CITY OF VANCOUVER

# VANCOUVER SHORELINE FLOOD PROTECTION DESIGN REFERENCE

FINAL (REV 0) - MARCH 2021


KERR WOOD LEIDAL
consulting engineers

THURBER ENGINEERING LTD.

HAPA

Royal HaskoningDHV
Enhancing Society Together

# Contents

# Figures



# Tables

# 1. Introduction

The Vancouver Shoreline Flood Protection Design Reference provides guidance to flood protection designers involved in projects located in the City of Vancouver along the shorelines of English Bay, Burrard Inlet, False Creek, and the Fraser River.

Section 1 provides information on the purpose, application, limitations, and development of the design reference.

## 1.1 Purpose and Intended Audience

The primary purpose of the design reference is to define design criteria and considerations that describe shoreline flood protection works that are preferred by the City of Vancouver (City) and are appropriate for Vancouver's physical, land use, and policy contexts.

Additionally, the design reference seeks to achieve consistent quality in shoreline flood protection works which may be delivered directly by the City or by others (e.g., developers) on behalf of and under the oversight and approval of the City. Under both scenarios, the design may involve work by various consultants.

The primary intended audience for this design reference is the design consultant team working on shoreline projects which may involve structural flood protection works. Section 3 provides additional information on the core and supplementary professional disciplines that may be involved in such projects.

The design reference also serves as a technical resource for City staff in on-going flood management program activities, including City-led shoreline flood protection works, and the review of designs prepared by others.

## 1.2 Application and Limitations

The design reference is primarily applicable to structural flood protection works to be located along or near the shoreline, but may also have applicable content for flood protection works that are incorporated into areas significantly set back from the shoreline (e.g., incorporated into roads on the edge of floodplains). For significant projects, it is anticipated that a specific planning and engagement process will be conducted by the design of structural flood protection works and the application of this design reference. The planning and engagement process would consider an integrated flood management planning approach involving both structural and non-structural measures. This reference is applicable for situations where such planning processes determine that structural measures would be appropriate and preferred.

The design reference provides guidance and criteria but is not a strict design standard, specification, or typical design which will work in all situations. The design of shoreline flood protection works should consider this design reference, but professional responsibility for design development will lie with the design team of each individual project. In particular, the design team should pay close attention to potential site-specific issues. Some of the most common site-specific issues are identified in the design reference, but there may be others that have not been foreseen during preparation of this design reference.

While the design reference content represents the City's preferred criteria and approach, the design team should identify any future potential inconsistencies between the design reference and other relevant guidelines, and discuss them with City staff as part of the design process.

## 1.3 Development Process for Shoreline Design Reference

The first version of the design reference was developed between 2020 and 2021 through literature review of existing local, regional, and international guidance on design of structural flood protection works. Relevant design criteria, considerations, and case studies were gathered, and refined by professional judgement and local experience, to form guidance that is relevant for the Vancouver context.

### 1.3.1 Development Team

The design reference development project was led by the City's flood management team embedded in the Sewers and Drainage Design Branch within Engineering Services. The City's lead staff on the project are Jeannie Lee, M.A.Sc., P.Eng. (Flood Management Engineer) and Tiffany Kang, EIT (Flood Management Engineer).

The design reference document was produced by the following consulting firms and key individuals:

- Kerr Wood Leidal Associates Ltd. (KWL) – Civil/Hydrotechnical Engineering & Environmental
  - Amir Taleghani, M.Eng., P.Eng. – Project Manager & Project Engineer
  - Mike Currie, M.Eng., P.Eng., FEC – Senior Technical Reviewer
  - Eric Morris, M.A.Sc., P.Eng. – Coastal Engineering Reviewer
  - Laurel Morgan, M.Sc., P.Eng., P.E. – Internal Drainage Reviewer
  - Patrick Lilley, M.Sc., R.P.Bio., BC-CESCL – Senior Biologist
  - Larissa Low, M.Sc., B.I.T., BC-CESCL – Junior Biologist
- Thurber Engineering (Thurber) – Geotechnical Engineering
  - Steve Coulter, M.A.Sc., P.Eng. – Senior Geotechnical Engineer
- Hapa Collaborative (Hapa) – Landscape Architecture and Public Space
  - Joseph Fry, BCSLA CSLA ASLA – Senior Landscape Architect
  - Peggy Wong, MLA, BCSLA Intern – Landscape Designer
- Royal HaskoningDHV (RHDHV, based out of the Netherlands) – Civil/Hydrotechnical Engineering
  - Ir. Peter van der Scheer – International Flood Protection Design Advisor

# 2. Background Information

Section 2 provides information on the different flood hazards within Vancouver and how climate change is expected to intensify them. The section also provides an overview of the City's flood management program and relevant reference documents, including design guidelines from various jurisdictions that have been used in developing this design reference.

## 2.1 Flood Hazards

This section describes the various types of flood hazards that potentially affect Vancouver.

### 2.1.1 Coastal Flooding

Coastal flooding occurs when a combination of tide, storm surge, and wind-generated waves cause the coastal water level to exceed the elevation of the top of the shoreline and/or flood protection works. Each of these components is described below. All of Vancouver's shoreline areas are exposed to coastal flooding, including the Fraser River (North Arm).

Tides are the regular variation of sea level due to the gravitational interaction of the sun, moon, and Earth. Vancouver's shorelines experience a mixed, semi-diurnal tidal regime, meaning that 2 high tides and 2 low tides of varying sizes occur each day. The highest tides of the year are experienced during the periods of November to January; the tides in these periods are known as spring perigean tides, or popularly 'king tides'.

Storm surge is a moderately short duration (i.e., hours to days) rise in the sea level, measured above the predicted tide level, due to offshore or near-shore storm processes including pressure changes and wind setup. Additional water level changes due to wind-generated waves are not included in the definition of storm surge. The maximum recorded storm surge height in the region is approximately 1 m (recorded at Pt. Atkinson in 1965). It should be noted that storm surge heights can be sustained over a period of several hours, but the overall coastal water level will continue to change due to the tide.

The stillwater level is the term used to describe the combination of tide and storm surge, which are two physically separate processes (i.e., their combinations are random). However, the highest stillwater levels in the region typically occur in the winter period when storm surge weather events are more likely to occur, and when spring perigean tides ('king tides') occur. The stillwater level is not "still" over time because it falls and rises with the tide, but the term "still" is included to distinguish it from wave effects.

Wave effects (including wave setup and runup) are site-specific processes that act on top of the stillwater level. Wave effects vary by the near-shore and shoreline slope, sediments, and vegetation. Vessel-generated waves are also relevant for design, particularly for the design of bank protection works.

### 2.1.2 Fraser River Freshet Flooding

The portion of the Fraser River (North Arm) which defines the southern boundary of Vancouver is tidally influenced, meaning that water levels are the product of river flow and coastal water level. The Fraser River peak flow, referred to as the freshet, typically occurs between late May and late June, though climate change may impact the timing of the freshet in the future. During the freshet, the river water level in Vancouver is still tidally controlled (i.e., will rise and fall with the tide) but is elevated due to the freshet flow. River velocity is also elevated due to the freshet flow and is highest during low tide. Freshet conditions typically last multiple weeks.

It should be noted that extreme water levels in the lower Fraser River are governed by coastal floods (as noted above, caused by the combination of tide, storm surge, and wave effects), rather than the freshet flood level. This is discussed further in Section 6.3. Fortunately, extreme coastal floods and freshet flood hazards generally do not coincide.

### 2.1.3 Other Flood Hazards

Flood hazards not covered by this design reference include:

- Urban stormwater flooding caused by intense rainfall exceeding the design capacity of drainage systems (i.e., sewer infrastructure);
- Creek flooding on smaller, local creeks (i.e., Still Creek); and
- Tsunami wave runup and flooding.

Nevertheless, some principles of this design reference may be applicable in these other situations.

## 2.2 Sea Level Rise and Climate Change

Flood hazards within the City will be exacerbated by sea level rise and climate change effects on the Fraser River.

### 2.2.1 Sea Level Rise

Anthropogenic (human-caused) sea level is expected to continue rising throughout the 21$^{st}$ century due to a combination of factors resulting from carbon dioxide emissions, including:

1. An increase in ocean volume due to the melting of land ice; and
2. Thermal expansion of seawater and salinity effects on water density.

Based on NASA satellite data of mean sea level observations from 1993 to 2016, the world's oceans are rising at an average rate of about 3 mm/year (NASA, 2020).

The magnitude and timing of future sea level rise are dependent on the future rate of carbon dioxide emissions and are therefore uncertain. Regardless of future potential reductions in carbon dioxide emissions, some amount of sea level rise is expected.

The Province of BC provides guidance on sea level rise planning to local governments, including the BC sea level policy presented in Figure 2-1.

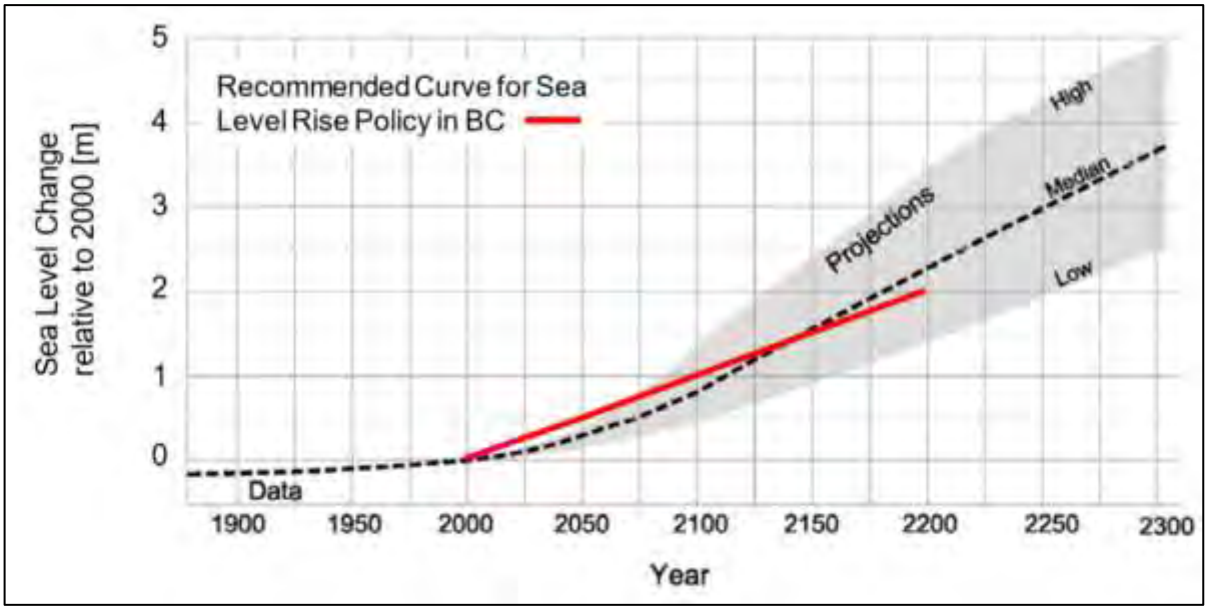



**Figure 2-1: BC Sea Level Rise Policy (Ausenco Sandwell, 2011)**

Using the Year 2000 as a baseline, the Province recommends planning with a linear rate of sea level rise resulting in 1 m of sea level rise by the Year 2100, and 2 m by the Year 2200. This rate of sea level rise does not consider local land subsidence / ground uplift impacts which are used to determine the relative sea level rise (i.e., relative to the ground in a specific location). This is discussed further in Section 6 The Province's sea level rise policy was published in 2011 and is based on a 2009 literature review. The linear approach was selected to be conservative against predictions in the short-term and average in the long-term.

The Province's guidance was adopted by the City in Phase 1 of its Coastal Flood Risk Assessment (NHC, 2014).

Regional factors, including land subsidence and postglacial rebound, can affect the rate of relative sea level rise such that it is different than the overall rate. Natural Resources Canada (NRCAN) has researched land subsidence and has published maps of estimated land subsidence rates for the BC coast based on GPS measurements (Lambert et al., 2008).

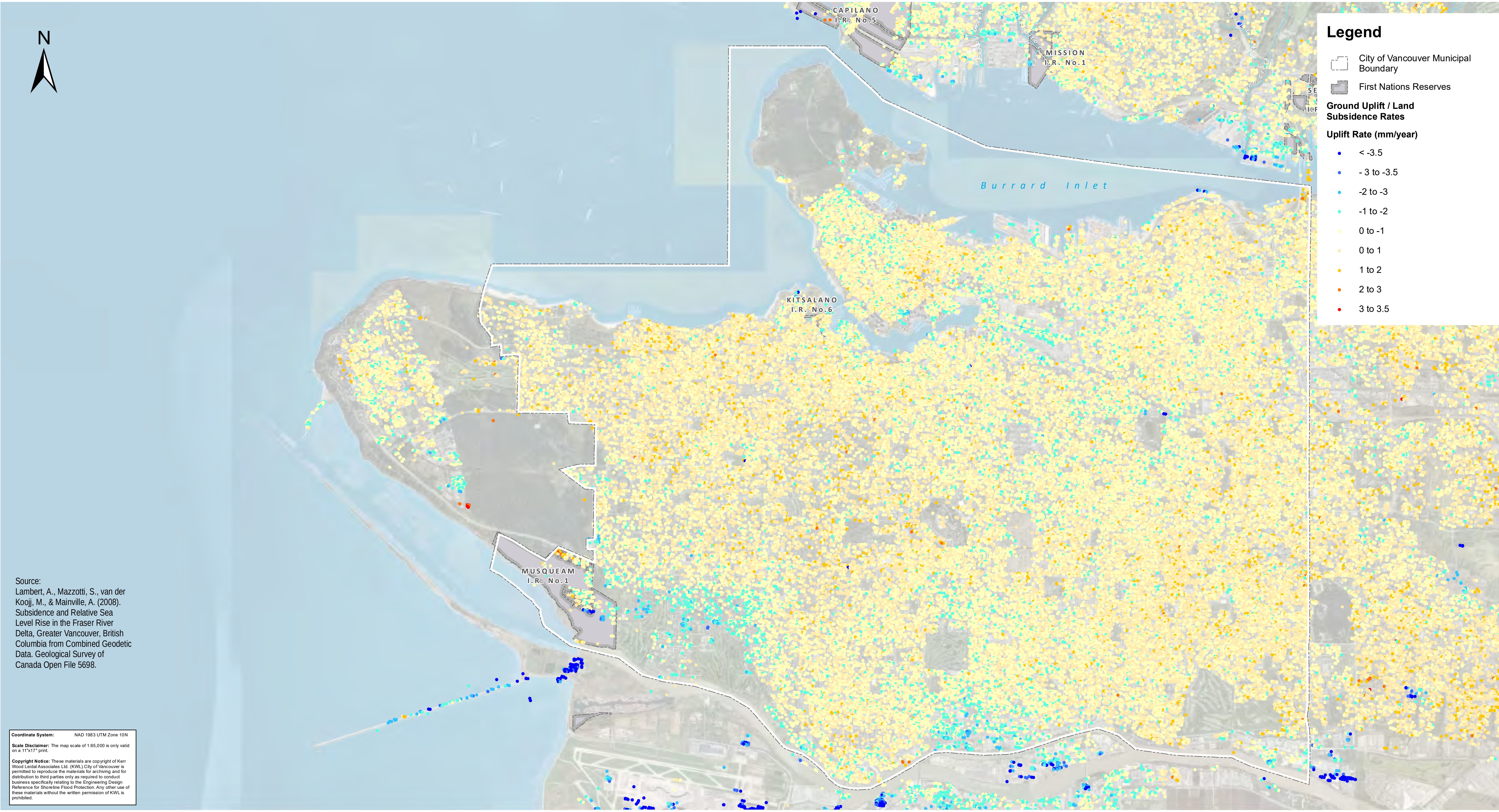
Figure 2-2 reproduces the results from Lambert et al. (2008) for Vancouver. The figure shows that land subsidence and ground uplift are both being observed and that there is no single value allowance that can be adopted for the City's floodplain areas. Earthquakes can also result in sudden land subsidence or ground uplift which affects relative sea level. However, it is understood that this is a more significant concern for Vancouver Island communities which are located closer to the Cascadia Subduction zone than Vancouver (Thomson et al., 2008).

Path: Z:\0000-0999\0000-0099\042-142\430-GIS\MXD-Rp\042142_Fig_3-1_LandSubsidence.mxd Date Saved: 2020-06-19 3:29:18 PM | Author: JLau

**City of Vancouver**

Engineering Design Reference for Shoreline Flood Protection

KERR WOOD LEIDAL
consulting engineers






Project No. 31.548

Date June 2020

Scale 1:65,000

1 0.5 0 1 km

## Land Subsidence Rates in the City of Vancouver

**Figure 2-2**

### 2.2.2 Fraser River Climate Change Projections

Climate change will increase precipitation amounts in the Fraser River watershed, but as the average temperature increases, the fraction of precipitation falling as snow will decrease. Models suggest this will result in substantial declines in snow accumulation at lower elevations across the watershed by mid-century (Islam et al., 2017). Research by the Pacific Climate Impacts Consortium (PCIC) (Shrestha et al., 2017) identifies a clear decreasing trend for moderate peak flows and small floods (e.g., 2-year to 20-year return period) on the Fraser River. The same study found that the trend for larger floods (100-year return period and greater) was inconclusive; the magnitude and direction of predicted changes varied with the choice of climate model.

Separately, the Province's Flood Safety Section modelled Fraser River floods under two statistically downscaled climate change scenarios (BC MFLNRO, 2014):

- a "moderate" climate change scenario where peak flow increased by approximately 21%; and
- an "intense" climate change scenario where peak flow increased by approximately 45%.

A cautious and conservative approach assuming increases to peak flows is appropriate given the uncertainty of the specificities of climate change.

## 2.3 City of Vancouver's Flood Management Program

The City has a history of flood planning; this section contains a primer on the City's flood management program and organization.

### 2.3.1 Coastal Flood Risk Assessment and Adaptation Planning

Below is a brief description of the past flood management work and on-going initiatives by the City.

**Coastal Flood Risk Assessment**

The City commissioned the Coastal Flood Risk Assessment to assess coastal flood risk for the present and future scenarios within the context of sea level rise. Phase I (NHC, 2014), herein referred to as CFRA-1, included wave and hydraulic modelling (for English Bay, Burrard Inlet, False Creek, and the Fraser River) to conduct a hazard assessment, as well as a vulnerability and consequence assessment. Phase II (Compass and Ebbwater, 2015) included high-level adaptation strategies, concepts, and recommendations as well as a zone-by-zone analysis for specific areas. Phase III presented a risk assessment tool to assist in developing a timeline road map for sea level rise planning across the City.

**Coastal Adaptation Plan - Fraser River and False Creek**

The Coastal Adaptation Plan (CAP) is a long-term planning program to address sea level rise adaptation and coastal flood management needs for the City.

