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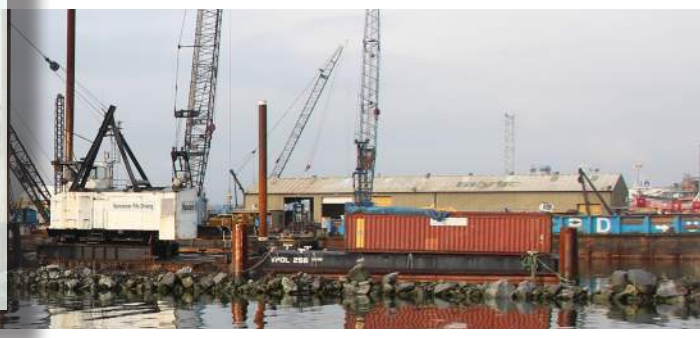
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Squamish Nation

PORT of vancouver



North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy





Final Report
February 2021



KWL File No. 031.548-300

KERR WOOD LEIDAL
consulting engineers

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Executive Summary

Anthropogenic (human-caused) climate change is leading to a gradual and long-term rise in the base sea level (sea level rise). Sea level rise is changing how natural forces such as tides, storm surge, and waves interact with coastal areas. As a result, the exposure of people and assets (physical, natural, and cultural) to coastal area hazards is also changing.

Located on the unceded lands of Coast Salish First Nations, the North Shore region of Metro Vancouver, Canada is home to over 180,000 people, the Port of Vancouver, and vast natural and cultural assets. With over 65 km of Salish Sea (Georgia Strait and Burrard Inlet) shoreline, sea level rise is a significant concern for the North Shore. Coastal land uses include port, industrial and commercial, critical transportation and power infrastructure, high-density mixed-use and single-family residential, and park (recreational and natural).

The North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy ('the Strategy') is the initial milestone of a collaborative planning process started by the following five North Shore partner governments and organizations: District of North Vancouver (DNV), District of West Vancouver (DWV), Sḵwx̱wú7mesh - Squamish Nation (SN), City of North Vancouver (CNV), North Shore Emergency Management Office (NSEM), and Vancouver Fraser Port Authority (PA). The Tsleil-Waututh Nation (TWN) is undertaking a separate Climate Change Resiliency Planning program that also considers sea level rise adaptation. The implementation of the Strategy will further engage TWN and other key North Shore groups (e.g. CN Rail).

With a vision "to work together to reduce risk and strengthen community resilience to sea level rise across the North Shore", the partners acknowledge that sea level rise does not respect jurisdictional borders between their communities and that their collaboration strengthens their planning efforts.

The Strategy was developed on a foundation of technical hazard and risk analyses, which focused on how sea level rise related coastal flooding and intertidal area change are increasing risk across 6 sectors on the North Shore: social services, development and infrastructure, transportation, economy, environment, and culture and heritage. Analysis was based on sea level rise projections of up to 2 m above the recent sea level. Based on current Province of British Columbia policy guidance the 2 m projection is anticipated for the Year 2200. However, the Strategy acknowledges that significant scientific uncertainty may result in future changes to projections, and also to provincial policy; as such, the 2 m projection was included in current planning. Analysis results highlight the need for adaptation across all sectors but specifically highlight the need to focus on buildings and businesses, transportation and wastewater infrastructure, and intertidal habitats.

The Strategy includes resources, concepts, and implementation actions to support and guide collaborative sea level rise adaptation planning over approximately 10 years (to Year 2030). These include high-level adaptation approaches (resist, accommodate, avoid, retreat, and advance), a North Shore sea level rise adaptation toolkit with 26 tools, policy guidance on managing development in the coastal floodplain, and initial adaptation concepts for 9 comprehensive adaptation planning zones (CAPZ) where future collaborative planning is recommended.

Engagement with the public, SN membership, port terminal operators, and other key groups was conducted at two levels: a North Shore-wide virtual engagement (spring 2020 and fall 2020) led by DNV, and individual partner engagements (spring 2020 and further planned in 2021). Engagement findings have been used to refine the adaptation planning resources in the Strategy. The Strategy has been received by each partner organization, including through presentations in fall 2020 to DNV and SN councils.

The Strategy's implementation plan recommends 6 high-priority next steps and a progress monitoring framework to support coordinated implementation among North Shore partners over time.

