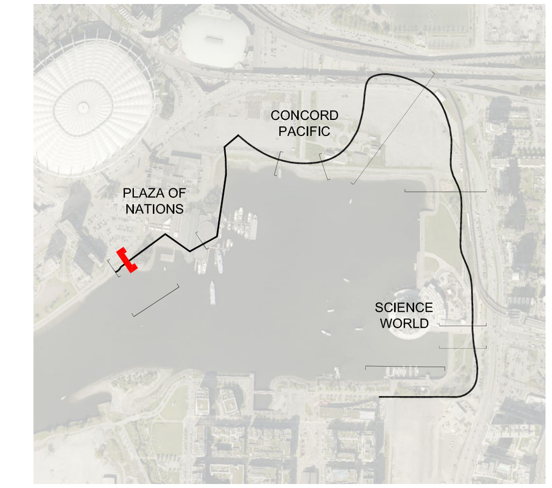


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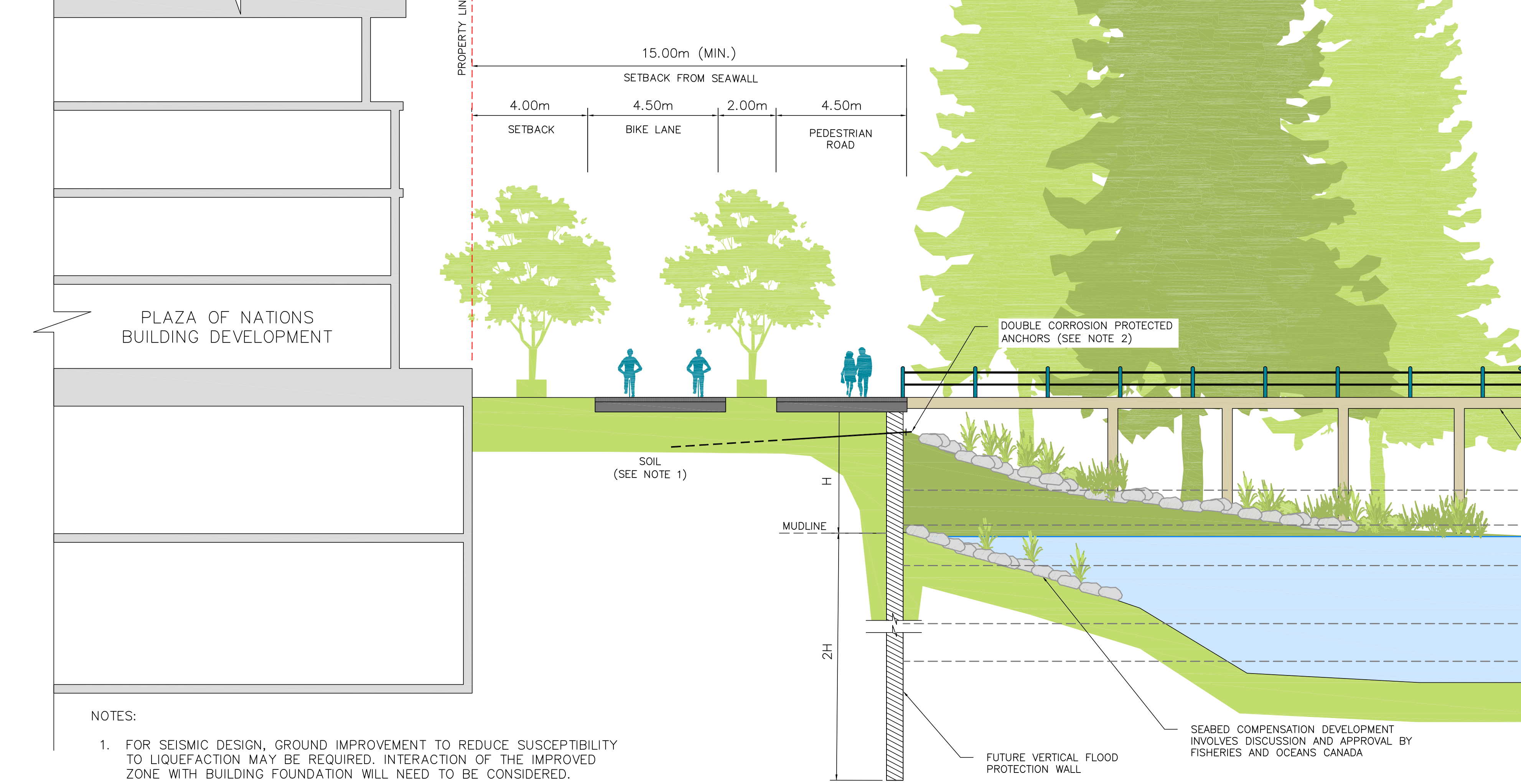


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3. "H" WOULD BE MEASURED UP AND DOWN FROM THE APPROXIMATE MUDLINE LEVEL.