Phase 1 of the CAP was conducted in 2018 and focused on the Fraser River floodplain which is the area of the City with the highest likelihood of coastal flooding. Phase 1 consisted of engagement with residential communities, Musqueam First Nation, and businesses, which culminated in a report (City of Vancouver, 2018) outlining engagement results including values and design principles.

Phase 2 of the CAP (City of Vancouver, 2020) was conducted in 2020 and focused on the False Creek floodplain. The project engaged over 2,000 people from a wide range of stakeholder perspectives. Multiple engagement events, activities, and platforms were used to reach a diverse audience.

The CAP community values and planning and design principles for the Fraser River and False Creek are presented and discussed in Section 7 of the design reference which focuses on urban design and public amenity integration.

**Sea2City Design Challenge**

Anticipated to start in 2021, the Sea2City Design Challenge will be a participatory and interdisciplinary planning and design challenge that will add to the City's toolbox of coastal flood management approaches. The Sea2City Design Challenge will focus on the Fraser River and False Creek floodplains and will build on the Coastal Adaptation Plan to guide urban planning and development, infrastructure management, and ecosystem enhancement.

### 2.3.2 Designated Floodplain Areas

Designated floodplain areas are based on 500-year return period (0.2% annual exceedance probability) flood exposure with 1 m of sea level rise anticipated by the Year 2100. Areas defined and mapped as designated floodplains (City of Vancouver, 2015 – available at www.vancouver.ca/sealevelrise) are:

- Fraser River North Arm (the entire southern border of the City); and
- English Bay, False Creek, and Burrard Inlet floodplain sub-areas, including:
    - Point Grey – Kitsilano (along the northern shoreline of the City, including Jericho Beach Park, Spanish Banks/Locarno Beach and Kitsilano Beach Park);
    - False Creek (a short inlet extension of Burrard Inlet, east of Kitsilano Point);
    - English Bay – Stanley Park (north of the mouth of False Creek, continuing north and east around Stanley Park); and
    - Inner Harbour (Burrard Inlet east of the Brockton peninsula of Stanley Park).

### 2.3.3 Floodplain Standards and Requirements (2015)

Floodplain development standards and flood construction levels (FCLs) within the City are outlined in a land use guideline that came into effect on January 1st, 2015 (City of Vancouver, 2015), and is summarized within this section. Floodplain development standards and FCLs apply to buildings on land designated as floodplain within the City, to reduce injury, loss of life, property damage and recovery time in the case of a flood.

The FCL within designated Vancouver floodplain areas is a minimum of 4.6 m CGVD28, plus site-specific allowances for subsidence and wave effects. The underside of a wooden floor system, or the top of a concrete floor slab, of any building used for habitation, business or storage of goods shall not be lower than the FCL. In certain areas, it may be necessary to increase the FCL to allow for wave run-up. Conditional approval of a reduction in elevation may be approved by the Chief Building Official (CBO) on a site-by-site basis. During the Development Permit process, the CBO may require FCLs for any buildings in a designated floodplain, regardless of whether they are habitable.

Below the FCL, the following building components are prohibited: furnaces, electrical switchgear, electrical panels, fire protection systems or other fixed building services susceptible to flood damage, unless such services are protected from flood damage and accessible for servicing during a flood, to the satisfaction of the CBO. Furthermore, the storage of hazardous or toxic substances below the FCL is prohibited.

The document also specifies minimum setbacks (with some variance conditions) from the natural boundary of watercourses or the land-side edge of flood protection structures to any buildings, including supporting structures and fill, as follows:

- 30 m for the Fraser River;
- 15 m for English Bay, False Creek, and Burrard Inlet;
- 5 m for Still Creek; and
- 7.5 m for any structure erected for flood protection or seepage control.

The design team should seek input from the City where there may be conflicts between the above and more specific setbacks defined in the design reference.

## 2.4 Other Relevant City Policies

This section notes other City policies that may be relevant in applying the design reference.

### 2.4.1 Climate Adaptation Strategy

Initially adopted in 2012 and updated in 2018, the Climate Change Adaptation Strategy presents priority adaptation actions for the City to take for a variety of climate change related hazards. The 2012 report identifies flooding and/or inundation due to sea level rise as the most relevant climate change impact. The 2018 update lists coastline preparedness as one of the five 'core action priorities', with 18 corresponding adaptation actions to be taken in the short to medium term.

### 2.4.2 Rain City Strategy

Developed as part of the City's green rainwater infrastructure planning process, the Rain City Strategy provides a roadmap for advancing rainwater management practices. This policy relates to flood protection as there is an increase in the risk of urban flooding (or sewer and water backups) during a coastal high water event.

## 2.5 Relevant External Guidelines

The following design, policy, and professional practice guidelines from BC and international jurisdictions were considered in the development of the design reference and can serve as additional information resources for the design team.

### 2.5.1 Provincial Guidelines

- Dike Design and Construction Guide, Best Management Practices for British Columba – Ministry of Water, Land, and Air Protection, July 2003.
- Riprap Design and Construction Guide – Ministry of Environment, Lands, and Parks, March 2000.
- Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment – Ministry of Environment, Lands, and Parks, and Department of Fisheries and Oceans Canada, March 1999.
- Seismic Design Guidelines for Dikes 2nd Edition – Ministry of Forests, Lands, and Natural Resource Operations, 2014.

- BC Ministry of Environment Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use (Ausenco Sandwell, 2011a; 2011b; 2011c).
- EGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC (EGBC, 2012 and amended in 2018).
- BC Flood Hazard Area Land Use Management Guidelines (BC MWALP, 2004 and amended by BC MFLNRORD in 2018).

### 2.5.2 International Jurisdiction Guidelines

- Design and Construction of Levees – US Army Corps of Engineers, 2000.
- Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures - US Army Corps of Engineers, 2014.
- FloodSafe California. 2012. Urban Levee Design Criteria.
- The International Levee Handbook – Construction Industry Research and Information Association (UK), US Army Corps of Engineers, and the French Ministry of Ecology, 2014.
- EA, ENW, KFKI. 2007. EurOtop. Wave Overtopping of Sea Defenses and Related Structures: Assessment Manual.

# 3. Design Team Roles and Expertise

Section 3 describes the design team's key roles and associated qualifications for the design of shoreline flood protection works in Vancouver.

## 3.1 Core Roles and Disciplines

This section describes the core disciplines that are typically involved in a shoreline flood protection project. This list is not exhaustive or mandatory but is an indication of the City's general expectations for roles and expertise for typical projects.

Reference to "engineer" means a Professional Engineer who is registered with Engineers and Geoscientists BC, and is considered to be a Qualified Professional (QP) for the pertinent work.

### 3.1.1 Civil / Hydrotechnical Engineer

The civil/hydrotechnical engineer will generally focus on design aspects related to the hydrotechnical design criteria, flood protection elevation, alignment and configuration of works, erosion protection, internal drainage, local utility issues, and interaction with adjacent properties and infrastructure.

The civil/hydrotechnical engineer will typically lead the flood protection design project because of their role in identifying driving criteria (e.g., flood levels, crest elevation, configuration of works), and leading the production of design drawings, specifications, and construction documents.

The design team should include a hydrotechnical engineer with expertise in some or all of: flood and erosion protection, river engineering, and floodplain management. This role may be combined with the general civil engineering role if the same professional is adequately experienced in both. The hydrotechnical engineer may need to be supplemented with a fluvial geomorphologist if the project is located in a reach of the Fraser River where river sediment aggradation and degradation (scour) is a potential concern.

Depending on the project location and wave hazard exposure, a coastal engineer may also be required to assess wave effects, particularly wave runup and overtopping calculations in support of the design. This is discussed further under the supplemental disciplines sub-section.

### 3.1.2 Geotechnical Engineer

The design team should include a geotechnical engineer with expertise in dike slope and/or riverbank stability analysis and design, and seismic performance assessment and ground improvement work design for flood protection works.

The geotechnical engineer should lead geotechnical field investigations and numerical slope stability analyses that will help to define the flood protection cross-sectional geometry, dike fill materials, layering, drainage requirements, and the need for and extent of ground improvement works for seismic performance.

### 3.1.3 Biologist / Qualified Environmental Professional

Vancouver's shorelines provide important ecosystem services and shoreline flood protection projects should aim to minimize habitat impacts and, where possible, enhance habitat and incorporate nature-based solutions (discussed further in Section 8).

The core project team should include a registered professional biologist and/or other environmental professionals to provide baseline habitat inventories, impact assessment, habitat preservation and/or enhancement design input, and regulatory environmental permitting assistance services.

On a site-specific basis, the biologist's role may also need to be supplemented by an arborist to conduct a tree survey in support of habitat assessments and detailed design.

## 3.2 Supplemental Roles and Disciplines

This section describes additional disciplines that may be involved in a shoreline flood protection project depending on the context.

### 3.2.1 Coastal Engineer

A coastal engineer should be included on the design team for shoreline flood protection design projects in areas subject to wave effects (English Bay, Burrard Inlet, False Creek, and the Fraser River downstream of Deering Island).

While some high-level information on nearshore wind-generated waves is available from the City's CFRA-1 project (NHC, 2014), individual shoreline flood protection projects may need to review the available information and conduct wave transformation and wave runup calculations which are dependent on the proposed design shoreline geometry.

The design team should discuss the need for coastal engineering analysis with the City at the beginning of the project to determine the extent of additional analysis that may be required.

### 3.2.2 Landscape Architect

Vancouver's shoreline parks and trails are some of the most cherished public spaces in the city, and the design of shoreline flood protection works needs to accommodate the City's functional and aesthetic objectives. Where possible, flood protection works should enable enhancement of public space features to deliver co-benefits beyond flood protection.

Depending on location and context, the design team should include a landscape architect to enable an integrated design approach. It is recommended that the design team discuss the need for landscape architecture services with the City at the beginning of the project. Projects located within parks may be led by the Vancouver Board of Parks and Recreation, and in some cases, the landscape architect may be the project team lead.

### 3.2.3 Other Potential Disciplines

In addition to the above, the City may expect the following disciplines to be involved as part of the flood protection design team depending on project context:

- Archaeology to consider the need for special consideration of archaeological resources and provide input into design alignment and the approach to construction;
- Structural engineering for medium to large transportation, public space, or other structures that may need to connect on top of, through, or below the proposed shoreline flood protection works;
- Structural engineering, including marine structural engineering, for multifunctional flood protection structures and/or structures that sit out over the water;
- Environmental engineering where the flood protection works alignment and construction could interact with contaminated sites and/or the related treatment facilities;
- Transportation engineering where the flood protection works may be incorporated into vehicle and active transportation corridors; and
- First Nations and community stakeholder engagement to inform and empower participation in the design process where relevant and requested by the City.

# 4. Project Phases and Documentation

Section 4 provides information to guide project implementation, including the types of documentation that may be required. It is important to note that such provisions may be specific to a location and/or project.

Active and direct communication with City staff is encouraged throughout the project to confirm and discuss various items highlighted in this reference. This would be more efficient than communication routed through a third-party such as the project owner/developer.

While the focus of this design reference is on design, this section provides some information pertaining to construction in order to support project team assembly and project planning.

## 4.1 Planning, Engagement, and Design Concept

The design reference focuses on the preliminary and detailed design of shoreline flood protection works. However, in most cases, planning, engagement, and conceptual design phase are critical to the successful implementation of a project. Depending on location, context, and scale of project, planning, engagement, and conceptual design work may be conducted separately and previously by the City as part of larger sea level rise and coastal flood adaptation programs. In particular, planning, engagement, and conceptual design work is underway in the Fraser River and False Creek floodplains as part of the City's Coastal Adaptation Plan program and the Sea2City Design Challenge anticipated to start in 2021 (refer to Section 2 for more information). In these areas, it is anticipated that the general alignment and preferred form of flood protection will be defined by the application of the design reference for project-specific design.

In addition, other City planning documents (e.g. official development plans, area plans, etc.) may already contain pertinent information such as land uses, infrastructure, and transportation features to be incorporated and accommodated.

It is recommended that the design team confirm the appropriate starting point and the extent of additional planning, engagement, and conceptual design required by preliminary and detailed design.

Ideally, the preferred flood protection concept, including general alignment and general typology cross-section shape, has been pre-determined through high-level planning and engagement. In reality, shoreline flood protection design projects will likely continue to proceed while the City continues to work on high level planning processes. Consequently, a balanced approach involving some planning, engagement, and conceptual design may be required by preliminary design. The need for stakeholder and community engagement should be confirmed with City staff. If a clear design concept has not been previously determined, the design team should review available background documents and consult with City staff to select an appropriate alignment and typology cross-section.

For projects located adjacent to existing development and/or high traffic public spaces (e.g., seawall), engagement is recommended to include a minimum of 2 public/stakeholder events to provide information, gather feedback, and report back on the final design. The engagement should provide easy to understand information about proposed elevation changes and view impacts, overall footprint of the project, and environmental impacts.

## 4.2 Preliminary Design, Permitting, and Detailed Design

### 4.2.1 Data Collection

The design project should start with a data collection phase which may include the following tasks:

- Geotechnical field investigations and technical report;
- Baseline environmental habitat desktop and field assessment and summary report;
- Land tenure investigation;
- Topographic (and potentially bathymetric) survey;
- Subsurface and surface utility location and survey;
- Bank protection and shoreline hazard field investigation; and
- Tree survey (conducted by an arborist); and
- General background information desktop review and field investigations related to other disciplines (e.g., archaeology, contaminated sites, park/public space, etc.).

### 4.2.2 Preliminary Design

The preliminary design phase typically involves site-specific analyses to define key design criteria (discussed in Section 6) and development of design documents to implement the criteria.

The following tasks and documentation are typically included this phase:

- Deep-water wave conditions analysis (if required);
- Near-shore wave runup and overtopping calculations (if required);
- Consideration of river engineering issues (for the Fraser River) such as river current, erosion and the potential for river changes such as dredging;
- Geotechnical slope stability (non-seismic) analyses to confirm stable cross-section geometry, fill materials, and potential need for seepage/piping control works;
- Geotechnical seismic stability analysis and technical report to determine the need and extent of ground improvement works;
- Site-specific land subsidence rate selection and post-construction settlement allowance analysis;
- Geometric design of works (side slopes, crest width, etc.);
- Preliminary design for structural elements (e.g. walls);
- Riprap sizing and typical cross-section design;
- Configuration of bank protection works (if other than riprap);
- Identification of operation and maintenance requirements (high-level);
- Preliminary design tasks related to other disciplines;
- Preparation of a draft design basis report to document the above;

- Preparation of preliminary design drawings including plan and profile drawings, cross-section drawings, and details;
- Preparation of draft technical specifications for construction; and
- Preparation of a Class C or Class B construction cost estimate.

The preliminary design phase should involve at minimum one round of City staff review and revision of the design. This process is the responsibility of the lead designer who should coordinate addressing comments with the other designers as needed.

### 4.2.3 Permitting

The following provides a summary of the common federal and provincial legislation which may require permits for the construction of shoreline flood protection works. The design team should give early consideration to the actual list of required permits based on the project's unique context, and discuss the permitting process with City staff.

**Federal Statues**

<u>Fisheries Act:</u> Projects near water must ensure that activities do not adversely affect fish or fish habitat. The modernized *Fisheries Act* [RSC, 1985, c. F-14] prohibits obstructing the free passage of fish (§ 34.3 (2)); causing the death of fish (§ 34.4 (1)); causing the harmful alteration, disruption or destruction of fish habitat (§ 35 (1)); depositing deleterious substances in waterbodies (§ 36 (3)); and other actions. The Fish and Fish Habitat Protection Program of the Department of Fisheries and Oceans (DFO) oversees projects near water. A *Fisheries Act* Authorization can be obtained from the Minister of Fisheries, Oceans and the Canadian Coast Guard.

<u>Species at Risk Act:</u> Wildlife species are protected on federal lands and gazetted critical habitat is protected across all jurisdictions. The *Species at Risk Act* [SC 2002, c. 29] prohibits killing or harassing species listed on Schedule 1 of the Act (§ 32 (1)); damage or destruction to a residence of a species listed on schedule 1 of the Act (§ 33); destruction of critical habitat (§ 58(1)); and other actions. Critical habitat is identified for species listed as Endangered or Threatened under the *Species at Risk Act* as critical to the survival or recovery of listed species (§ 2).

The Species at Risk (SAR) Program oversees protection for terrestrial and aquatic species at risk. A *Species at Risk Act* Authorization under Section 73 can be obtained from the relevant minister.

<u>Migratory Birds Convention Act, 1994:</u> Migratory birds are protected by the *Migratory Birds Convention Act, 1994* [SC 1994, c. 22] and the Migratory Birds Regulations [CRC, c. 1035]. Under the *Migratory Birds Convention Act*, it is unlawful to deposit a substance that is harmful to migratory birds. Under the Migratory Birds Regulations, it is prohibited to disturb, destroy, or take a nest or egg of a migratory bird.

The Canadian Wildlife Service provides nesting calendars to avoid impacts to breeding birds (Government of Canada 2020). Trees and vegetation in Vancouver that may contain birds should not be disturbed during the regional nesting period between late March and mid-August.

**Other Federal Regulatory Considerations**

- *Canadian Navigable Waters Act* [RSC 1985, c. N-22]: Navigation Protection Program (NPP) of Transport Canada approves and sets terms for works in navigable waters.
- *Impact Assessment Act* [SC 2019, c. 28, s. 1]: Major projects must be reviewed by the federal Environment Minister following a public consultation process. Projects are designated according to the list of activities in the Regulations Designating Physical Activities (SOR/2012-147).

**Provincial Statutes**

Dike Maintenance Act: The *Dike Maintenance Act* (DMA) [RSBC 1996, c. 95] regulates flood protection works and related infrastructure (e.g., drainage pump stations) that protect more than one property. The DMA applies to lands under provincial jurisdiction, including municipalities as defined in the Community Charter, and does not apply to federally regulated lands (e.g., First Nation reserves). The approval process under the DMA is administered by the Inspector of Dikes office which is linked with the Ministry of Forests, Lands, and Natural Resource Operations and Rural Development.

Under the Vancouver Charter, the City may not seek approval from the Inspector of Dikes Office but will work in collaboration with its staff. The Inspector of Dikes Office plays an important role as an invaluable source of guidance and support in Vancouver's flood protection endeavours.

Water Sustainability Act: Changes "in and about a stream" in British Columbia require authorization by the Ministry of Forests, Lands, Natural Resource Operations and Rural Development under the *Water Sustainability Act* [SBC, 2014, c. 14]. For this application, "stream" is defined very broadly to include a river, creek or small watercourse, whether usually containing water or not. Major works require a Change Approval under Section 11 of the Act, which includes regulatory conditions set by the habitat officer with respect to water use, habitat, contaminants, and general environmental protection. Approval timelines range widely and may take up to twelve months or more depending on the complexity of the proposed works.