Key Terms and Definitions

Alluvial Fan	Deposits of water-transported material often referred to as alluvium, that is deposited as the flow of a river decreases in velocity.
AEP	Annual exceedance probability is the probability that an event (e.g., a coastal flood water level) will occur or be exceeded in any given year. For example, a 10% AEP event has a 10% probability in any given year that it or a larger event will occur. AEP is calculated as a 1 divided by the return period.
Anthropogenic	Originating in human activity.
Atmospheric River	A long, meandering plume of water vapour often originating over the tropical oceans that bring sustained, heavy precipitation to the west coasts of North America and northern Europe throughout the winter months.
Backwater	Water backed up in its course by an obstruction, an opposing current, or the tide.
CGVD28	The Canadian Geodetic Vertical Datum of 1928. A reference datum for measuring elevations that are currently used on the North Shore. Historically, 0 m CGVD28 represented mean sea level.
CGVD2013	The Canadian Geodetic Vertical Datum of 2013. An emerging reference datum for measuring elevations that will eventually be adopted on the North Shore.
Climate Change	A change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.
Datum	A reference system or an approximation of the Earth's surface against which positional measurements are made for computing locations.
Digital Elevation Model	A 3D computer graphic representation of a terrain's surface, created from a terrain's elevation data.
El Nino Southern Oscillation	An irregularly periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting the climate of much of the tropics and subtropics.
Fetch	Area of water surface over which the wind blows in an essentially constant direction, thus generating waves. The term also is used as a synonym for fetch length, which is the horizontal distance over which wave-generating winds blow.
Floodplain	An area of low-lying ground adjacent to a river or ocean that is subject to flooding. Floodplains are often characterized by a relatively flat topography.
Freeboard	A vertical distance added to water surface elevations to account for scientific uncertainty and other unknown factors.
Frequency-magnitude Relationship	A relationship where events with a smaller magnitude happen more often than events with large magnitudes. Large floods (higher water level, larger spatial extent) typically have a lower probability of occurrence or AEP in any given year.
Greenhouse Gases	A gas that contributes to the greenhouse effect by absorbing infrared radiation, e.g., carbon dioxide, water vapour, methane, nitrous oxides, ozone and fluorocarbons.

Hazard Pathway	A hazard pathway is a natural hazard mechanism (e.g., coastal flooding) that impacts elements exposed to the hazard (e.g., buildings within a coastal flood extent).
Hydrodynamic	A branch of physics that deals with the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them. A hydrodynamic model is a numerical simulation of water movement over a surface, usually a floodplain.
Intertidal Area	The area that is defined by temporary inundation and exposure during the tide cycle by the limits of low tide and high tide. Otherwise known as foreshore.
King Tide	A non-scientific term for spring perigean tides, which are especially high tides occurring three to four times per year.
LiDAR	A surveying method that measures distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor. Stands for Light Detection and Ranging.
Mean Sea Level	The middle (mean or average) of the tidal range. Historically, ~0 m CGVD28.
Overland Flooding	Flood waters flowing from an outside source or body of water onto typically dry land.
Pacific Decadal Oscillation	A robust, recurring pattern of ocean-atmosphere climate variability centered over the mid-latitude Pacific basin that persists for 20 to 30 years.
Return Period	Return period is a way of describing the probability of an event (e.g., a coastal flood water level). Return period is calculated as 1 divided by the annual exceedance probability (AEP). For example, for a 10-year return period event, there is a 1/10=0.1=10% probability in any given year that the event or a larger event will occur. Return period is not the strict frequency of an event, i.e. if a 10-year return period event occurs this year, there is still a 10% probability that will occur next year as well.
Risk	Risk is a function of the probability and severity of a consequence occurring. In the flood risk context, the probability is generally dictated by the hazard and the performance of flood protection infrastructure.
Sea Level	The elevation of the water surface of the ocean at a location and time. Sea level varies due to several processes with a wide range of timescales. This includes tides and storm surges, which affect sea level on hourly and daily scales; climate variability patterns with seasonal and decadal scales; and geologic processes with scales spanning centuries and longer.
Sea Level Rise	The gradual rise in the base sea level due to various processes including thermal expansion of the oceans and loss of glaciers/land ice caused primarily by anthropogenic factors, which have significantly increased the level of greenhouse gases within the atmosphere.
Stillwater Level	The combination of tide and storm surge results in a water surface called the stillwater level. It does not include wave effects (wind setup, wave setup, and wave runup). It is only 'theoretically' still because tidal water levels are always changing with the tide.
Storm Surge	The temporary rise in water level, measured above the astronomical tide water level, due to offshore or near-shore storm processes including pressure changes and wind. Storm surge does not explicitly include wave effects (wind setup, wave setup, and wave runup) in this project.