4. BOARDWALK ELEVATION CAN BE ALTERNATE (LOWER) ELEVATION IF DESIRED.

## SECTION 02

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SECTION 02

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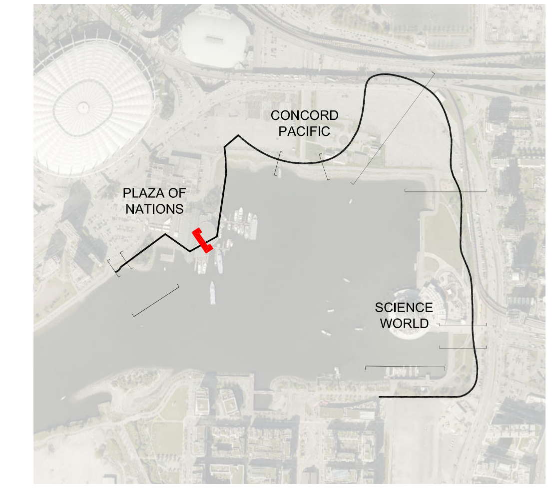


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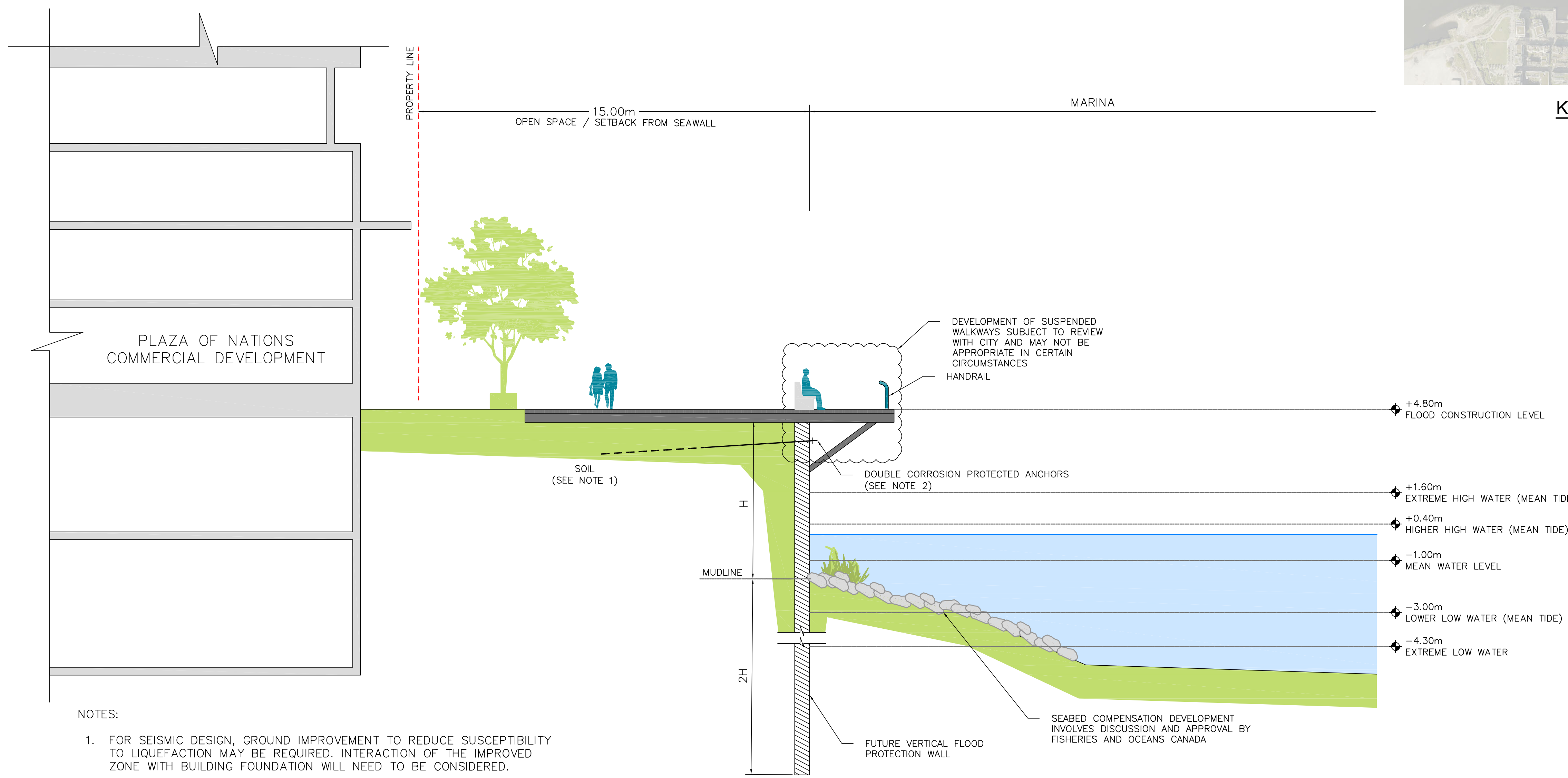


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3. "H" WOULD BE MEASURED UP AND DOWN FROM THE APPROXIMATE MUDLINE LEVEL.