Applications for Change Approval typically involve referral of the application to a broad range of groups including First Nations, environmental organizations, non-governmental organizations, and potentially impacted parties.

Projects in and about a stream should be planned to occur within regional timing windows when risk to fish and wildlife is lowest. Periods of least risk to fish and fish habitat in Vancouver typically occur in late summer, between July and October.

Wildlife Act: The *Wildlife Act* [RSBC 1996, c. 488] decrees all wildlife in British Columbia as property vested in the provincial government. The Act also outlines statutory requirements for killing or taking wildlife. The Act contains prohibitions against taking or disturbing birds, their eggs, and some nests.

**Other Provincial Regulatory Considerations**

- *Heritage Conservation Act* [RSBC 1996, c. 187]: Archeological permits may be required through the Forests, Lands, Natural Resource Operations & Rural Development.
- *Environmental Assessment Act, 2018* [RSBC 2018, c. 51]: Major water management projects must be reviewed by the Minister of Environment and Climate Change Strategy and the Minister of Municipal Affairs and Housing.

### 4.2.4 Detailed Design

The detailed design phase involves finalizing key design decisions (e.g., confirmation of ground improvement requirements and preferred method for seismic performance) and adding the level of detail required to prepare the project for final permitting requirements and construction.

The following tasks and documentation are typically included in this phase:

- Conduct supplemental project investigations as may be appropriate;
- Finalization of the design basis report and other supporting reports;
- Resolution of comments from the City, internal stakeholders, stakeholder and community engagement, and permitting agencies;
- Preparation of final design drawings and specifications;
- Preparation of a Class A construction cost estimate; and
- Preparation of Issued for Tender and/or Issued for Construction drawings, specifications, and related documents.

## 4.3 Construction

The construction phase should include field review by the engineer(s) of record, typically including both the civil/hydrotechnical engineer and the geotechnical engineer.

Construction management should include coordination with and monitoring of potential impacts to adjacent infrastructure, private property, and adjacent concurrent construction projects, including excavations. Design considerations related to this are provided in Section 6.

Record drawings should be prepared for the constructed works. Ideally, a construction completion report is also prepared to describe the constructed works, key issues encountered during construction, and any major design changes.

## 4.4 Operation and Maintenance

The responsibility for and key features of operation and maintenance (O&M) should be determined during the design stage. It is preferred that the City be responsible for O&M with an appropriate form of secured land tenure in place. This is discussed further in Section 6.

The design team should prepare an O&M manual for the flood protection works. The O&M manual should be prepared based on a potential City-specific template (if one is developed in the future) or the provincial template available through the BC Inspector of Dikes office. Key aspects of an O&M manual include the need and timing for inspections (regular, during high water events, and post-high water/flood events), guidance on routine maintenance and repair work, and guidance on restoration to pre-flood conditions following a flood event.

# 5. Design Principles

Section 5 introduces four principles that describe the general vision for the design and performance of shoreline flood protection in Vancouver. The design basis report (refer to Section 4) should describe how the proposed design considers and incorporates the principles.

These principles focus on flood protection performance and do not include other principles related to the accommodation of public space/amenities and environmental habitat preservation/enhancement which are discussed in Section 7 and Section 8.

It should be noted that these design principles are separate and supplemental to the design principles described in the Fraser River and False Creek coastal adaptation plans referenced in Section 2. The principles in this section focus more on the engineering performance of the structural works whereas the design principles in the coastal adaptation plans are broader.

## 5.1 Passive

The flood protection works should perform as intended *passively* without reliance on any manual labour or mechanical/electronic systems (e.g., gates) for operation.

Hydraulic gates that raise automatically with the water level may be suitable as part of secondary protection at the building site level (e.g., parkade entrance flood gate), but still rely on mechanical systems and should not be incorporated into the primary shoreline flood protection works.

Designs should also aim to be passive with regards to maintenance requirements which should be confirmed by the maintenance authority (ideally the City) early in the design process. Reliance on third-party (e.g., developer, strata, utility, etc.) maintenance is discouraged.

## 5.2 Independent

The flood protection works exist, perform, and are maintained *independently* of adjacent infrastructure, private property, and natural features.

In particular, the design should incorporate features that as much as possible separate the performance of the flood protection works from the existence, performance, and maintenance of adjacent buried infrastructure and building foundations. For example, watermains located adjacent to earthfill dikes raise a potential internal erosion concern related to watermain breaks which could quickly erode dike fill and cause sinkholes. Independent performance can be increased by locating the watermain away from the dike and by incorporating granular filter layers into the dike design that would reduce the likelihood of internal erosion.

## 5.3 Robust

The flood protection works perform *robustly* under a variety of conditions and against all key failure modes. This means that the design has considered all possible failure modes and incorporated design features to address them.

For example, animal burrows are a dike performance concern in naturalized shoreline areas. Typical designs rely on annual inspection and maintenance programs to address this. However, design robustness can be increased by incorporating barriers (e.g., wire fence) into the dike design in areas where animal burrowing is a high concern and/or inspection/maintenance is expected to be an issue.

Robustness can also be achieved through which reduce the likelihood of failure or the severity of failure under scenarios exceeding design conditions. This is also sometimes referred to as a “fail-safe” approach.

For example, a paved dike crest and armoured land-side slope may slow erosion in the event of overtopping better than a granular crest and a grass side slope. Slowing erosion when design conditions are exceeded could mean the difference between limited overtopping flooding and a total dike breach. The design team should identify low-cost and/or co-benefit opportunities that can increase the robustness of the design. In this example, there may be landscape or urban design benefits related to a paved crest and an armoured land-side slope.

For flood protection works protecting critical infrastructure, the City may require that the design incorporate robustness features to reduce failure risk based on the “As Low As Reasonably Practicable” or ALARP principle, where risk reduction features are incorporated until the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained.

## 5.4 Adaptable

The flood protection works are *adaptable* to changing conditions with minimal impacts to external / adjacent land, infrastructure, and natural features. Changing conditions can include sea level rise, changing river bathymetry adjacent to a site, natural shoreline erosion, and adjacent property development. As described in Section 6, sea level rise design criteria includes designing for 1 m of sea level rise (above Year 2000 historic baseline) plus land subsidence allowances and providing a proof-of-concept for upgrading to allow for 2 m of sea level rise. Emphasis should be placed on the magnitude of sea level rise instead of the projection timeline to provide flexibility and clarity as projections are likely to change and may involve sea level rise acceleration.

The design of flood protection works should facilitate future raising/upgrading of the works to the extent reasonably possible. In addition to raising the height of the works, this could include installing more robust features for erosion protection.

# 6. Flood Protection Design Criteria

This section provides minimum design criteria to be considered in the design of shoreline flood protection works.

Geotechnical engineering criteria have been summarized and integrated into this section from a separate geotechnical engineering technical memorandum (Thurber, 2020) prepared in support of the design reference.

## 6.1 Design Time Horizon and Level of Protection

### 6.1.1 Sea Level Rise and Land Subsidence Design Time Horizon

Shoreline flood protection works should be designed and constructed to perform for 1 m of sea level rise (above Year 2000 baseline), which is currently anticipated by Year 2100 in line with both provincial guidelines and City flood management policies. This does not include local land subsidence/ground uplift impacts which are used to determine the relative sea level rise (i.e., relative to the ground at a specific location).

The rationale for constructing works for future conditions is to maintain a minimum level of protection throughout the design life of the works. Given that sea level rise is a gradual and on-going process, the design should also include a proof-of-concept for upgrading of the works to allow for 2 m of sea level rise (Year 2200).

The timeline for these sea level rise projections may change as climate change science and City policies evolve. The design team should confirm the design time horizon with the City at project initiation.

An allowance for land subsidence (described in Section 2) should be included in the design based on the selected rate of land subsidence for the project site and the duration of time between construction and the projected year for 1 m of sea level rise (currently Year 2100).

For example, if the selected land subsidence rate for the project site is 1 mm per year, the construction year is 2020, and the current timing projection for 1 m of global sea level rise is the Year 2100, then the design land subsidence allowance is:

*1 mm/year x (Year 2100 – Year 2020) = 80 mm above Year 2020 ground elevation.*

The addition of sea level rise and land subsidence allowances is described as part of the design crest elevation criteria (Section 6.3).

Land subsidence should be considered on a site-specific basis with review of the most recent research and monitoring of ground elevation changes. The City may develop policies or guidance in the future for this topic which may standardize land subsidence allowances across different regions of Vancouver. The design team should confirm with the City at project initiation.

Site-specific land subsidence assessment may reveal areas experiencing ground uplift (the opposite of subsidence) which can dampen sea level rise. It is recommended that the design ignore the potential for ground uplift (i.e., zero allowance) to be conservative.

### 6.1.2 Level of Protection and Failure Modes

Separately and in addition to sea level rise, shoreline flood protection works should be designed to perform safely in all failure modes triggered by hazards with an annual exceedance probability (AEP) of 0.2%, which is equivalent to performance for up to a 500-year return period event. The City may specify a higher level of protection for projects that protect critical infrastructure.

This criteria is in line with the City's policies for building floodproofing, including flood construction levels.

The design team is responsible for identifying all possible and relevant failure modes for consideration which should include, but is not limited to:

- Crest and land-side slope erosion by flood level overtopping;
- Water-side slope erosion by high velocity (Fraser River) and/or wave impacts (wind- or vessel-generated);
- Slope instability related to water-side water level including static (flood) and rapid drawdown (ebb tide) conditions, as well as bathymetric changes in the adjacent river or sea bed;
- Slope instability related to land-side water level including potential land-side ditch water level fluctuations (e.g., pump station rapid drawdown);
- Slope instability related to piping, which is the loss of fine material due to high hydraulic gradient and seepage water exit velocities on the land-side slope toe;
- Slope instability related to animal burrows, large tree root penetration and eventual decay, and/or existing/abandoned infrastructure cavities or seepage paths;
- Slope instability related to seismic events (earthquakes) including both direct slope failure and indirect failure associated with reduced crest elevation following an earthquake and subsequent flood level overtopping; and
- Unacceptable seepage flow rate/volume resulting in nuisance flooding.

For each failure mode, design features should be incorporated to provide adequate factors of safety or freeboard (discussed further in this section) against failure with an AEP greater than 0.2% or a return period up to 500 years.

It should be noted that provincial seismic design guidelines for dikes recommend a higher level of performance for earthquake-related failure modes. This is discussed further in Section 6.7.

## 6.2 Typologies and Cross-section Geometry

The following typologies are generally considered preferred or acceptable for shoreline flood protection in Vancouver. For most situations, the design process should start with selecting one of these typologies in consultation with City staff.

A typical cross-section, including required setback distances, is provided for each typology.

### 6.2.1 Superdike (Earthfill Dike + Adjacent Land Raising)

The superdike typology supplements a conventional earthfill embankment dike with a continuous 30 m or wider strip of land adjacent to the dike crest that is raised to the dike design elevation.

Basic cross-section geometry for the superdike typology is presented in Figure 6-2 and is described below.

The superdike typology has two components:

1. **Designated dike** - an earthfill dike maintained by the City, with land tenure in the favour of the City, forming the water-side edge of the superdike; and
2. **Land raising area** - a wide land raising area on the land-side of the designated dike. The land raising area may be located on private property and is raised to the dike crest elevation through redevelopment approved by the City. The land raising area is also distinguished from the designated dike because buildings, infrastructure, and other land uses may be incorporated into the area under certain conditions, such as setbacks described below. These conditions would typically be applied as part of the development application review process and would be enforced through legal tools such as restrictive covenants registered on land title and/or agreements. The land raising area would ideally be as wide as possible where width is measured perpendicularly to the designated dike centreline. A minimum 30 m width is recommended to meet the typology definition. It is important to note that the key feature of the land raising area is that the entire finished surface elevation meets the designated dike crest elevation.

Geometric and setback criteria are listed in Table 6-1.

**Table 6-1: Superdike Typology Geometric and Setback Criteria**

| Item | Value |
|---|---|
| Crest elevation (designated dike and land raising area) | Refer to Section 6.3 |
| Designated dike crest width (minimum) | 4 m |
| Land raising area width (minimum, measured from designated dike crest land-side edge) | 30 m |
| Designated dike water-side slope (maximum) | 3H:1V (vegetated) or 2H:1V (riprap revetment) |
| Designated dike theoretical internal land-side slope line (used to define the land-side boundary of the designated dike) | 3H:1V |
| Minimum setback between the designated dike crest land-side edge and any surface or sub-surface structures/infrastructure | Maximum of: 7.5 m or the space required for future upgrading of the designated dike for 2 m of sea level rise |
| Minimum setback between the theoretical designated dike land-side slope toe (where it would meet the pre-construction ground elevation) and any surface or sub-surface structures/infrastructure | 3 m |
| A proof of concept design for 2 m of sea level rise should be prepared to confirm that there is sufficient space to the land-side and/or water-side of the designated dike to accommodate future upgrading. | |

These setback conditions are less than the conventional earthfill dike setback (provided below). This reduction is warranted because the superdike typology is more robust. In particular, the designated dike land-side slope is buried by the adjacent land raising and therefore seepage paths and areas for potential high seepage exit gradients are much further away increasing the effective dike width. A superdike is also more robust against overtopping-related dike failure because the width of dike that would need to be eroded before a dike breach occurs is much longer.

Given the robustness of the superdike typology, it may be acceptable to have minor surface features (e.g., path lighting and furniture) and minor buried parallel linear infrastructure (e.g., electrical conduit, irrigation lines) within the setback zone as long as they are located outside of the designated dike core as indicated by the theoretical internal land-side slope line, presented on Figure 6-2.

**Applicability and Examples**

The superdike typology is likely most appropriate for the implementation of flood protection as part of medium to high density redevelopment on waterfront parcels where it may be economically feasible for the development process to incorporate land raising and finished grading to the dike crest elevation. Ideally, the width of the land raising is the entire adjacent land parcel that is being redeveloped, but at minimum, the width of finished grade on the parcel meeting or exceeding the dike crest design elevation should be 30 m to fall under this typology.

Applications of this typology exist locally on a small scale in Richmond's Fraser River Middle Arm reach where mixed-used and institutional developments including the Olympic Oval have been raised to the Lulu Island perimeter dike level or higher. This typology is also being applied through redevelopment in sections of the East Fraser Lands (River District) area of Vancouver along the Fraser River (North Arm).

Internationally, there is a multi-decadal history of superdikes or superlevees ("super teibo") in Japan. The general concept of the Japanese superdike is presented in Figure 6-1. Examples from Tokyo (sample photos and graphics to the right and below) can be as wide as the average waterfront parcel or much wider (> 300 m wide), covering multiple city blocks. Superdikes in Tokyo have successfully been incorporated with high-density mixed-use developments that are on the same scale or larger than Vancouver's envisioned high-density waterfront redevelopment areas (e.g., Northeast False Creek, NEFC).

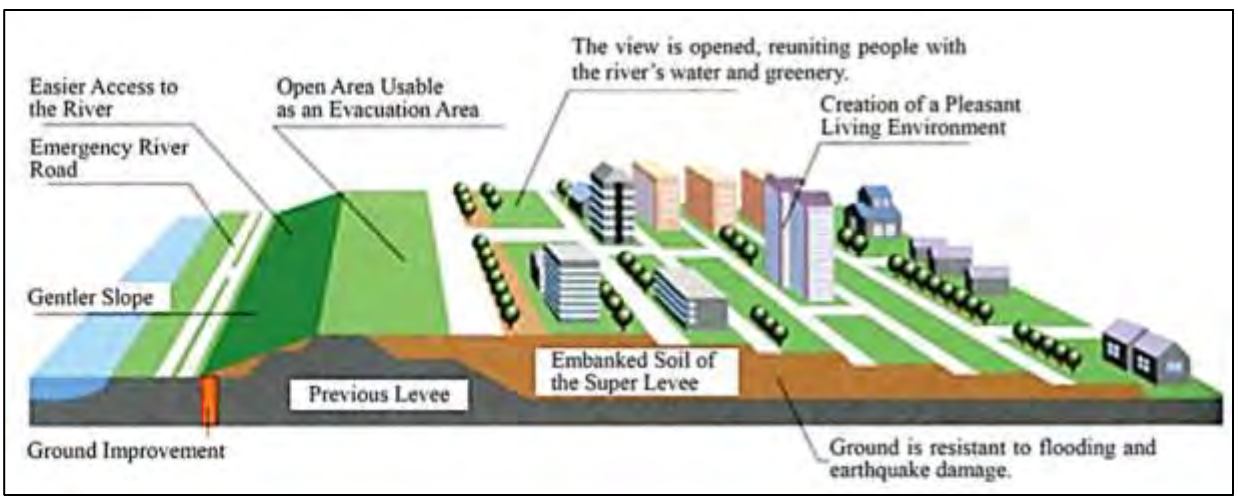
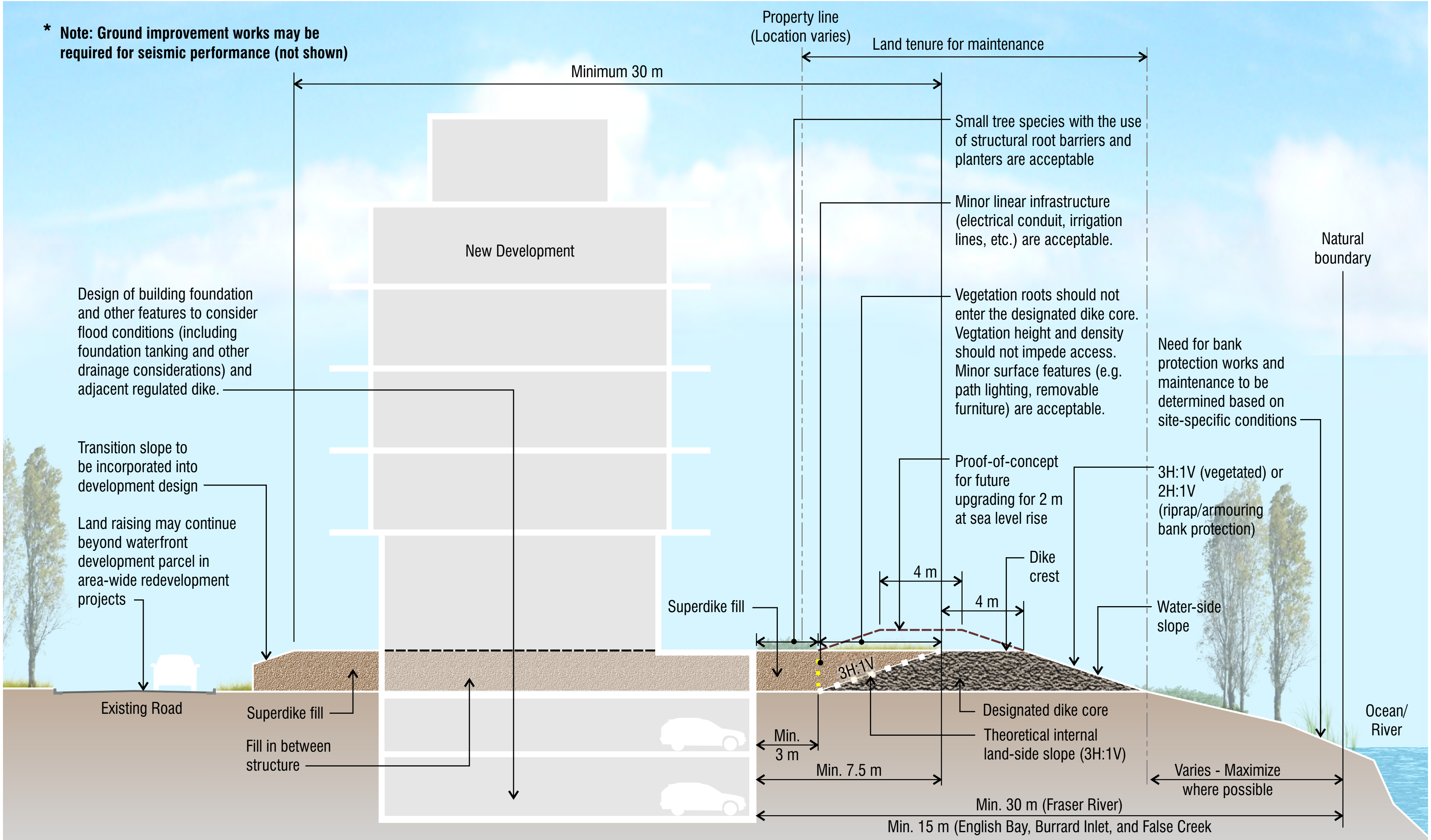



**Figure 6-1: Japanese Superdike ("super teibo") Cross-section (from Hitoshi, 2016)**

The following photographs show a smaller (less wide) application on the Sumida River in Tokyo. The ground level around the high-rise buildings is raised to the dike level, and transitions to meet the adjacent road behind the buildings with an urban plaza feature incorporated into the transition slope (bottom right photo). Multi-use paths are provided both on the dike crest and at a lower level closer to the water which would be flooded under storm conditions.

**City of Vancouver**
Engineering Design Reference for Shoreline Flood Protection

KERR WOOD LEIDAL
consulting engineers




| | |
|---|---|
| Project No. | 042.142 |
| Date | March 2021 |
| Scale | Not to Scale |

## Superdike - Basic Cross-section Geometry

**Figure 6-2**

### 6.2.2 Earthfill Dike with Vegetated Side Slopes

This typology is generally derived from the provincial standard dike design and involves an earthfill embankment with a minimum 4 m wide crest and vegetated side slopes.

Basic cross-section geometry is presented in Figure 6-3.

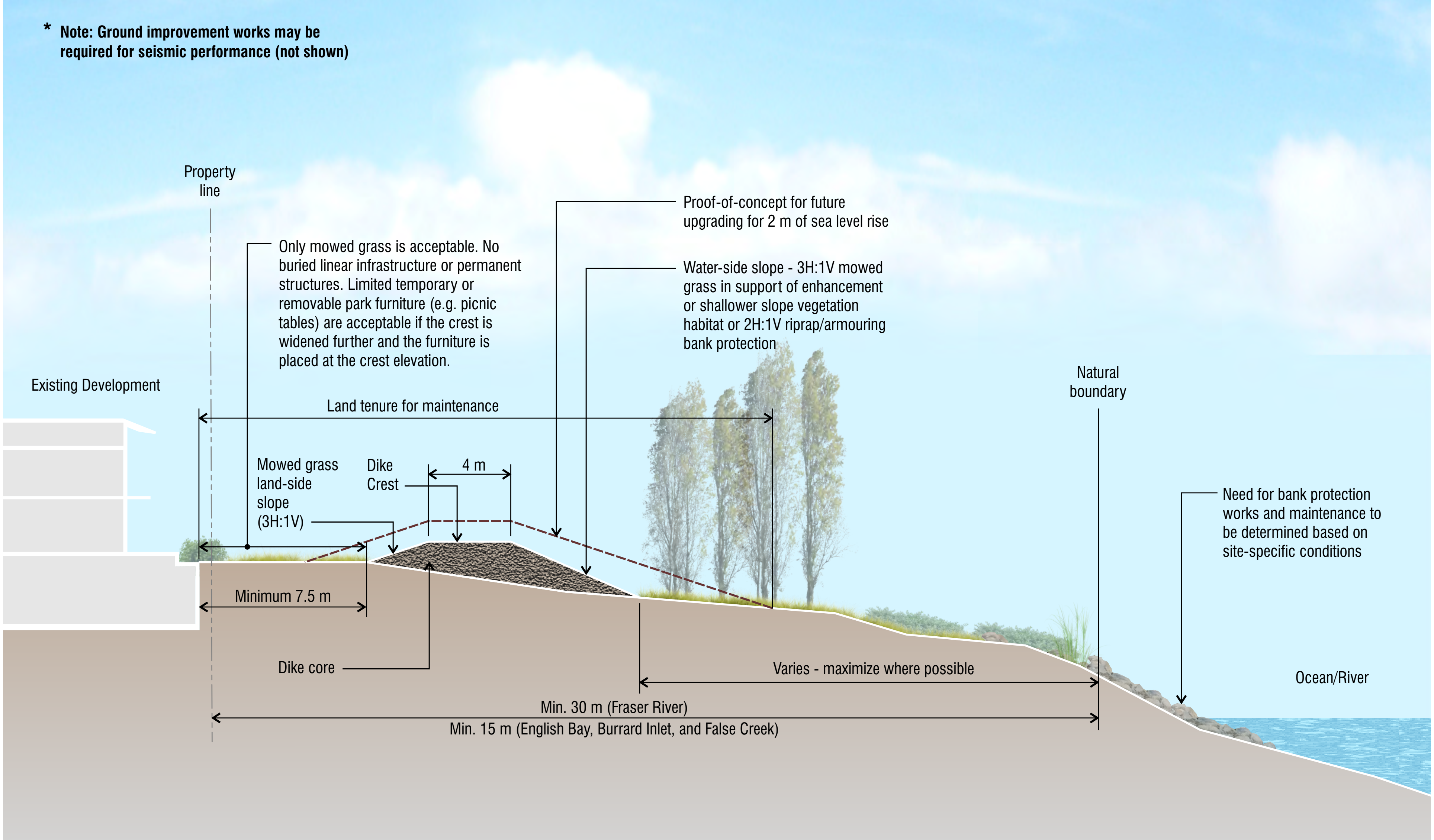
While not as robust as the superdike, this typology is acceptable and is likely most appropriate for shoreline flood protection in parks, adjacent to roads, or adjacent to lower density, previously developed areas. Ideally, the dike is set back from the shoreline to reduce impacts to riparian habitat and to reduce the need for placement and maintenance of engineered bank protection works.

Geometric and setback criteria are listed in Table 6-2.

**Table 6-2: Earthfill Dike with Vegetated Side Slopes Typology Geometric and Setback Criteria**

| Item | Value |
|---|---|
| Crest elevation | Refer to Section 6.3 |
| Dike crest width (minimum) | 4 m |
| Dike water-side slope (maximum) | 3H:1V (vegetated) or 2H:1V (riprap or rock revetment) |
| Dike land-side slope (maximum) | 3H:1V |
| Minimum setback between the land-side slope toe and any surface or sub-surface structures/infrastructure | Maximum of:<br>7.5 m<br>or<br>the space required for future upgrading of the designated dike for 2 m of sea level rise |
| A proof of concept design for 2 m of sea level rise should be prepared to confirm that there is sufficient space to the land-side and/or water-side of the designated dike to accommodate future upgrading. | |

Permanent structures and parallel linear infrastructure should be avoided within the setback zone as they can contribute to seepage and piping issues. Limited park furniture (e.g., picnic tables, etc.) may be permitted.




| | |
|---|---|
| Project No. | 042.142 |
| Date | March 2021 |
| Scale | Not to Scale |

# Earthfill Dike with Vegetated Side Slopes
# Basic Cross-section Geometry

**Figure 6-3**

### 6.2.3 Earthfill Dike with Water-side Retaining Wall

The footprint of the earthfill dike vegetated side slopes may result in space limitations in previously developed and urban shoreline areas (e.g., seawall areas). This typology involves replacing the water-side slope with a vertical or near-vertical retaining wall to reduce the overall footprint. This typology should only be applied if there are insurmountable space issues to implementing the superdike or earthfill dike with vegetates side slope typologies.

The addition of a retaining wall would reduce the passiveness of the dike because additional inspection and maintenance may be required for the retaining wall. Adaptability is also reduced as there the dike footprint is smaller and provides less room for future raising. Accordingly, the application of this typology should be limited. It is also recommended that the retaining wall height be limited to 1.5 m or less.

Basic cross-section geometry is presented in Figure 6-4.

Geometric and setback criteria are listed in Table 6-3.

**Table 6-3: Earthfill Dike with Water-side Retaining Wall Typology Geometric and Setback Criteria**

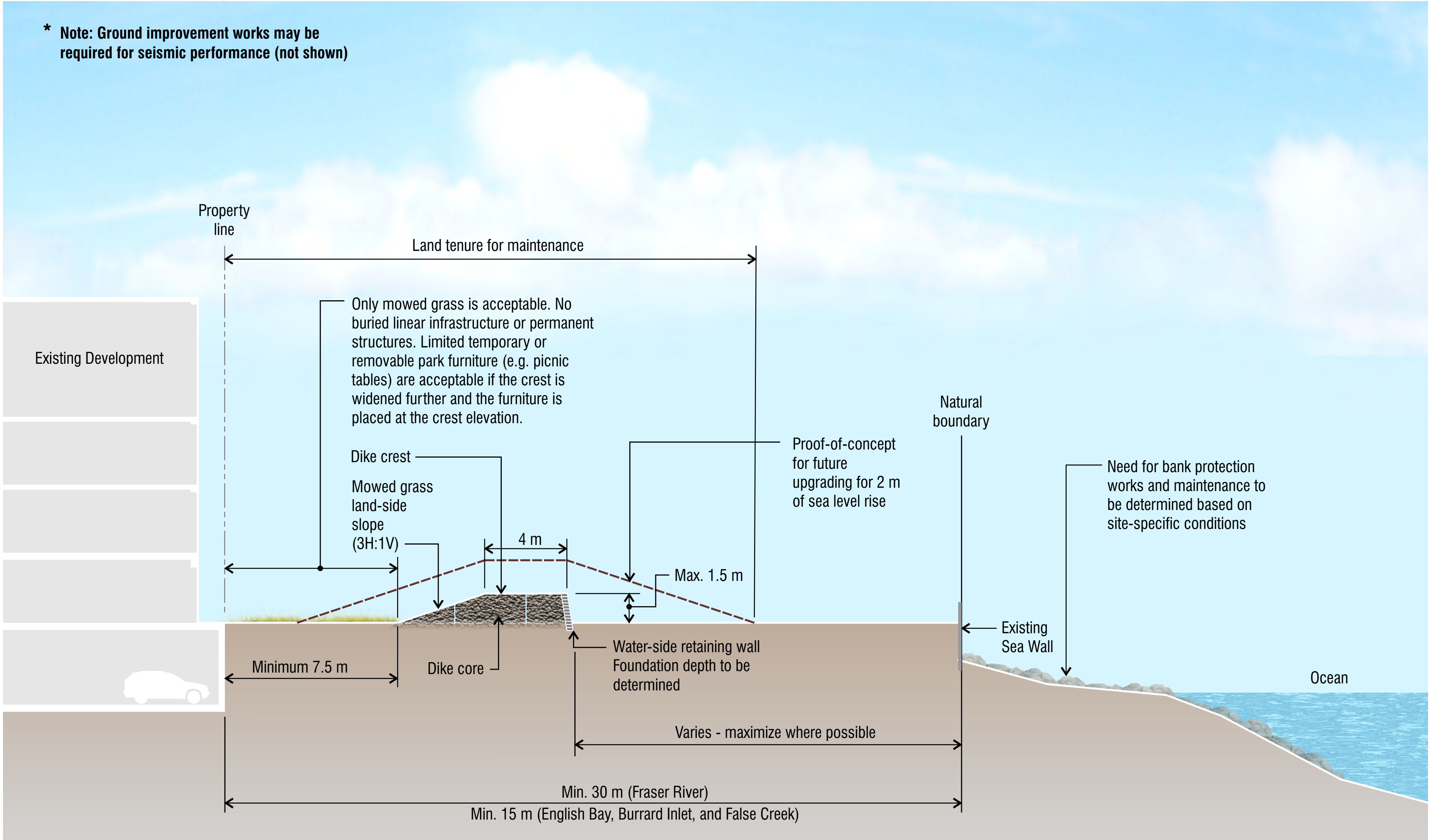
| Item | Value |
|---|---|
| Crest elevation | Refer to Section 6.3 |
| Dike crest width (minimum) | 4 m |
| Dike water-side slope (maximum) | Vertical retaining wall with maximum 1.5 m height |
| Dike land-side slope (maximum) | 3H:1V |
| Minimum setback between the land-side slope toe and any surface or sub-surface structures/infrastructure | Maximum of:<br>7.5 m<br>or<br>the space required for future upgrading of the designated dike for 2 m of sea level rise |
| A proof of concept design for 2 m of sea level rise should be prepared to confirm that there is sufficient space to the land-side and/or water-side of the designated dike to accommodate future upgrading. | |

The type of retaining wall (steel sheetpile, cast-in-place concrete, pre-cast interlocking, etc.) should be pre-approved by the City through consideration of multiple perspectives (flood protection design, maintenance requirements, and aesthetics). The preference is for wall types with low maintenance requirements and wall types that could limit wall failure to localized areas as opposed to propagating to a longer length. Ease of repair and upgrading should also be considered. Vegetated mechanically-stabilized earth (MSE) or Vancouver seawall masonry style walls should be considered carefully and applied with a clear design rationale and features for increasing robustness and passiveness. Another approach may be to include an aesthetic wall facing (e.g., masonry) that is independent and does not impact an internal robust retaining wall (e.g., driven steel sheetpile).

It is important to clarify that this typology is not a standalone floodwall, which is addressed separately below. The key distinction is that this typology involves a 4 m wide crest at the design elevation adjacent to the retaining wall.

Additionally, it should be noted that a vertical water-side slope can have significant impacts on how waves interact with the dike and could result in increased wave overtopping. Ideally, the dike is set back from the shoreline to minimize direct wave attack on the retaining wall which can significantly increase the need for maintenance. Alternatively, a hardened land-side slope achieved through a retaining wall can increase the dike's robustness against overtopping erosion.

Retaining wall design is subject to other design requirements and guidelines not specified in this design reference, including EGBC professional practice guidelines and City requirements such as the requirement for handrails for fall protection.




| | |
|---|---|
| Project No. | 042.142 |
| Date | March 2021 |
| Scale | Not to Scale |

## Earthfill Dike with Water-side Retaining Wall Basic Cross-section Geometry

**Figure 6-4**

### 6.2.4 Standalone Flood Wall

The standalone flood wall is designed to withstand flood conditions on the water-side while having no fill on the land-side. This typology is not preferred because it is not considered to be as robust as an earthfill dike because the width of material holding back floodwaters is much narrower and localized issues (e.g. debris impact, corrosion, vandalism, etc.) are perceived as a larger threat for a standalone floodwall than for a wide earthfill dike. A standalone floodwall is also not as easily adaptable for future raising as an earthfill dike.

Limited use of a standalone flood wall with a maximum exposed height of 0.6 m may be acceptable under special conditions where an earthfill dike with a retaining wall edge cannot be accommodated.

Ideally, the standalone flood wall is only an interim measure and future redevelopment and/or upgrading for future sea level rise will implement a superdike or an earthfill dike on a separate alignment.

The exposed height limitation to 0.6 m is linked with the typical 0.6 m freeboard added to the design flood level to achieve the dike crest elevation (refer to Section 6.3). In this sense, the reliance on the standalone flood wall would be limited to only very rare conditions where the flood level reaches the freeboard range.

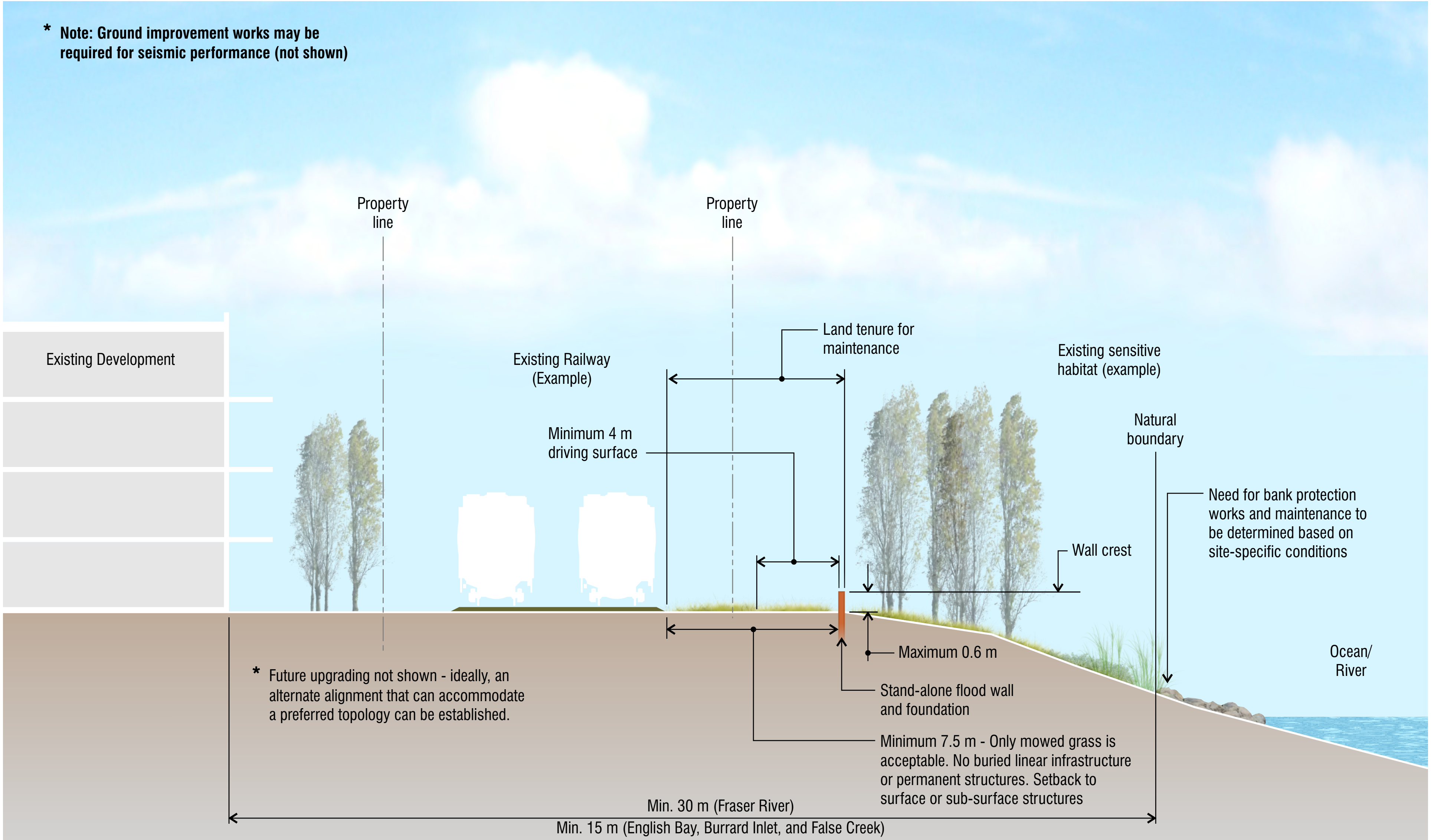
Application of this typology should only be considered when all other preferred and acceptable typologies are insurmountable.