## SECTION 03

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SECTION 03

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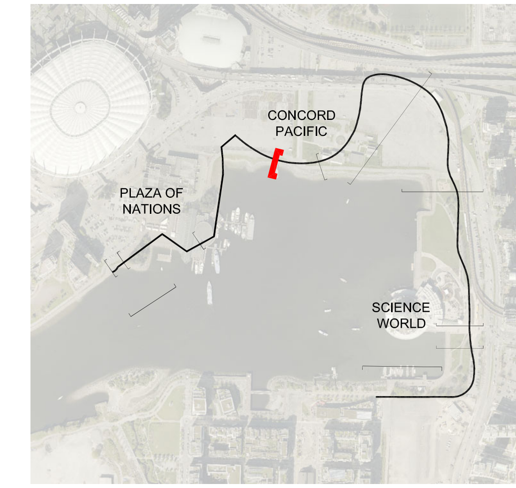


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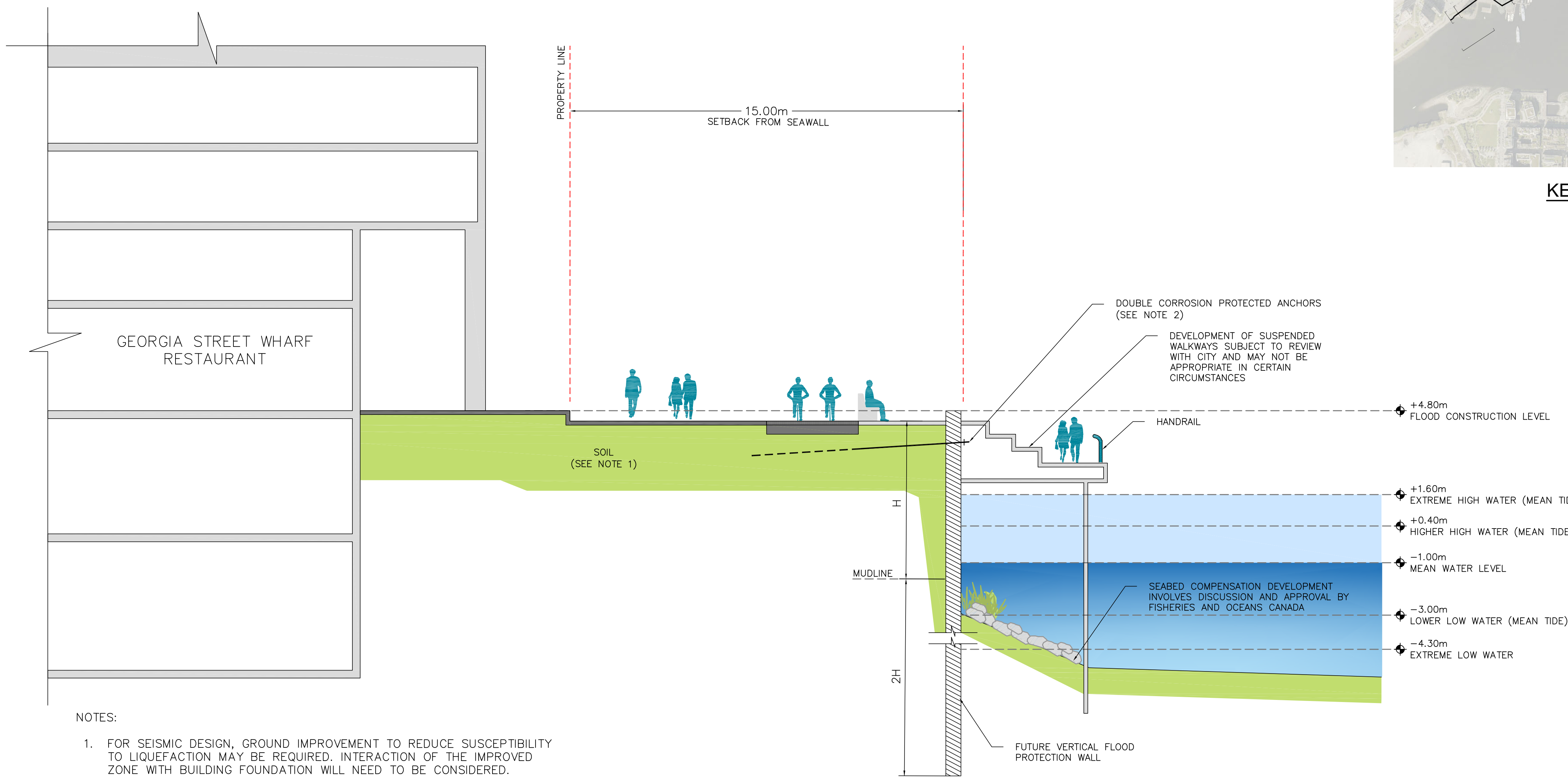


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3. "H" WOULD BE MEASURED UP AND DOWN FROM THE APPROXIMATE MUDLINE LEVEL.

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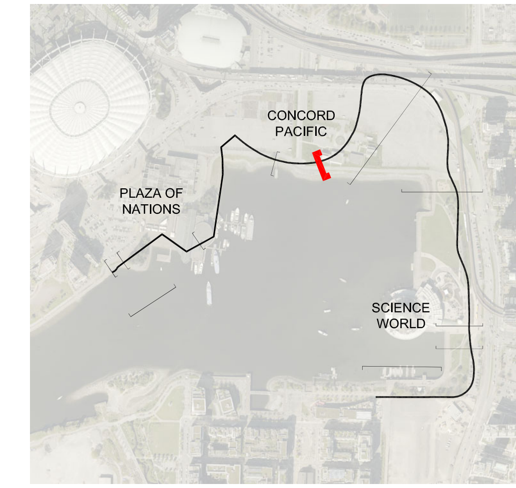


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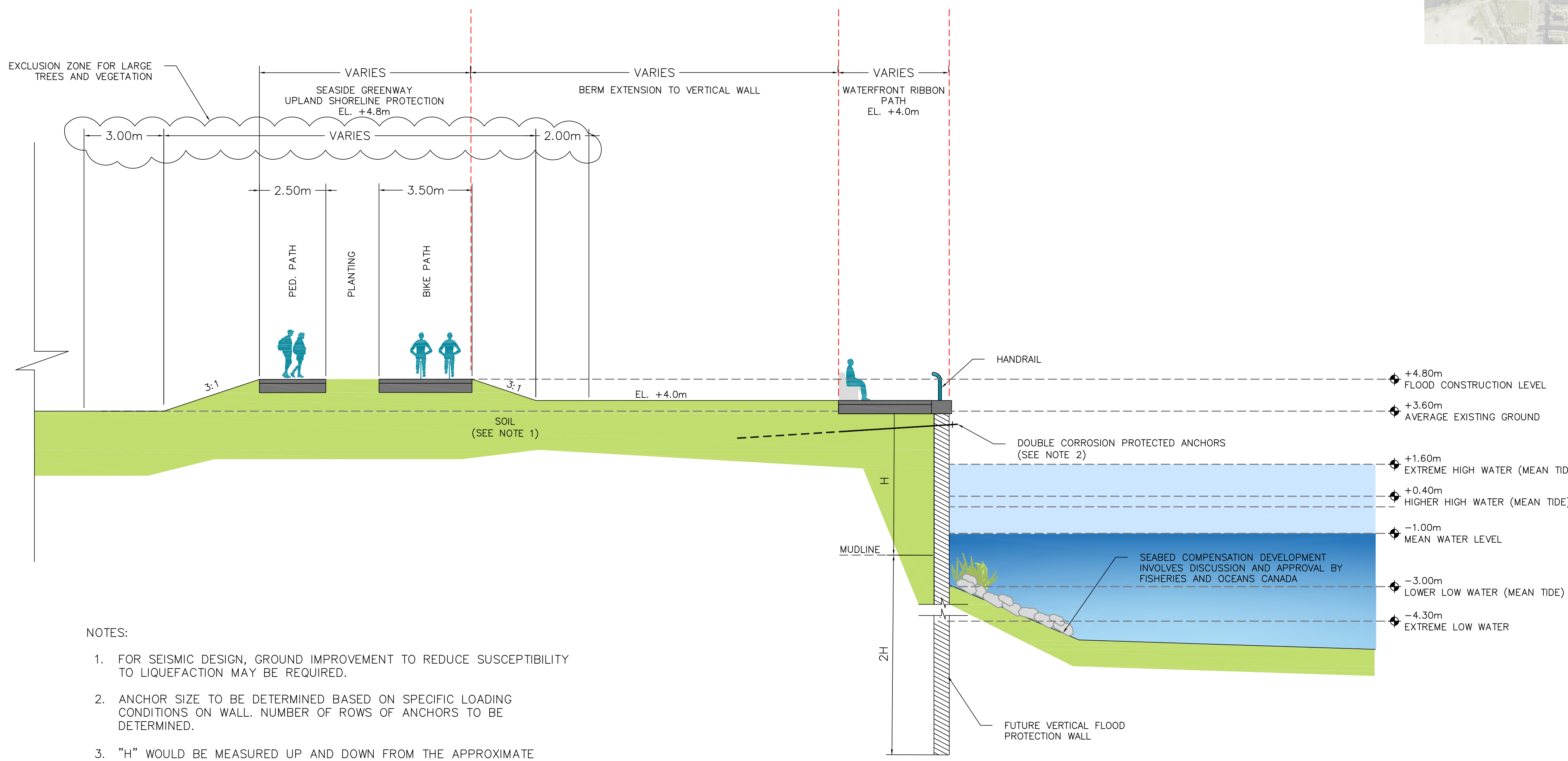