Basic cross-section geometry is presented in Figure 6-5.

Geometric and setback criteria are listed in Table 6-4.

**Table 6-4: Standalone Flood Wall Typology Geometric and Setback Criteria**

| Item | Value |
|---|---|
| Crest elevation | Refer to Section 6.3 |
| Maximum flood wall height | 0.6 m |
| Minimum setback between the land-side slope toe and any surface or sub-surface structures/infrastructure | 7.5 m |
| The design should also incorporate space for future upgrading for 2 m of sea level rise through replacing the standalone flood wall with another approved typology. | |




| | |
|---|---|
| Project No. | 042.142 |
| Date | March 2021 |
| Scale | Not to Scale |

**Stand-alone Flood Wall Basic Cross-section Geometry**

**Figure 6-5**

## 6.3 Design Flood Level and Crest Elevation

The design flood level (DFL) is the estimated water surface elevation which is the primary input used to calculate the design crest elevation (DCE) for flood protection works. Other inputs include allowances for water level uncertainty (freeboard), wave effects, land subsidence, and post-construction settlement. This sub-section provides information and guidance for calculating the DFL and DCE. These terms differ from the flood construction level (FCL) which applies to the building elevation in a floodplain area

### 6.3.1 Design Flood Level (English Bay, False Creek, and Burrard Inlet)

Under a coastal flood context, the DFL generally refers to a stillwater level (combination of tide and storm surge) for the design return period (500-year) or annual exceedance probability (0.2%) and design sea level rise allowance (1 m). Wave effects, land subsidence, uncertainty (freeboard), and other allowances are added separately as part of the DCE calculation.

While the design team should confirm the DFL, available information from the City's CFRA-1 project includes statistical analysis of the 0.2% annual exceedance probability / 500-year return period coastal flood level for multiple zones covering the City's English Bay, False Creek and Burrard Inlet shorelines under different sea level rise scenarios. The results showed very similar values across the zones and have been rounded to simplified values as presented in Table 6-5.

**Table 6-5: Coastal Design Flood Level (excluding freeboard and wave runup effects) interpreted from CFRA-1**

| Zone | 0.2% Annual Exceedance Probability | | |
|---|---|---|---|
| | Current/Historic Sea Level | 1 m Sea Level Rise | 2 m Sea Level Rise |
| English Bay, False Creek, and Burrard Inlet | 3.0 | 4.0 | 5.0 |

### 6.3.2 Design Crest Elevation (English Bay, False Creek, and Burrard Inlet)

The DCE for English Bay, False Creek, and Burrard Inlet shorelines should be calculated by adding allowances for the following items to the DFL:

- Wave runup height to limit overtopping to a tolerable threshold (1 L/s/m);
- Freeboard (to allow for general uncertainty);
- Land subsidence; and
- Post-construction settlement.

The design crest elevation calculation components are presented in Table 6-6.

**Table 6-6: English Bay, Burrard Inlet, and False Creek Design Crest Elevation Components**

| Component | Value |
|---|---|
| 1 m sea level rise, 0.2% AEP DFL | 4.0 m CGVD28 |
| Concurrent 0.2% AEP wind-generated wave runup height to limit overtopping to 1 L/s/m | Site-specific |
| Land Subsidence Allowance for Year 2100 | Site-specific |
| Freeboard | 0.6 m |
| Post-construction (short-term) Settlement Allowance | Site-specific |
| Design Crest Elevation | 4.6 m CGVD28 + site-specific allowances |

The wave runup height allowance is intended to set the crest elevation above the DFL such that wave overtopping is limited to a tolerable amount in terms of:

- Resisting dike failure due to erosion of the dike crest and land-side slope;
- Physical safety of trained flood emergency response professionals who may need to be on the crest during overtopping; and
- Safety managing the overtopping discharge through internal drainage infrastructure.

A maximum average overtopping flow of 1 litre per second per lineal metre (L/s/m) is recommended for shoreline flood protection works in Vancouver. The 1 L/s/m threshold was selected based on review of provincial and international design guidelines which include thresholds ranging from 0.1 L/s/m to 10 L/s/m. The selected threshold (1 L/s/m) is considered appropriate for Vancouver given the types of shoreline flood protection works described in this reference, and given that an additional 0.6 m freeboard allowance will be added in addition to the wave runup height allowance.

To calculate the wave runup height allowance, the coastal engineer should use a 1-dimensional wave model to estimate the transformation of wind-generated deep-water wave conditions over the near-shore topography, including the proposed flood protection water-side slope and crest geometry. The calculation should assume that 500-year return period wave conditions will occur at the same time as the 500-year return period stillwater level (DFL), without freeboard. This assumption is conservative given that tide, storm surge, and waves are not physically correlated processes and the 'true' return period may be higher. However, this assumption is considered appropriately conservative for design purposes.

Design deep-water wave conditions vary around English Bay, Burrard Inlet, and False Creek and the wave analysis conducted as part of the CFRA-1 was not intended to be directly used in the design of flood protection. The design team should develop site-specific deep-water wave conditions (significant wave height, Hs and peak wave period, Tp) for the project site. Alternatively, the City may in the future consider providing design deep-water wave conditions for sub-areas to enable better consistency along similar shoreline areas.

The design should also assess the impact of overtopping flow on the land-side topography and land use. The total overtopping flow volume should be estimated over a conservative, but reasonable storm duration (e.g., 6 hours) and the design team should determine what internal drainage works may be required to safely collect and convey the overtopping flow volume/discharge. This is discussed further with other internal drainage considerations in sub-section 6.13.

In addition to wave runup and overtopping, the DCE should include an allowance for land subsidence for the Year 2100, 0.6 m freeboard, and a post-construction settlement allowance. The design team should review available information on land subsidence rates at the time of the project with City staff. A reference to a high-level land subsidence study is provided in Section 2 and on Figure 2-2. Additional studies may be conducted by the City in the future. A 0.6 m freeboard to allow for uncertainties in the design flood level and other potential uncertainties should be added. This is also consistent with the approach used for river dikes. Finally, a post-construction settlement allowance should be provided by the geotechnical engineer to offset the short-term settlement that is expected to occur after construction due to the added weight of material on the underlying soil.

### 6.3.3 Design Flood Level (Fraser River)

Vancouver's Fraser River shoreline is exposed to both coastal flooding and spring freshet (snowmelt) flooding. Previous studies, including CFRA-1, have shown that at the 500-year return period, the coastal stillwater level is higher in elevation than spring freshet water level; therefore the coastal condition is used to calculate the DFL.

CFRA-1 assessed the Fraser River coastal flood level by using hydrodynamic modelling to determine the river flood profile associated with the combination of:

- sea level rise;
- coastal stillwater level at the downstream boundary; and
- a winter season 0.5% annual exceedance probability / 200-year return period Fraser River peak flow.

The combination of the winter season Fraser River peak flow and the downstream coastal flood level may be considered conservative, but CFRA-1 showed that the impact of river flow on this scenario is minor; the difference between using a 20-year return period peak flow and the 200-year return period peak flow was approximately 0.14 m (NHC, 2014).

Table 6-7 presents the Fraser River design flood level. CFRA-1 (NHC, 2014) showed that design flood level reduces by approximately 0.1 m downstream of Ontario Street to 3.9 m CGVD28. However, for consistency with the City's flood construction level policy, it is recommended that a 4.0 m CGVD28 DFL be used for the entire Fraser River shoreline.

**Table 6-7: Fraser River Design Flood Level (excludes freeboard) interpreted from CFRA-1**

| Fraser River Reach | Fraser River Design Flood Level (m, CGVD28) |
|---|---|
| Fraser River mouth to Boundary Road | 4.0 |

Note:
1 m sea level rise plus 0.2% annual exceedance probability coastal flood with concurrent 0.5% annual exceedance probability winter season peak flow.
CFRA-1 (NHC, 2014) found that the design flood level is 3.9 m CGVD28 downstream of Ontario Street. However, for consistency with the City's flood construction level policy, a DFL of 4.0 m CGVD28 is recommended for the entire Fraser River shoreline.

### 6.3.4 Design Crest Elevation (Fraser River)

The Fraser River shoreline is generally sheltered against wind-generated waves upstream of Deering Island. Wind-generated wave effects and overtopping can be considered relatively minor and sufficiently addressed by the standard 0.6 m freeboard applied to the dike crest elevation.

The North Arm Jetty may provide some shelter against wind-generated waves downstream of Deering Island, but this has not been studied in detail. Site-specific wind-generated wave hazard reviews are suggested on a case-by-case basis for shoreline flood protection designs downstream of Deering Island where exposure to direct ocean waves increases and are subject to change if the North Arm Jetty (which is under the jurisdiction of the Government of Canada) is altered in the future.

For sheltered shoreline locations, the design crest elevation calculation components are presented in Table 6-8.

**Table 6-8: Fraser River Design Crest Elevation Components**

| Component | Value |
|---|---|
| 1 m Sea Level Rise, 0.2% AEP Design Flood Level | 4.0 m CGVD28 |
| Land Subsidence Allowance for 1 m Sea Level Rise Time Horizon | Site-specific |
| Freeboard | 0.6 m |
| Post-construction (short-term) Settlement Allowance | Site-specific |
| Design Crest Elevation | 4.6 m CGVD28 + site-specific allowances |

## 6.4 Tidal Water Levels

Tidal statistics are representative of normal tide water level ranges which may be required as part of geotechnical stability analysis (e.g., rapid drawdown based on tidal range from high tide to low tide), bank protection (e.g., riprap revetment toe elevation), and habitat enhancement measures (discussed further in Section 8).

Tidal statistics around Vancouver can be generally represented by the information available for the Vancouver Harbour tide gauge operated by the Canadian Hydrographic Service. The statistics are summarized in Table 6-9.

**Table 6-9: Vancouver Harbour Tidal Statistics**

| Tide Statistic | Description | CHS Vancouver (ID#7735) Elevation (m, CGVD28) |
|---|---|---|
| Lower Low Water Large Tide (LLWLT) | The average of the annual lowest low waters, one from each of 19 years of predictions. | -2.9 |
| Lower Low Water Mean Tide (LLWMT) | The average of all the lower low waters from 19 years of predictions. | -1.8 |
| Higher High Water Mean Tide (HHWMT) | The average from all the higher high waters from 19 years of predictions. Typically considered the average high tide. | 1.5 |

| Tide Statistic | Description | CHS Vancouver (ID#7735) Elevation (m, CGVD28) |
|---|---|---|
| Higher High Water Large Tide (HHWLT) | The average of the annual highest high waters, one from each of 19 years of predictions. Typically considered the extreme upper end of the tide cycle. | 2.0 |
| Extreme Tide Range | Difference in LLWLT and HHWLT. | 4.9* |
| Average Tide Range | Difference in LLWMT and HHWMT. | 3.3* |
| * range (m), not an elevation. | | |

The Fraser River shoreline is also influenced by river flow which is highest during the spring freshet (typically in May or June), during which river flow causes an increase in water level above the tide level. While not the governing condition for crest elevation, spring freshet water levels may be relevant for bank protection design and habitat enhancement designs, both of which should be addressed on a site-specific basis as required.

## 6.5 Geotechnical Factors of Safety for Stability

Minimum factors of safety are required to provide stability for the flood protection works under a variety of water level conditions and stability against other failure modes including seepage-induced piping.

Table 6-10 presents the recommended geotechnical factor of safety values to be incorporated into design.

**Table 6-10: Geotechnical Factors of Safety**

| Condition | Recommended Water Level Assumption | Recommended Factor of Safety |
|---|---|---|
| Slope stability - static – normal | Average high tide + relative sea level rise | 1.5 |
| Slope stability - static – flood | Water level at dike crest elevation | 1.4 |
| Slope stability dynamic – rapid drawdown | Extreme tidal range | 1.0 to 1.2 |
| Seepage-induced heave (ratio of the critical hydraulic gradient to the design hydraulic gradient (0.5)) | Water level at dike crest elevation | 1.6 |
| Passive, sliding, and bearing resistance for walls (cast-in-place concrete and steel sheetpile) | Water level at dike crest elevation | 2.0 |

## 6.6 Fill Materials and Seepage Control

Common sources of dike fill in the Vancouver area include glacial till from building excavations, and Fraser River sand from dredging. Till fill has lower permeability and is well-graded. Fraser River sand is more permeable and uniformly graded. The selection of the appropriate fill will depend on project-specific design, including existing foundation soils which can vary significantly and may include sensitive soils such as peat.

Future flood protection works are anticipated to be constructed mostly of till fill. Superdikes could be designed using a significant portion of Fraser River sand fill. In some cases, it will be necessary to import fill with appropriate specifications from outside the City.

Till fill could be suitable where low-permeability dike fill is required for seepage control. Till fill should typically be well-graded 75 mm minus material with 10% to 30% fines (i.e., silt or clay). The fines should have some plasticity. Dike fill should not be manufactured or blended. Till fill should be placed in maximum 200 mm to 300 mm thick loose lifts and compacted to at least 95% of modified standard Proctor maximum dry density. Care should be taken during placement of well-graded till fill to prevent segregation. Till fill might need to be placed within 2% of its optimum moisture content to be compactible. Accordingly, placement and compaction during wet weather may not be possible.

Fraser River sand fill could be suitable for very wide dikes, such as superdikes, where the hydraulic gradient is low. Fraser River sand fill should be compacted to at least 95% of modified standard Proctor maximum dry density. This can typically be achieved with placement in maximum 200 mm to 300 mm thick loose lifts and compaction with vibratory equipment, or with suitably designed hydraulic placement (i.e., dredging).

Design of seepage control measures will need to consider the seepage rate and the potential for heave and piping. Control of seepage is best achieved by selecting soil with an appropriate permeability and ensuring adequate compaction.

Heave can occur when there are excessive hydraulic pressures on the landside of the dike caused by a lower permeability soil layer near the ground surface that form a cap over a more permeable layer below. Heave can lift and fracture the lower permeability soil cap, resulting in localized seepage and internal erosion, which could cause a dike breach if it occurs near the dike.

Heave occurs when the water pressure exceeds the weight of soil above it and is anticipated to initiate when the average hydraulic gradient through the less permeable surficial cap exceeds about 0.8. This is the critical hydraulic gradient. To provide an appropriate factor of safety against heave, design of earth dikes must control gradients to values lower than the critical gradient. The factor of safety against heave is calculated as the ratio of the critical hydraulic gradient to the design hydraulic gradient. A factor of safety of 1.6 against heave is recommended for developing dike designs. Accordingly, the design hydraulic gradient should be typically limited to 0.5 (slope, no units).

Heave can be controlled by providing a berm on the landside of the dike or providing pressure relief with wells or trenches. It is expected that for Vancouver flood heights (flood level minus ground elevation), either pressure relief trenches or landside berms will be acceptable if needed. Pressure relief design must consider the effect on increased seepage volumes.

Piping occurs when excessive seepage forces cause the migration of soil particles through the soil matrix resulting in internal erosion and eventually retrogressive failure. Evaluating the potential for piping in unfiltered dikes is difficult to analyze and predict. Dikes with higher hydraulic gradient are more likely to be susceptible to piping. Piping is one of the leading causes of failure of dikes that have unfiltered seepage exits.

Where the dikes are wide and have low seepage gradients, (possibly in a superdike) the average hydraulic gradient could be low enough that an unfiltered seepage exit could be acceptable. The design of narrow dikes (e.g.,4 m wide crest) with higher average hydraulic gradient should consider using toe filters, land-side toe berms, or other seepage control measures.

## 6.7 Seismic Performance

Vancouver is exposed to significant earthquake hazards which are heightened on the liquefiable soils found along much of the shoreline (e.g., Fraser River, False Creek).

Earthquakes can impact flood protection works through two main mechanisms:

1. Full failure of the works resulting through sliding into the ocean/river ("flowslide failure"); or
2. Partial failure of the works through reduced crest elevation and fill material integrity.

Full failure is most concerning in low-lying areas where the normal tidal range (e.g., LLWMT to HHWMT) exceeds the land-side ground elevation and the works provide flood protection for several hours per day every day, even without storm conditions. In these areas, full failure of the works due to an earthquake would result in immediate flooding. Given the existing shoreline elevations in Vancouver and the tidal elevations presented earlier, this is generally not expected to apply in Vancouver until 2 m of sea level rise occurs.

Full failure and partial failure will have a similar impact of increasing flood exposure until interim or permanent repairs are conducted to restore the level of flood protection. However, repair of a partial failure is generally easier than replacing works that have experienced a flow slide failure into the ocean or river. However, following a major earthquake, all recovery construction activities may be constrained by available resources and competing priorities.

Seismic performance of flood protection works is typically improved by providing an adequate setback from the shoreline and/or conducting ground improvement works (e.g., stone column or rapid compaction densification, or timber pile reinforcement). Alternatively, the post-earthquake flood exposure risk may be quantified and tolerated through emergency response planning.

The Province specifies seismic performance criteria in its 2014 Seismic Design Guidelines for Dikes (2$^{nd}$ Edition) for "high consequence" dikes. All flood protection works in Vancouver may be considered as high consequence given population density and extent of development and infrastructure located in the floodplain.

There are two key performance targets in the provincial guidelines:

1. Maximum tolerable horizontal and vertical displacement of dikes across 3 earthquake scenarios; and
2. Preservation of 0.3 m of freeboard above a 10-year return period flood level following an earthquake.

The horizontal and vertical displacement limits are reproduced in Table 6-11. The guidelines require that the limits be met at each earthquake return period listed in the table.