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SECTION 05

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SECTION 05

CITY OF VANCOUVER
SHORELINE FLOOD PROTECTION
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CITY OF VANCOUVER

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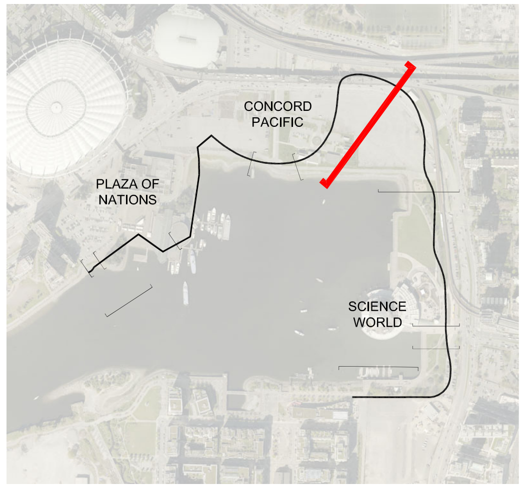


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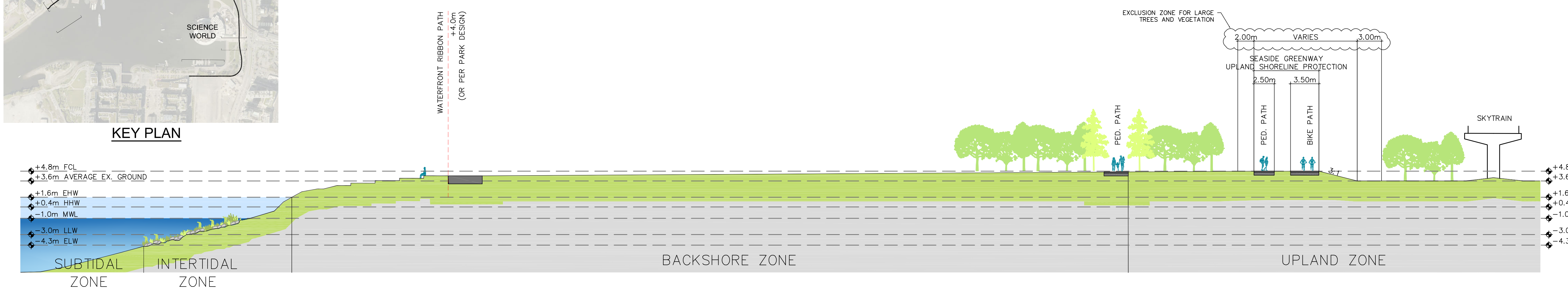


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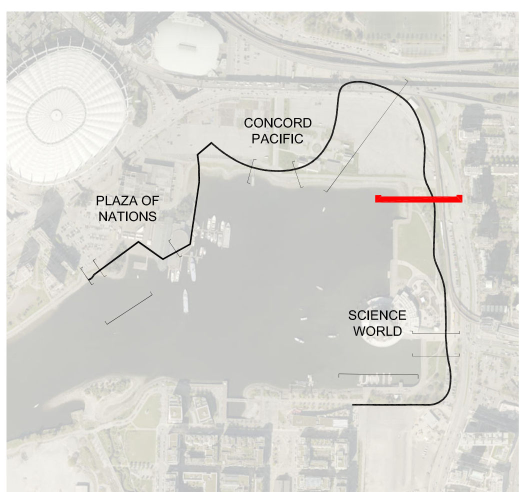


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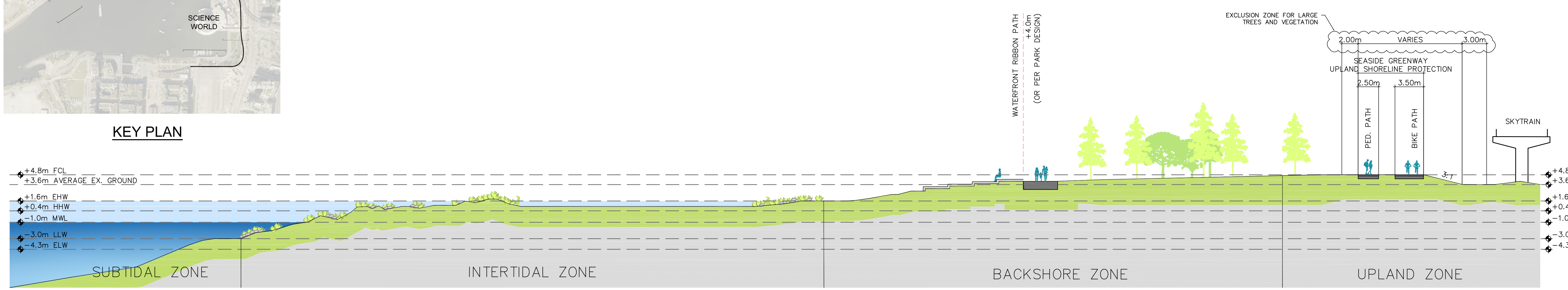


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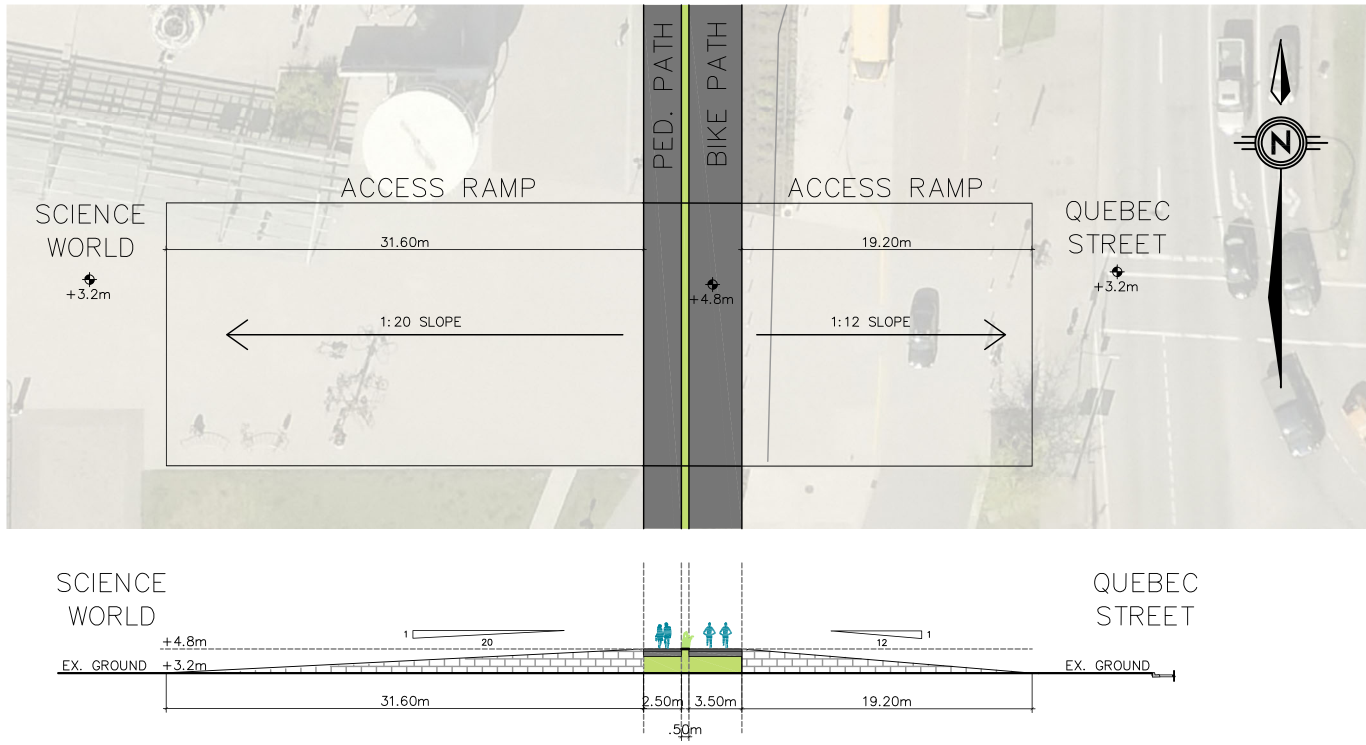
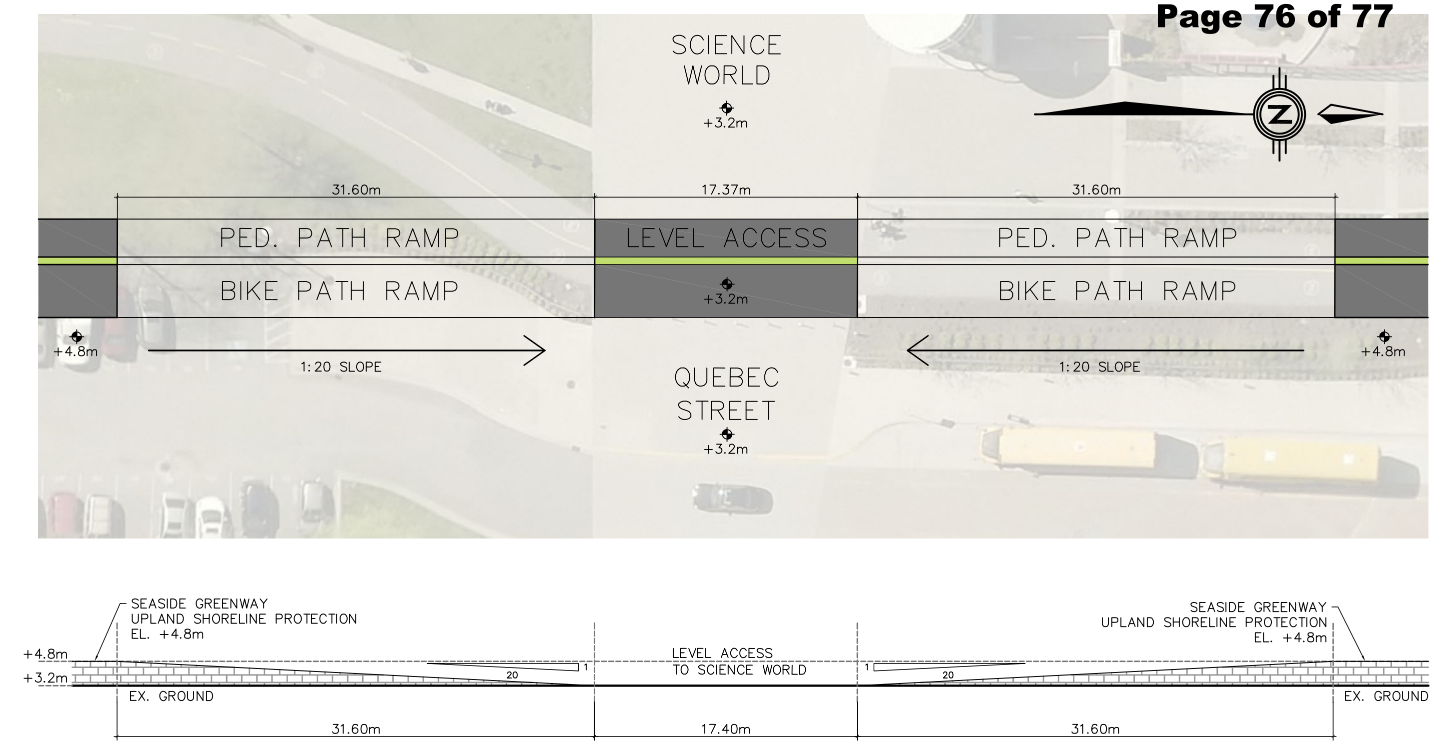