**Table 6-11: Provincial Seismic Performance Criteria Horizontal and Vertical Displacement Limits**

| Earthquake Return Period | Maximum Allowable Horizontal Displacement | Maximum Allowable Vertical Displacement |
|---|---|---|
| 100-year | Small (< 0.03 m) | Small (< 0.03 m) |
| 475-year | 0.3 m | 0.15 m |
| 2,475-year | 0.9 m | 0.5 m |

The post-earthquake freeboard requirement over the 10-year return period flood level is interpreted to refer to the most extreme earthquake scenario referenced in the guidelines, the 2,475-year return period earthquake. It is important to note that these performance criteria exceeds the overall 0.2% annual exceedance probability level of protection introduced earlier because the combination of a 10-year return period flood occurring after a 2,475-year return period earthquake is exceptionally rare. Assuming one year between the earthquake and the flood, the probability of such an event is 0.004%.

This is expected to be an area of evolving criteria and the design team should confirm with the City the seismic performance criteria and policy in place at the time of design. The provincial guidelines are undergoing a review process as of July 2020, and it is understood that Engineers and Geoscientists British Columbia (EGBC) plans to publish professional practice guidelines related to seismic performance of dikes.

## 6.8 Bank Protection

The need for bank protection (including scour consideration) criteria is best determined through a site-specific investigation of exposure to waves (wind generated or vessel generated) and river currents, river morphology, existing bank material and condition, distance between the existing bank and the proposed water-side toe of the works, and the extent and consequences of existing bank failure (both sudden and gradual).

As a general rule-of-thumb, the following questions can be posed to inform the decision:

- Is the water-side toe of the proposed works within 30 m of the Fraser River natural boundary or 15 m of the English Bay / Burrard Inlet / False Creek natural boundary?
- If the project is linked to new development, is a setback relaxation being sought for the proposed development?
- Would the proposed works be impacted if the existing shoreline bank failed (suddenly or gradually) and reached a slope indicating a natural state of equilibrium for that material?
- Would wave effects or river velocity cause erosion at the water-side toe of the proposed works during the design flood event without bank protection?
- Is there a history of general or point scour adjacent to the shoreline or are there features (e.g., river channel narrowing) that suggest scouring could occur?
- Is the shoreline adjacent to an area of the waterbody that is dredged for industrial or recreational vessels (e.g., marina)?

If the answer is yes or maybe to at least 1 or 2 of these questions, then bank and scour protection works may be required.

General design guidance for bank protection works is provided in provincial guidelines referenced in Section 2.

For the Fraser River, it is important to note that both vessel-generated wave conditions and spring freshet peak flow velocities should be checked to determine the governing condition for design. Experience suggests that unloaded tug boats travelling at speeds of up to 10 knots at low tide (i.e., reduced water depth) can produce the largest waves on the Fraser River North Arm. Dredging for industrial water access or recreational marinas may also need to be considered for projects along the Fraser River North Arm. Potential future dredging design profiles should be considered instead of current bathymetry to be appropriately conservative for design. This information can generally be obtained from the Port of Vancouver.

For coastal shorelines exposed to significant wind-generated waves, the design team should consider a variety of water levels and wave combinations to determine governing scenarios for design. For example, a 500-year return period wave condition occurring at a regular low tide may cause the most damage to bank protection protecting a dike. For more sheltered areas, vessel-generated waves may govern over wind-generated waves for the design of bank protection. The design team should investigate both possibilities.

In addition to bank protection, near-shore wave attenuation works such as breakwaters and engineered beaches can be used to attenuate wave energy to manage erosion and potentially to reduce the design crest elevation. This is an area where nature-based solutions can play a major role in shoreline flood protection. This is discussed further in Section 8.

## 6.9 Land Tenure and Responsibility for Maintenance

Land tenure challenges and opportunities should be discussed at the beginning of the design project, and are ideally addressed in preceding planning and policy work (e.g., area planning).

The recommended minimum width for land tenure includes the proposed works, setback areas, and space for future upgrading (for 2 m of sea level rise anticipated by the Year 2200). This is presented for each typology on the basic cross-section geometry figures presented earlier (Figure 6-2 to Figure 6-5).

For flood protection works set back from the shoreline, separate land tenure is recommended where bank protection works are required. Where bank protection works extend below the natural boundary, the City may need to establish a water lot lease through the Province of BC or the Port of Vancouver to facilitate the operation and maintenance of the works.

Land tenure ideally means full ownership by the City, but a statutory right-of-way may also be acceptable. Highly customized agreements with individual property owners are discouraged as they can be difficult to interpret or implement over time as conditions change. For the superdike typology, the City may wish to implement the designated dike portion by the development which would fill the development parcel grade up to the crest elevation. In this situation, it is recommended that the City secure an agreement with the private parcel owner that the land will be raised at the time of development to ensure that the superdike is completed. Specific attention should be given to the coordination of the connection of the designated dike and the land raising area for the superdike typology. If the designated dike is to be constructed before land raising through redevelopment, the party responsible for finishing the land raising to the designated dike crest should be identified. This can be documented in an agreement between the City and the adjacent landowner, or through land use planning documents.

In all cases, the responsibility for operation and maintenance of the works, including any adjacent bank protection works, should be with the City. The design team should incorporate design features that have reasonable and realistic maintenance requirements, and which do not easily lead to reduced performance if maintenance is missed.

## 6.10 Access

Table 6-12 presents minimum access criteria to be incorporated into the design.

**Table 6-12: Access Criteria**

| Item | Minimum Requirement |
|---|---|
| Crest access point frequency | 1 access point from the City street network onto the crest for every 2 km length of crest. |
| Crest access ramp slope | Access point ramp onto crest should have a maximum slope of 10%. |
| Crest access ramp width | Access point ramp onto crest should have a minimum width of 4 m. |
| Turn-around | 1 turn around point along the crest (over-wide crest width) for every 500 m length of crest without an access point. |
| Access to shoreline/bank protection works | 1 access point to shoreline/bank protection works for every 2 km length of crest. |
| Access path design loading | All access paths should be designed for AASHTO H-20 loading, except for sensitive habitat shoreline areas where a site-specific approach should be developed. |

Construction vehicle access may be difficult to formally establish for highly urbanized shoreline areas. In these areas, the design team should consult with the City on how shoreline maintenance has occurred by flood protection works and the potential need for impacts to landscaping and surface features as part of emergency repairs.

## 6.11 Surface Treatment and Vegetation Management

### 6.11.1 Crest Surface Treatment

The crest of the flood protection works should provide a minimum 4 m wide level surface suitable for light vehicles and construction equipment, including excavators, compaction equipment, and tandem axle trucks. The 4 m crest width should be indicated on both the 1 m sea level rise design and the proof-of-concept design for 2 m of sea level rise.

Flexible crest finishes, such as granular road base, are generally preferred over rigid finishes such as cast-in-place concrete. This is due to settlement, maintenance, and future upgrading considerations. Asphalt paving is more flexible than concrete, but it is also subject to cracking and vegetation impacts.

The crest material design can also add robustness to works exposed to wave overtopping by providing additional erosion protection where it is practicable or economic to do so. There may be trade-offs for the design team to consider on a site-specific basis. For example, an asphalt surface may be more resistant to overtopping erosion, but will generally make future upgrading more complex due to the need to remove multiple layers of material instead of a single granular layer. In higher risk or post-disaster design situations, crest overtopping erosion protection could be incorporated more formally through buried armour layers. Coordination would be required with the geotechnical design to avoid negative impacts to seepage performance and piping resistance components of the design.

If the flood protection works will provide a public multi-use path on the crest, then the design team should include a landscape architect to develop a design that satisfies multiple objectives. This may require additional crest width to be provided.

### 6.11.2 Vegetation

Vegetation on flood protection works can trigger the following potential issues:

- Roots penetrating the dike fill leading to cavities in dikes which can lead to internal erosion and piping issues;
- Root growth causing damage to wall structures (retaining walls or standalone flood wall);
- Large tree blow-over during high wind resulting in loss of fill material; and
- Impediment to regular and flood emergency inspection for seepage, piping (sand boils), and animal burrows on the land-side slope and toe of earthfill dikes.

Some limited potential flood protection benefits of vegetation include increasing the resistance to overtopping erosion. For example, research programs in the Netherlands have shown how different grass planting and maintenance approaches can increase the resistance to overtopping erosion. Interestingly, the results show that conventional mowing to short height can lead to reduced resistance to erosion due to shallower roots. This is an example of conflicting design features because short height trimmed grass is preferred from the perspective of inspection for seepage and piping issues. Additional research and local interpretation are required before recommendations can be made on specific mowing methods to increase robustness.

The design reference provides minimum requirements and guidance to the design team for selecting vegetation to incorporate into the design. This is provided by flood protection typology in Table 6-13 and is also indicated on the typology figures (Figures 6-2 to 6-5). The design team should consult with City staff to confirm their proposed planting and landscaping plan.

**Table 6-13: Vegetation Selection Guidance for Flood Protection Typologies**

| Location | Vegetation Selection Guidance | Example Vegetation Selection |
|---|---|---|
| **Superdike Typology – Refer to Figure 6-2** | | |
| On designated dike crest | No vegetation permitted | N/A |
| On the land raising area located landside of the designated dike crest and above the internal 3H:1V slope | Roots should not grow into the designated dike core (i.e., beyond the internal 3H:1V slope)<br><br>Vegetation size (diameter, density, and height) should not impede access for inspection and/or emergency repairs | Native or ornamental shrubs (preferred) or small tree species (if planted with structural root barriers or in planters), such as:<br>• Red osier dogwood (*Cornus stolonifera*)<br>• Beaked hazelnut (*Corylus cornuta*)<br>• Ocean spray (*Holodiscus discolor*)<br>• Salal (*Gaultheria shallon*)<br>• Wild rose (*Rosa* spp.) |

| Location | Vegetation Selection Guidance | Example Vegetation Selection |
|---|---|---|
| | | • Vine maple (*Acer circinatum*) |
| On the land raising area located landside of where the internal 3H:1V slope meets the pre-construction ground | Vegetation size (diameter, density, and height) should not impede access for inspection and/or emergency repairs | Various grass seed mixes or mowable, shallow rooted shrub species, such as:<br>• Salmonberry (*Rubus spectabilis*)<br>• Thimbleberry (*Rubus parviflorus*)<br>• Wild rose (*Rosa* spp.)<br>• Common snowberry (*Symphoricarpos albus*) |
| On water-side slope | Avoid trees on or adjacent to the waterside slope which could dislodge or remove waterside slope treatment (e.g. riprap) due to wind storms<br><br>Habitat enhancement is encouraged as long as bank protection considerations are integrated | Pocket plantings of smaller, salt-tolerant, shallow rooted shrub species such as:<br>• Black twinberry (*Lonicera involucrata*)<br>• Pacific ninebark (*Physocarpus capitatus*)<br>• Red elderberry (*Sambucus racemosa*)<br>• Hardhack (*Spiraea douglasii*) |
| **Earthfill Dike with Vegetated Side Slope Typology – Refer to Figures 6-3 and 6-4** | | |
| On designated dike crest | No vegetation permitted | N/A |
| On land-side slope | Only mowed grass is permitted to enable regular and emergency inspection for seepage, animal burrows, and other issues | Various grass seed mixes |
| Within the land-side slope toe setback zone (measured as 7.5 m from the land-side slope toe) | Vegetation size (diameter, density, and height) should not impede access for inspection and/or emergency repairs | Various grass seed mixes or mowable, shallow rooted shrub species, such as:<br>• Salmonberry (*Rubus spectabilis*)<br>• Thimbleberry (*Rubus parviflorus*)<br>• Wild rose (*Rosa* spp.)<br>• Common snowberry (*Symphoricarpos albus*) |
| On water-side slope | Avoid trees on or adjacent to the waterside slope which could dislodge or remove waterside slope treatment (e.g. riprap) due to wind storms | Pocket plantings of smaller, salt-tolerant, shallow rooted shrub species such as:<br>• Black twinberry (*Lonicera involucrata*) |

| Location | Vegetation Selection Guidance | Example Vegetation Selection |
|---|---|---|
| | Habitat enhancement is encouraged as long as bank protection considerations are integrated | • Pacific ninebark (*Physocarpus capitatus*)<br>• Red elderberry (*Sambucus racemosa*)<br>• Hardhack (*Spiraea douglasii*) |
| **Standalone Flood Wall Typology – Refer to Figure 6-5** | | |
| Land-side setback zone (measured as 7.5 m from the land-side toe of the wall) | Only mowed grass is permitted to enable regular and emergency inspection for seepage, animal burrows, and other issues | Various grass seed mixes |
| Water-side of the wall | Avoid trees on or adjacent to the waterside slope which could dislodge or remove waterside slope treatment (e.g. riprap) due to wind storms<br><br>Habitat enhancement is encouraged as long as bank protection considerations are integrated | Smaller, salt-tolerant, shallow rooted shrub species such as:<br>• Black twinberry (*Lonicera involucrata*)<br>• Pacific ninebark (*Physocarpus capitatus*)<br>• Red elderberry (*Sambucus racemosa*)<br>• Hardhack (*Spiraea douglasii*) |

## 6.12 Third-party Construction Coordination

Construction, including temporary excavations for buildings, is expected to occur adjacent to shoreline flood protection works. It is recommended that the City require signoff by a professional engineer on safety and mitigation of impacts on both the flood protection and the other structures by construction. Flood protection works near temporary excavations, including the designated dike portion of superdikes, should be continuously monitored to assess any effects on them. The monitoring requirements should be defined by the professional engineer providing the signoff and approved by the City. For flood protection works, settlement of the crest is one of the key monitoring considerations.

Anchors supporting temporary excavation passing under flood protection works should be removed to a depth of 1.5 m below the underside of the works. The anchor hole should be fully grouted after removal.

Sub-surface structures (basements, parkades, etc.) adjacent to earthfill dikes and superdikes should be designed to mitigate the effects of permanent pumping on seepage and the drainage system to which flow will be pumped. The extent of the effect of permanent pumping would have to be assessed on a project-specific basis.

## 6.13 Internal Drainage Considerations

### 6.13.1 Stormwater Internal Drainage

Vancouver's shoreline and coastal floodplain areas are generally urbanized and the City has significant programs, policies, and design standards for managing urban stormwater. This includes the grey infrastructure system of subsurface storm sewers and overland flow routes (typically on roads), and emerging green infrastructure systems that slow down and infiltrate rainwater into the ground to reduce the loading of the grey infrastructure system. These systems and other initiatives are part of the City's integrated water management approach.

Stormwater is conveyed into English Bay, Burrard Inlet, False Creek, and the Fraser River through stormwater outfalls, combined stormwater and sanitary outfalls, and overland drainage routes terminating at the shoreline.

As sea level rises, the performance of the existing outfalls will be impacted by backwater effects. To supplement shoreline flood protection works, backflow prevention gates can be installed on outfalls to avoid flooding of underground structures and surface areas located below the coastal water level. Concurrently, the flow capacity of the stormwater outfall will be reduced and the likelihood of overland flow route activation will increase.

Overland drainage routes to the ocean or river can be blocked by shoreline flood protection works which can lead to internal drainage flooding as the flood protection works create a 'bathtub' effect during rainfall events exceeding the minor system design event. The extent of this issue can be quantified and mapped through 2-dimensional stormwater hydraulic modelling that incorporates the flood protection works and future sea levels.

There are three general potential response approaches to this issue:

1. Tolerate the associated risk and manage it through education, internal floodproofing of buildings and infrastructure, and emergency response planning such as defining the maximum tolerable flood depth to maintain emergency vehicle access;
2. Strategically raise land on the protected side of the flood protection works to enable unobstructed and safe overland drainage flow over the dike; and
3. Implement internal drainage infrastructure upgrades such as pump stations and/or stormwater siphons (pressurized stormwater pipes) to mitigate the bathtub effect.

The strategic land raising approach is generally in line with the superdike typology. However, the desired land raising may only be feasible in certain areas with favourable topography (narrow coastal floodplain) and area-wide land use planning opportunities (e.g., NEFC), and maybe interrupted by fixed linear infrastructure crossings (e.g., rail corridors).

Implementing drainage pump stations may be required to address the above issues in parts of the City. One of the key challenges with implementing pump stations in Vancouver is that in addition to the pump station building, they require space for an upstream reservoir or forebay with volume storage. The required pumping capacity and the capital cost of the pump station are inversely proportional to the volume storage (i.e., more storage volume means less required pumping capacity and lower cost).

While other low-land areas in the region such as Surrey and Richmond have agricultural or low-density residential land use that can accommodate large pump station forebays and drainage canals, Vancouver's coastal floodplain areas are mostly urbanized without significant drainage storage capacity. The primary exception to this is the Southlands area along the Fraser River which has a long history of lowlands drainage management and has a series of drainage ditches and stormwater pumping infrastructure.

A potential tool in reducing the need for and size of drainage pump stations is the implementation of stormwater siphons (pressurized stormwater pipes) to convey upland drainage directly into the ocean or river by taking advantage of the steep topography of some areas of Vancouver. A stormwater siphon would separate the stormwater drainage area into an upland portion and a lowland portion. Depending on location, the upland drainage area may be much larger than the lowland and the pressurized system would significantly reduce the required pumping capacity for lowland area. Under this approach, the implementation cost of the siphon would aim to be lower than incremental avoided capital and operation and maintenance costs of pumping capacity to serve the upland drainage area.

Existing overland drainage routes and potential impacts should ideally be identified at the planning and conceptual design phase or at the early preliminary design phase to enable design decisions with consideration of the above topics.

The design team should contact the City's integrated water management staff to discuss site-specific approaches for addressing stormwater internal drainage issues, including the need for the shoreline flood protection project to install backflow prevention gates on existing outfalls, reserve space for future pump stations, and considerations around overland drainage routes and new stormwater outfalls.

### 6.13.2 Wave Overtopping and Seepage Internal Drainage

In addition to stormwater, internal drainage flooding may occur due to wave overtopping at flood protection works exposed to significant wave hazards and/or sites that are topographically constrained and even the limited 1 L/s/m overtopping discharge can lead to significant flood depths.

Depending on the estimated overtopping average flow rate, the adjacent topography, and land use tolerance for overtopping, the design team may need to assess overtopping volumes and design internal drainage collection and conveyance systems. Alternatively, the design team could raise the crest of the flood protection works to further reduce the overtopping discharge.

The same issue may apply to seepage-induced internal flooding. However, given the tidal water level variation, seepage volumes may be negligible because of the hydraulic relief provided by the low tide cycle which can lower the water level by up to 3 m.

# 7. Urban Design and Public Amenity Integration

Section 7 describes how shoreline flood protection can be incorporated into highly urban spaces with objectives, case studies, and criteria. The section also describes how more elaborate public amenities can be incorporated into shoreline flood protection (e.g., public plazas, structures, etc.).