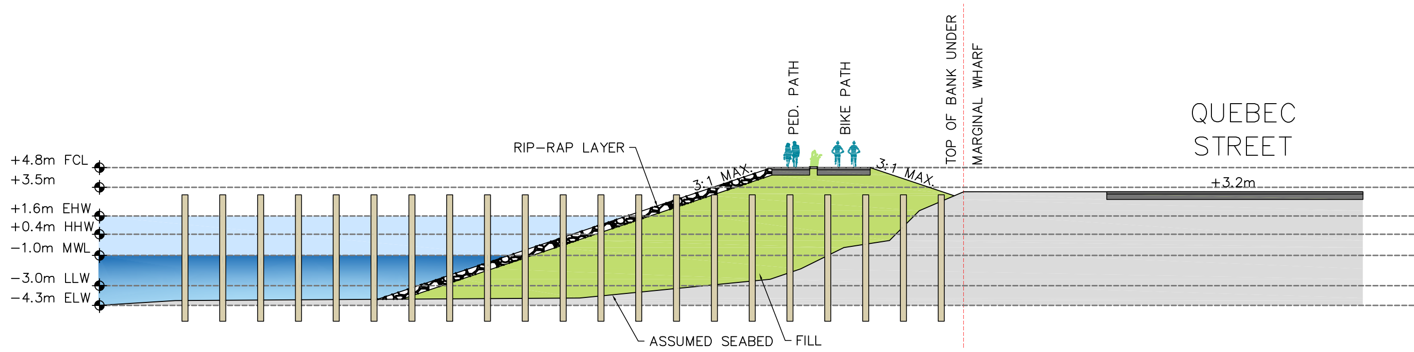

PLAN + SECTION 8 - OPTION 1

SCALE 1:500



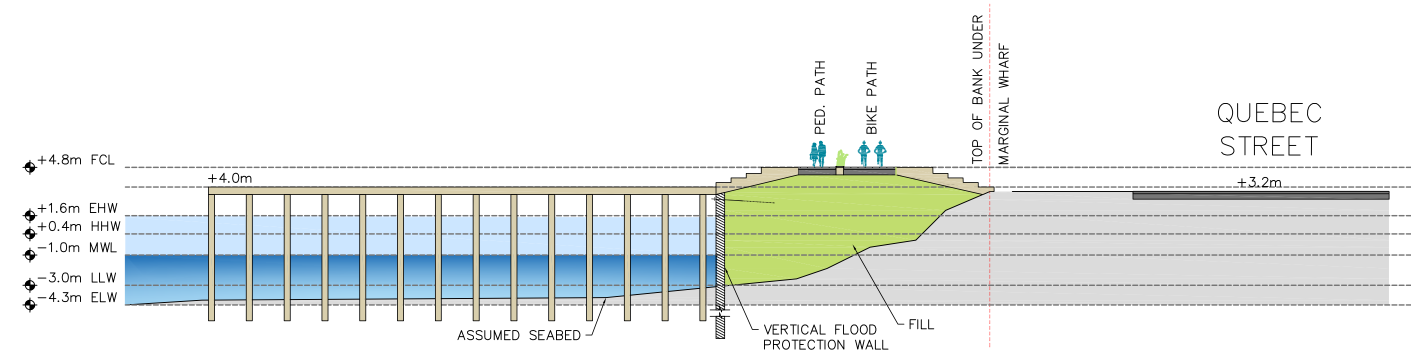

PLAN + SECTION 8 - OPTION 2

SCALE 1:500



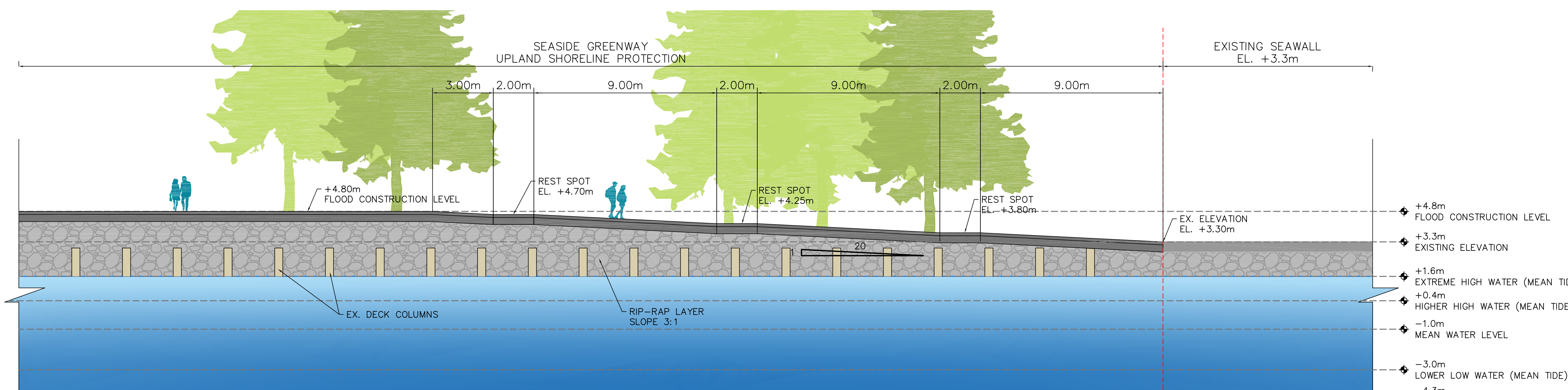

SECTION 9 - OPTION 1: REMOVE MARGINAL WHARF AND LEAVE PILES IN PLACE

SCALE 1:500



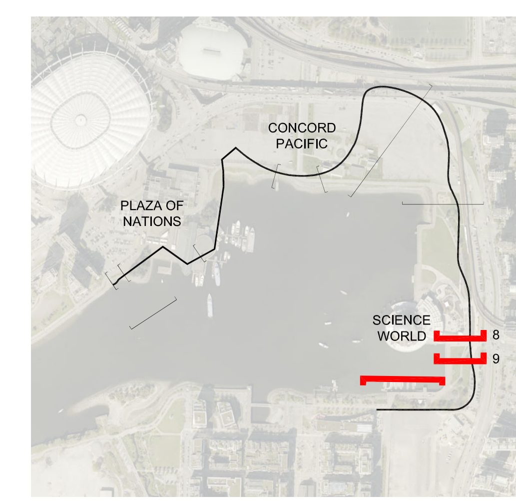

SECTION 9 - OPTION 2: REBUILD MARGINAL WHARF

SCALE 1:500




SECTION 9 (OPTION 1) ELEVATION | TRANSITIONING TO EXISTING SEAWALL NEAR OLYMPIC VILLAGE

SCALE 1:250




KEY PLAN

2021-Feb-12 12:08:03 PM H:\DATA\673983 - NE False Creek Shoreline\4P - Marine\4PDK - Sketches\673983-BaseMap+Sections_ML_210203.dwg

| SECTION 08 & 09 | CITY OF VANCOUVER<br>SHORELINE FLOOD PROTECTION<br>PERFORMANCE CRITERIA<br>CONCEPT SKETCHES |
|---|---|

| DESIGNED | CHECKED |
|---|---|
| - | KD |
| DRAWN | SEALED |
| ML | - |

| REV | DESCRIPTION | BY | DATE |
|---|---|---|---|
| 0 | SUBMITTED WITH FINAL REPORT | KD | 15/02/2021 |

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NOTES
1. ELEVATIONS ARE IN GEODETIC DATUM (GD)

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