## 7.1 Coastal Adaptation Plan - Values and Principles

Planning, engagement, and conceptual design are critical to the successful implementation of flood protection. Detailed design must be conducted on the foundation of comprehensive planning and engagement. The City of Vancouver has and continues to conduct extensive planning and engagement related to sea level rise adaptation and coastal flood management. Section 2 provides background information on initiatives including the Coastal Adaptation Plan (CAP) and the Sea2City Design Challenge. As discussed in Section 4 (project phases and documentation), design teams should review the CAP and other documents as one of the first steps of a flood protection design project.

The CAP also provides guidance on urban design and public amenity integration through community values and planning and design principles. The community values and planning and design principles for the Fraser River and False Creek floodplains are re-produced from the CAP (City of Vancouver, 2018 and 2020) below. The design team should review the CAP reports in detail for additional information and context.

### 7.1.1 Fraser River

The Fraser River community values identified in the CAP are:

- Communities and People
- Environment
- Health and Safety
- Infrastructure and Transportation
- Local and Regional Economy
- Culture and Heritage
- Recreation

The Fraser River planning and design principles identified in the CAP are:

- **Plan for integration**: Integrate flood management strategy with relevant City-wide plans (e.g., Citywide Integrated Rainwater Management Plan) and local level, neighbourhood plans (e.g., Marpole Neighbourhood Plan), and where required, provide direction on necessary amendments (e.g., zoning changes). Coordinate with other relevant municipalities.
- **Plan for reconciliation**: Specifically address Musqueam, cultural values (hunting, gathering, ceremony sites), and cultural/ archeological sites (e.g., Marpole Midden). Incorporate City of Reconciliation policy and related emerging City of Vancouver protocols, procedures and plans.
- **Plan for transparency (education)**: Flood management approaches should include educational and awareness building components that openly communicate flood risks facing the area, as well as the City's decision-making and management processes.
- **Plan for cost-sharing**: work with all levels of government, asset holders and other stakeholders to implement short-, medium-, and long-term flood control infrastructure measures and maintenance efforts.

- **Design for adaptability**: Develop flexible options that can adjust to a wide range of future conditions, including the pace of sea level rise, the height of sea level rise, and future land uses.
- **Design for co-benefits**: Ensure that new approaches support multiple community values (e.g., recreation, health and wellbeing, communities and people).
- **Design for nature**: While the study area is heavily urbanized, the Fraser River is the most significant salmon river in BC. It is also home to other threatened species (e.g., sturgeon) and regionally critical and rare estuary habitats.
- **Design for safe-to-fail infrastructure systems**: Ensure risks to lifeline infrastructure and services are minimized,
- **Design for safety and public health**: Ensure public safety risks are minimized, and that public health and wellbeing are protected.
- **Design for access**: Improve access to and around the Fraser River and include recreational and interpretive opportunities where feasible.

The Fraser River CAP report (City of Vancouver, 2018) provides additional discussion on the attributes of the planning and design principles which serves as relevant guidance for preliminary and detailed design.

### 7.1.2 False Creek

The False Creek community values identified in the CAP are:

- Communities, People, and Homes
- Health and Safety
- Infrastructure and Transportation
- Environment
- Local and Regional Economy
- Arts, Culture, and Heritage
- Recreation

The False Creek planning and design principles identified in the CAP are:

- **Plan for integration**: Integrate the flood management strategy with relevant and concurrent City-wide plans (e.g., Vancouver Plan, Climate Emergency Action Plan, RainCity Strategy).
- **Plan for coordination**: Coordinate planning with other organizations, agencies, and asset owners manage lands, water, and assets in False Creek. Where required, provide direction and input on necessary policy amendments (e.g., zoning changes, development review).
- **Plan for reconciliation**: Ongoing coordination, collaboration, and engagement with Musqueam, Squamish, and Tsleil-Waututh Nations is critical given their interests and rights in False Creek, and, for Squamish, the emerging Seṅáḵw development.
- **Plan for transparency (education)**: Flood management approaches should include educational and awareness building components that openly communicate flood risks facing the area, as well as the City's decision-making and management processes.
- **Plan for equity**: Ensure that future sea level rise planning and implementation integrates equity considerations into project processes (how we engage, and with whom) and outcomes (what is

prioritized). Equity should be supported towards the promotion of justice and fairness and the removal of systemic barriers that may cause or aggravate disparities experienced by equity-seeking groups.

- **Plan for cost-sharing**: Work with all levels of government, asset holders, and other stakeholders to implement short-, medium-, and long-term flood control infrastructure measures and maintenance efforts.
- **Design for safe-to-fail infrastructure systems**: Ensure risks to lifeline infrastructure and services are minimized, and that redundant systems are in place in case of failure.
- **Design for safety and public health**: Ensure risks to lifeline infrastructure and services are minimized, and that public health and wellbeing are protected.
- **Design for adaptability**: Develop flexible options that can adjust to a wide range of future conditions, including the pace of sea level rise, the height of sea level rise, and future land uses.
- **Design with nature**: Ensure that approaches support ecological revitalization.
- **Design for co-benefits**: Ensure that new approaches support multiple community values (e.g., recreation, health and wellbeing, communities and people).
- **Design for access**: Improve access to False Creek and include recreational and interpretive opportunities where feasible.

## 7.2 Urban Waterfront Design Considerations

In addition to the community values and planning and design principles identified in the Coastal Adaptation Plan (CAP), several design considerations are identified related to urban waterfront design to further guide preliminary and detailed design. These considerations are closely linked to the principles identified in the CAP and aim to provide additional detail for urban waterfront design integration.

The urban waterfront design considerations are summarized in Figure 7-1 and described further below. The design considerations were originally developed by Hapa Collaborative and refined by KWL and City of Vancouver staff to align them with the CAP principles.

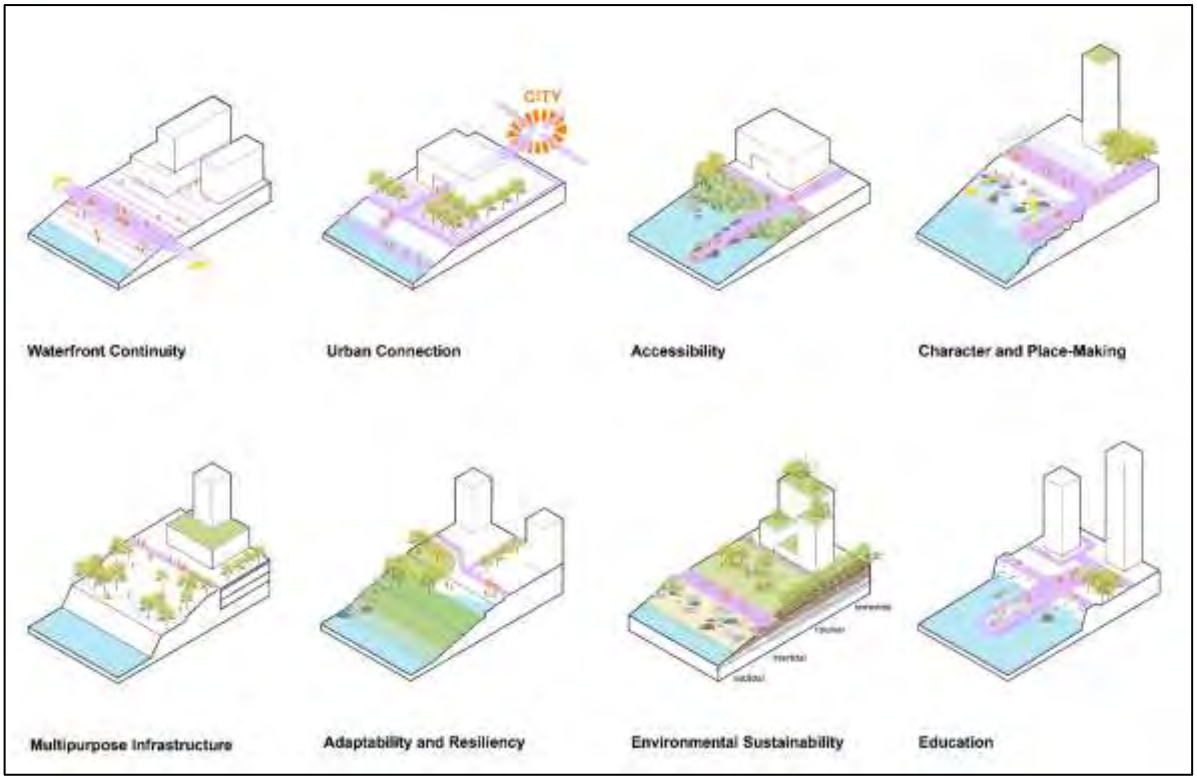
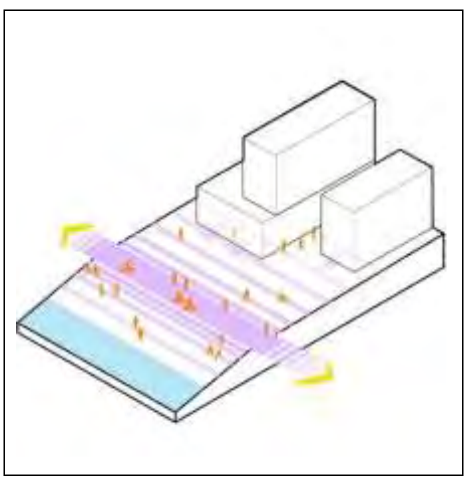



**Figure 7-1: Urban Waterfront Design Considerations (Source: Hapa Collaborative)**

## 7.2.1 Waterfront Continuity

**Associated CAP planning/design principle(s): plan for integration**

Designs should maintain and strengthen Vancouver's iconic waterfront path network and series of interconnected spaces.



Key considerations:

- Provide continuous waterfront access both along the water and to the water;
- Enable accessible and multi-modal movements, connections and facilities;
- Provide a direct connection to the existing waterfront pathway network; and
- Consider the contribution to Vancouver's identity that is intimately tied to the iconic waterfront through the seawall and interconnected public spaces.

### 7.2.2 Urban Connection

**Associated CAP planning/design principle(s): plan for integration**

Clear, legible and identifiable connections between development, parks, and the waterfront.

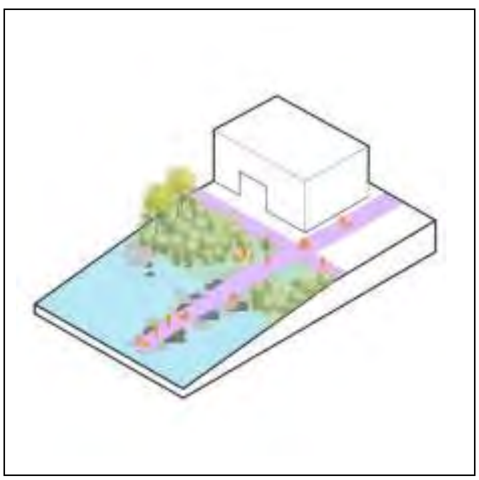

Key considerations:

- Consider an intentional integration from the waterfront to the larger urban fabric;
- Consider well-designed frontages that enhance pedestrian access and visual interest;
- Consider how architecture and landscape work in a reciprocal relationship to create an interconnected indoor/outdoor experience; and
- Consider the opportunity to define public and semi-public realms that potentially overlap and support each other and lengthen their use into the shoulder seasons.

### 7.2.3 Accessibility

**Associated CAP planning/design principle(s): design for accessibility**

Designs should be accessible and promote inclusivity for people of all ages and abilities.



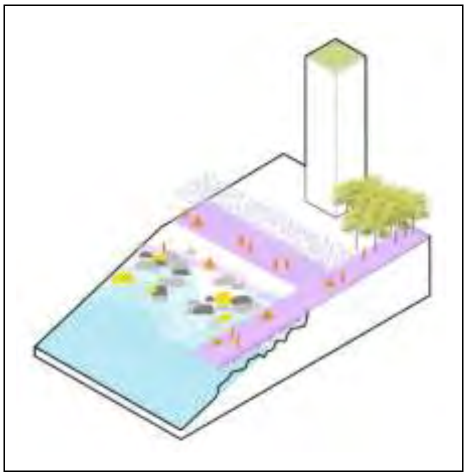
Key considerations:

- Should include a balance of movement and gathering, providing opportunities for safe, comfortable and enjoyable options to rest, celebrate and get around;
- Consider the slope transition to street level to ensure accessibility for all;
- Consider a maximum slope of 8% with a preferred slope of 5% especially when designing connections and open spaces; and
- Consider how important waterfront views and experiences can be accessed and inclusive for all.

### 7.2.4 Character and Place-making

**Associated with CAP community values.**

Designs should reinforce the unique character of the edge and create a sense of place amongst a series of interconnected spaces.



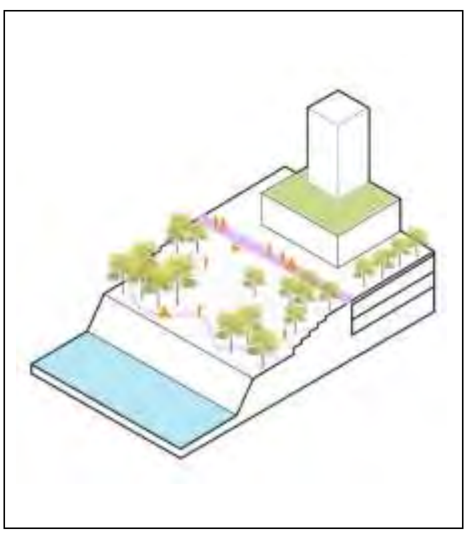
Key considerations:

- Consider important and memorable views to and from the water;
- Consider designs that support temporary event activation and pop-up destinations; and
- Consider creating emphasis on special places (ecological, historical, cultural, etc.) through the design and axis of corridors and the placement of gathering places.

### 7.2.5 Multipurpose Infrastructure

**Associated CAP planning/design principle(s): design for co-benefits**

Designs for flooding infrastructure should balance a mix of social, ecological and educational functions.



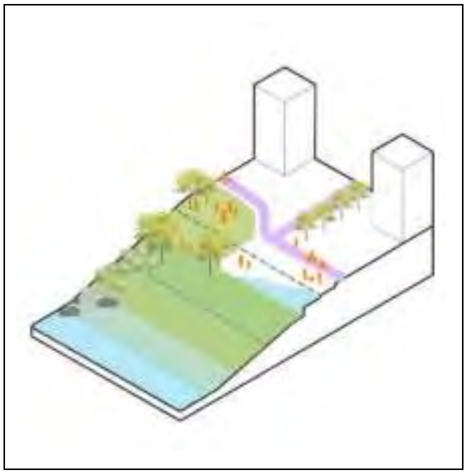
Key considerations:

- Consider incorporating ecological habitat features into waterfront structures, such as:
    - Complex surfaces of seawalls or subsurface treatment of decks to increase ecosystem productivity;
    - Light-penetrating surfaces to provide light for fish during migration;
- Consider raising building parcels to the dike level (superdike typology) and incorporating development and landscape on the transition down to the street grade; and
- Consider alternatives to the current dike profile and features including planting.

### 7.2.6 Adaptability and Resiliency

**Associated CAP planning/design principle(s): design for adaptability**

Designs should accommodate future changes to infrastructure and rising sea levels.



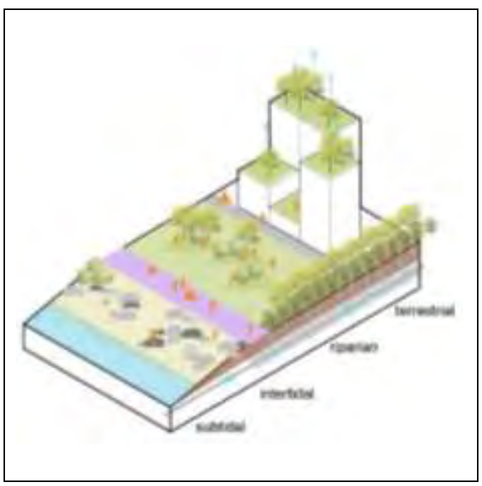
Key considerations:

- Consider floodable parks and options where recreational space can be outside the line of protection and used only during non-flooding times; and
- Consider the long-term benefits of ecological restoration and habitat development along a changing shoreline.

### 7.2.7 Environmental Sustainability

**Associated CAP planning/design principle(s): design with/for nature**

Designs should respond to and enhance the ecological gradient from land to water.



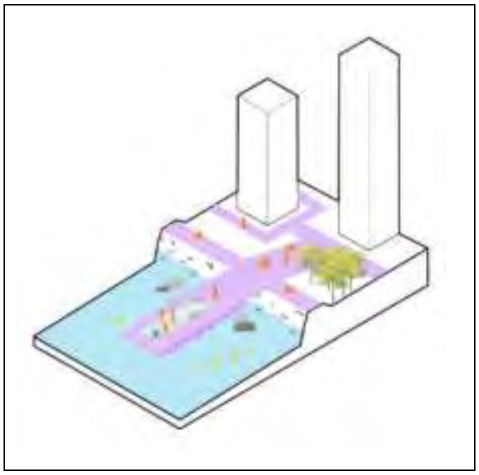

Key considerations:

- Consider the full landscape from water to land including subtidal, intertidal, riparian and terrestrial together;
- Consider coastal wetland creation or restoration as a “transition zone” between land and sea with both upland and aquatic characteristics;
- Consider the integration of water management throughout the project including green roofs (transpiration), swales and rain gardens (infiltration), and allowing for water to drain to the ocean (conveyance); and
- Designs should incorporate permeable surfaces and treatments where possible.

### 7.2.8 Education

**Associated CAP planning/design principle(s): plan for transparency/education, plan for reconciliation**

Designs should consider public understanding and legibility of flood protection, waterfront history and ecology.



Key considerations:

- Provide signage that includes Indigenous, ecological and historical storytelling to illustrate the richness of place;
- Consider public art pieces that are interactive, kinetic and engage the public in a conversation about rising sea levels; and
- Consider creating windows to reveal hidden infrastructure, highlight ecological restoration or connect to larger systems.

## 7.3 Urban Integration Case Studies

### 7.3.1 Superdikes and Waterfront Parks

The superdike typology presented in Section 6 is well suited for advancing the urban design and public amenity objectives presented above. The superdike approach is also highly compatible for integration with waterfront linear parks. Two recent, local projects are highlighted below as case studies.

**Kawaki Waterfront Park (The Pier at London Landing), Richmond**

The Pier at London Landing is a multi-use suburban village development with residential units, commercial space, live-work studios, and a large community amenity spilling into a park and plaza. The unique Kawaki Waterfront park is one of few places where people can access land on the outside of the city's flood protection dike. By shaping the interaction between the waterfront and the newly built village, visitors can connect easily with the river's rich natural habitat while enjoying a pleasant place to socialize. Balancing flood protection engineering while preserving the existing foreshore habitat was essential. Kawaki Waterfront Park is a part of the larger urban design of the Middle Arm and the Olympic Oval, raised as a superdike.

**East Fraser Lands Parks, Vancouver**

The East Fraser Lands lies in the southeast corner of Vancouver on the Fraser River. The Canadian White Pine sawmill operated on the land south of the rail corridor until the mill closed in 2001.

Currently, under design and construction, the park is composed of sections that serve the newly developed community surrounding the park and includes a long stretch of foreshore park that is focused on improving the biodiversity and ecology of the river. This park will also enhance the unique qualities of living in a riverfront community. The park has an emphasis on large, flexible park area that will be used for informal sports, community events or cultural celebrations. There will be a large children's playscape to serve the children and families in the area.

Park elements and public art focus on the site's rich cultural stories, including the history of the sawmill and the relationship of First Nations with the land and the river. A sanctuary island is one of the main features of the park and provides inaccessible wildlife habitat separated from the rest of the park by a tidal marsh/slough. Sanctuary Island sits at the base of the Kinross Park corridor. A watercourse flowing through Kinross Park terminates in a perched, seasonal, fresh-water wetland just north-west of the island. Vancouver's first modern shoreline flood protection works have been integrated into the park design and adjacent land use planning in the form of superdikes, dikes with vegetated side slopes, and a limited length of standalone flood wall.

### 7.3.2 Multifunctional Structures

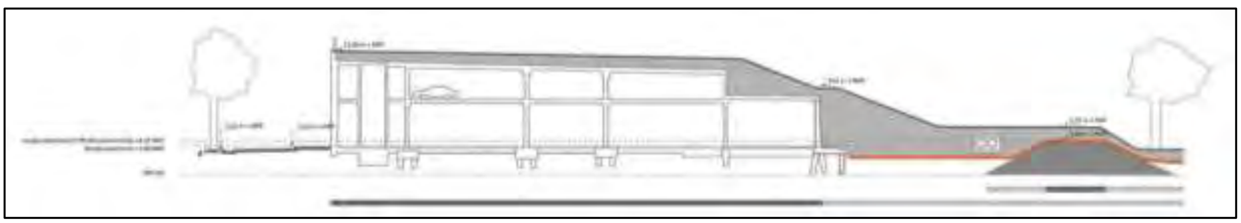
While the preferred typologies introduced in Section 6 will be appropriate for most shoreline areas, an alternative typology may be required for unique, landmark developments that need to incorporate shoreline flood protection.

In these special conditions, it may be feasible and acceptable to design a single waterfront structure to act directly as flood protection in addition to other functions. This special typology should be applied cautiously and with consideration of a variety of technical and administrative challenges discussed in Section 6. In particular, the land tenure and maintenance authority/protocol for flood protection should be established clearly in the City's favour with no maintenance responsibility on private entities. Accordingly, this special typology is likely to be only appropriate for waterfront civil facilities and/or infrastructure.

An example of a multifunctional flood protection structure is the Four Harbour Roof Park in Rotterdam, the Netherlands described below.

**Four Harbour Roof Park (DakPark), Rotterdam**

The multifunctional structure combines a dike, a concrete parkade building, the largest rooftop park in Europe, and adjacent mixed-use development. The parkade structure is attached on the water-side of the pre-existing dike and is therefore structurally designed for flood conditions. The structure's height also adds robustness to the flood protection by exceeding the required dike elevation by several meters. Despite the large scale of the project, the main objective of the project was accessibility and integration to the adjacent neighbourhood and surroundings. One end of the park is 8 metres above ground level on top of commercial facilities with the other end folds in two levels to the ground level with a direct connection to the neighbouring community. The project catalyzes the urban transformation of the other city harbours and the larger urban design of Rotterdam.

*Cross-section of DakPark with original dike on the right and multifunctional structure on the left. (van Veelen et al., 2015)*

# 8. Habitat Enhancement and Nature-based Solutions

Section 8 describes design considerations for potential habitat enhancement opportunities as part of shoreline flood protection projects. An overview of the opportunity for nature-based solutions to contribute to flood protection in Vancouver is also provided.

## 8.1 Existing Habitat and Habitat Impact Compensation

Avoiding impacts to existing habitat is generally the highest habitat priority, but is not always possible when implementing shoreline flood protection works. When avoiding impacts is not possible, it is generally preferred to compensate for impacts on site as opposed to off site.

Guided by the biologist, the design team should aim to avoid impacts to existing habitats wherever possible. Locating flood protection alignments away from natural shorelines is often the best approach to avoiding impacts. As discussed in Section 3, the biologist's role involves identifying existing habitats, potential impacts from the proposed design, providing design input, and leading the environmental regulatory permitting process which will determine if the identified habitat impacts can be tolerated, what mitigation practices are required during construction, and what compensation works will be required.

Habitat enhancement to achieve compensation requirements for impacts anticipated from proposed flood protection works is a complex topic and requires the involvement of a suitably qualified biologist. The biologist should work with the hydrotechnical engineer and the rest of the design team to develop suitable measures.

While not in place at this time, habitat compensation for impacts from flood protection projects could also be managed and tracked through a habitat offsetting and banking program. Examples of existing habitat banking in the Lower Mainland include the Port of Vancouver Habitat Bank, which is an agreement between the Vancouver Fraser Port Authority and Fisheries and Oceans Canada (2019). This agreement allows the Port Authority to undertake habitat enhancement projects in advance of infrastructure development, and to produce habitat credits to be stored in the Habitat Bank. The credits can be applied later to meet offsetting requirements for future projects.

## 8.2 General Habitat Enhancement Design Considerations

The following are important design considerations for integrating habitat enhancement into flood protection projects:

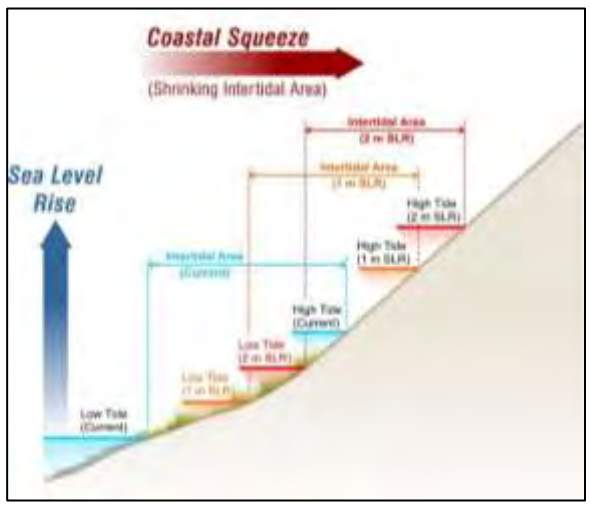
- **Enhancement goals and adaptive management:** A habitat enhancement project cannot be successful if it does not have stated goals and a monitoring program with indicators to gauge success. Ideally, an adaptive management approach can be implemented where the habitat is managed through a process defined at the design stage, the performance of the enhancement is monitored, management lessons learned through the monitoring, and design and management practices are updated. This consideration is particularly important for habitat enhancement works that are required as compensation for impacts from the construction of flood protection works.

- **Biophysical process (spatial scale):** Physical landscapes are shaped by the interaction between sediments, hydrodynamics, and ecology. Therefore, an alteration in any of these interactions can lead to changes in both landscape morphology and ecology. These interactions are strongly influenced by riverine and coastal processes as well as anthropogenic factors such as existing infrastructure and human use. Understanding a selected site's biophysical characteristics and processes such as wave energy, erosion potential, and existing vegetation are important for determining if a site has the potential to implement an enhancement feature.

- **Climate change and ecosystem potential (time scale):** On-going changes in the surrounding environment that can affect the biophysical characteristics of the site over a long time scale should be identified. Sea level rise is an obvious change, but other changes such as land use change and impacts to runoff, increases in annual precipitation, temperature changes, and water quality should also be considered for designing habitat enhancement works. Designs should incorporate the range of conditions that can occur and how the system can change over time. For example, as sea levels continue to rise designs should be looking at the impacts of this increase in water levels. Questions such as "will the design withstand projected sea level rise?" or "is the surrounding landscape compatible to allow for the migration of the shoreline landward?" should be asked during the early stages of site selection and design.
- **Integration with existing or previous natural habitat conditions:** Making use of existing ecosystems and native species are crucial. A historical review of the project site should be completed to get an understanding of changes and trends to the habitat. Where appropriate, a restoration approach focusing on reconstructing proper abiotic conditions is preferred as more diverse ecosystems are also more resilient to disturbances.

## 8.3 Coastal Squeeze and Future Intertidal Zone

The intertidal zone is the area of marine foreshore that is exposed at low tide and inundated at high tide, refer to Section 6.4 for tidal elevations. The intertidal zone provides a variety of ecosystem and societal benefits, including habitat for aquatic species and recreational/cultural spaces.




Sea level rise increases the elevation of the tidal range and shifts the intertidal zone towards the land. Where there are vertical walls and/or armoured shorelines that increase in steepness, the land-ward shift can result in a net loss of intertidal area; this is commonly called "coastal squeeze" and is depicted to the right. Coastal squeeze can also happen without the influence of shoreline protection in steep shoreline topographies (i.e., cliffs, bedrock shoreline).

Using the tidal elevations provided in Section 6.4 and topographic information, the design team should estimate the intertidal area under current sea level, 1 m sea level rise, and 2 m sea level rise for both existing shoreline conditions and proposed flood protection shoreline alterations. Ideally, the flood protection project should avoid reducing the intertidal area over time (i.e., causing coastal squeeze). This is best achieved by locating flood protection works away from the shoreline and on ground that is higher than current and future high tide (HHWLT) elevations.

Where the flood protection works alignment will cause coastal squeeze, the project team should consider whether there are opportunities on the project site on the water-side of the flood protection works to create an intertidal area by regrading the shoreline into a terraced landscape that provides a defined area within the tidal range. This approach may involve trade-offs between riparian and intertidal habitat that should be considered by the project biologist on a site-specific basis. An alternative approach to creating future intertidal habitats is to fill land that is currently below the tidal range. This approach also involves trade-offs as the construction would itself cause impacts to sub-tidal habitat.

## 8.4 Nature-Based Solutions

Nature-based solutions utilize landscape, vegetation, and habitat features to reduce flood risk while providing environmental and/or social co-benefits.

For Vancouver's context, nature-based solutions can be incorporated into sea level rise adaptation and flood protection projects through nature-based wave energy attenuation measures and nature-based Fraser River bank protection measures.

### 8.4.1 Nature-based Solutions for Wave Energy Attenuation

Mudflats, salt marshes, beaches, and intertidal/subtidal vegetation (e.g., kelp beds) are examples of natural features that can be incorporated into near-shore topography and water-side slope of flood protection works to reduce the wave energy reaching the crest. The nature-based measures, particularly vegetation components providing roughness, can contribute to a reduction in the wave runup allowance required to limit overtopping which would, in turn, reduce the design crest elevation. This is an emerging area of practice that should be considered by the design team because it is in line with the City's overall climate change adaptation strategy and other city-wide initiatives.

While there are no formal, local examples of nature-based wave attenuation works specifically integrated into flood protection works at this time, there are many similar and emerging projects that are relevant examples:

**Boundary Bay Living Dike Project**

The joint City of Surrey and City of Delta 'Living Dike' project on Boundary Bay is one component of the suite of structural flood protection works being implemented as part of a Disaster Mitigation and Adaptation Fund (DMAF) grant awarded to the City of Surrey and partners resulting from the City of Surrey's Coastal Flood Adaptation Strategy. The Living Dike project aims to develop experimental foreshore habitat enhancement approaches that will gradually raise the elevation of the marsh habitats providing erosion protection to the Boundary Bay dike system to adapt the marsh to sea level rise. The project is about to enter the design phase and implementation and monitoring are expected to continue over several years. Ideally, the project will provide a local case study of how marsh habitat enhancement can help reduce wave energy and runup on sea dikes.

**New Brighton Park Shoreline Habitat Restoration Project**

While not specifically focused on flood protection, this collaborative effort of the Port of Vancouver's Habitat Enhancement Program and the Vancouver Board of Parks along with Musqueam, Squamish and Tsleil-Waututh Nations resulted in a high profile and successful shoreline habitat design that can be considered as an example for incorporating nature-based measures on the water-side of shoreline flood protection works.

The project resulted in conversion of a historic industrial infilling into productive fish and wildlife habitat that will benefit juvenile Pacific salmon, as well as other fish species, birds, and wildlife utilizing Burrard Inlet. The project recently received a gold rating under the Stewardship Centre for B.C.'s Green Shores® for Coastal Development program, which demonstrates the highest possible achievement of project environmental goals and leadership in shoreline stewardship. In addition to the habitat enhancement, the marsh vegetation helps manage erosion from wind-generated waves and Burrard Inlet vessel traffic generated waves and eliminated the need for a formal rock revetment.

**Kitsilano Foreshore Erosion Protection (2003)**

In 2003, the Vancouver Parks Board recognized that sandstone bluffs along Kitsilano Beach Park (west of Kitsilano Beach Pool) were slowly eroding under natural weathering processes and larger wave events. To limit the impact of conventional rock revetment erosion protection on the beach intertidal and riparian habitat, an early example of a nature-based approach was implemented west of Kitsilano Pool involving:

- a stacked rock wall to protect the lower portions of the wall from waves;
- a vegetated geogrid using biodegradable erosion control products to construct a reinforced slope;
- live willow brush layers in the vegetated geogrid;
- live willow staking;
- planting of plug vegetation in the vegetated geogrid; and
- shrub planting along the top of slope.

*Before Construction*

*After Construction Showing Successful Foreshore Vegetation Development*

### 8.4.2 Nature-based Solutions for River Bank Protection

For Vancouver's Fraser River shoreline, riverbank bioengineering bank protection and slope stabilization practices involving fascines, willow staking, and coir soil wraps can help reduce the need for riprap revetment bank protection. These approaches are well-established in creeks and rivers throughout British Columbia. However, there has been the less formal application of bioengineering bank protection practices on the water-side slopes of dikes. Bioengineering bank protection for shoreline flood protection in Vancouver is likely most appropriate in lower energy reaches of the Fraser River where the channel thalweg (deepest location with fast-moving water) is not located near the riverbank, and where the flood protection works are set back (not located directly on the river bank). These conditions provide more confidence for the design team to rely on bioengineering bank protection approaches which are still not standard bank protection design practice despite application over multiple decades.

One of the largest and highest-profile applications of river bioengineering bank protection is the Bow River Bioengineering Demonstration and Education Project in Calgary, Alberta. Borne in response to the 2013 Calgary flood, is the largest initiative under the Southern Alberta Fisheries Habitat Enhancement and Sustainability program and is the largest bioengineering project in Calgary. It elevates the understanding, acceptance and application of bioengineering design by showcasing seven successful common techniques and introducing seven new techniques to expand the bioengineering design toolbox, and by openly sharing project technical documentation, research findings, and performance monitoring results.

# Submission

The design reference was primarily prepared and reviewed by the undersigned, with additional input and review from individuals listed in Section 1.

Geotechnical criteria input and design considerations listed in Section 6 are summarized from a geotechnical technical memorandum (Thurber, 2020) prepared for this project.

Prepared by:

**KERR WOOD LEIDAL ASSOCIATES LTD.**

2021-03-24

PROFESSIONAL PROVINCE OF A. TALEGHANI # 45901 BRITISH COLUMBIA ENGINEER

*Civil / Hydrotechnical*

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

Reviewed by:

Mike V. Currie, M.Eng., P.Eng., FEC
Principal, Senior Water Resources Engineer

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

# References

Ausenco Sandwell, 2011. Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use. Guidelines for Management of Coastal Flood Hazard Land Use. Prepared for BC Ministry of Environment.

City of Surrey, 2019. Coastal Flood Adaptation Strategy. Final Report. Available at: https://www.surrey.ca/files/CFASFinalReportNov2019.pdf

City of Vancouver, 2020. Coastal Adaptation Plan False Creek. Final Report – Draft December 2020.

City of Vancouver, 2018. Coastal Adaptation Plan Fraser River Foreshore. Final Report December 2018.

City of Vancouver, 2015. Land Use and Development Policies and Guidelines: Flood Plain Standards and Requirements. Available at: https://guidelines.vancouver.ca/F014.pdf

Compass Resources Management and Ebbwater Consulting, 2015. Coastal Flood Risk Assessment Phase 2. Prepared for the City of Vancouver. Available at: https://vancouver.ca/files/cov/CFRA-phase-2-final-report-oct-2016-revision.pdf

Islam, S.U., Déry, S.J., and Werner, A.T., 2017: Future climate change impacts on snow and water resources of the Fraser River Basin, British Columbia, Journal of Hydrometeorology, 18(2), 473-496, doi: 0.1175/JHM-D-16-0012.1.

Nakamura, Hitoshi. (2016). Possibilities of neighborhood evacuation within a district in the event of a large-scale flood in a low-lying area: A case study of Shinden district in Tokyo. E3S Web of Conferences. 7. 19005. 10.1051/e3sconf/20160719005.

NASA, 2020. Global Climate Change: Vital Signs of the Planet, Hosted by NASA's Jet Propulsion Laboratory. Available at: https://climate.nasa.gov/vital-signs/sea-level/

NHC, 2014. City of Vancouver Coastal Flood Risk Assessment. Prepared for City of Vancouver, December, 2014. Available at: https://vancouver.ca/files/cov/CFRA-Phase-1-Final_Report.pdf

Shrestha R.R; Cannon, A.J.; Schnorbus, M.A. and Zwiers F.W., 2017. "Projecting future nonstationary extreme streamflow for the Fraser River, Canada, "Climatic Change, Springer, vol. 145(3), pages 289-303, December. doi: 10.1007/s10584-017-2098-6.

Thurber, 2020. City of Vancouver Engineering Design Reference for Shoreline Flood Protection Geotechnical Engineering Input. Technical Memorandum dated June 9, 2020. Thurber File No. 28248.

Vancouver Fraser Port Authority and Minister of Fisheries and Oceans Canada, 2019. Habitat Bank Arrangement. Available at: https://www.portvancouver.com/wp-content/uploads/2019/05/2019-03-29-03-100-VFPA-DFO-Habitat-Bank-Arrangement-Rev0.pdf

van Veelen, P., Voorendt, M., & van der Zwet, C. (2015). Design challenges of multifunctional food defences. A comparative approach to assess spatial and structural integration. Research In Urbanism Series, 3(1), 275-292. doi:10.7480/rius.3.841.

## Statement of Limitations

This document has been prepared by Kerr Wood Leidal Associates Ltd. (KWL) for the exclusive use and benefit of the City of Vancouver for the Vancouver Shoreline Flood Protection Design Reference project. No other party is entitled to rely on any of the conclusions, data, opinions, or any other information contained in this document. The City of Vancouver may reproduce the materials and distribute to third parties as appropriate for implementation of shoreline flood protection projects.

This document represents KWL's professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

## Revision History

| Revision # | Date | Status | Revision | Author |
|---|---|---|---|---|
| 0 | March 23, 2021 | FINAL | Addressed final comments received on March 17, 2021 on DRAFT C | ATAL |

OQM CERTIFIED