Topography	The physical appearance of the natural features of an area of land, especially the shape of its surface.
Vulnerability	Vulnerability is the measure of the susceptibility of an asset to the impact of hazards. In terms of people and communities, this can be described as the degree to which an individual or group is unable to cope with the impact of hazards.
Wave Runup	Vertical distance between the mean water level (stillwater level plus wind and wave setup) and the highest point that a broken wave reaches on a shoreline. Wave runup varies with each wave. Given that a particular wind event will generate a spectrum wave heights, wave runup is sometimes reported as the runup distance that is only exceeded by 2% of the waves in the spectrum.
Wave Setup	Local increase in water level due to the momentum of breaking waves.
Wind Setup	A local increase in water level near the shoreline caused by the shear force of a wind blowing over the water surface towards the land.

1. Introduction

1.1 Project Background and Purpose

Bordering on Burrard Inlet and the Salish Sea, coastal areas of the North Shore can expect impacts from sea level rise. Waterfront areas across the North Shore support key Port-related activities and other industries, businesses, homes, transportation and other infrastructure, utilities, recreation areas, coastal ecosystems, natural habitats, culturally sensitive areas, and more.

The District of North Vancouver (DNV), the City of North Vancouver (CNV), the District of West Vancouver (DWV), North Shore Emergency Management (NSEM), Squamish Nation (SN), and the Vancouver Fraser Port Authority (hereafter referred to as the Port Authority (PA)) have partnered to develop a sea level rise adaptive management strategy with technical assistance from consultants, Kerr Wood Leidal Associates Ltd. (KWL) and specialist sub-consultant Davies Transportation Consulting Inc. (DCTI) providing an economic impact analysis for the Port Authority.

The purpose of this Strategy is to foster an understanding of the sea level rise risk across the North Shore, to establish a coordinated set of action areas to manage the risk and, ultimately, to build adaptability and resilience to sea level rise in all three North Shore municipalities, Squamish Nation, and the Port Authority. By undertaking this risk assessment and adaptive management project, the North Shore will be taking important proactive steps to prepare for and manage risks associated with sea level rise hazards including coastal flooding, intertidal area change, shoreline erosion, and creek/sewer backwatering.

This Strategy is intended to provide guidance for the next 10 years and is considered an initial step in what will likely be a multi-decade collaborative initiative. The strategy aims to address sea level rise adaptation from a variety of perspectives, but a major focus is on flood risk assessment and reduction through the application of a variety of policies, land use planning, building floodproofing, and structural flood protection measures.

It should also be noted that this Strategy has been developed under the current BC floodplain management regulatory framework where local governments have broad-ranging responsibilities including approval of development within the floodplain and implementing both structural and non-structural flood mitigation measures, while the Province of BC's role is generally limited to providing guidance. This Strategy should be revisited if the regulatory framework changes significantly.

1.2 Study Area

The study area (Figure 1-1) is the North Shore coastal area from the DNV municipal boundary near Silver Falls (Indian Arm) to Sunset Beach (north of Horseshoe Bay) in DWV, and includes the DNV, CNV, DWV, three SN reserves (Capilano I.R. No. 5, Mission I.R. No. 1, and Seymour Creek I.R. No. 2.), and PA's jurisdiction along the North Shore of Burrard Inlet, extending into the Strait of Georgia. There is a variety of land uses along the shoreline and within the coastal area, including single-family residential waterfront homes, medium to high density residential and commercial development, port terminals and transportation infrastructure, parks and public spaces, and riparian and intertidal habitats.

The study area is located on the traditional lands of the Squamish, Tsleil-Waututh, and Musqueam Nations. In addition to the three Squamish Nation reserves, the Tsleil-Waututh Nation's (TWN) Burrard Inlet Indian Reserve No. 3 is also in the North Shore coastal floodplain. TWN is currently conducting a

Community Climate Change Resilience Planning project and was consulted in this project. This project's technical work products (e.g., flood mapping) exclude the TWN Burrard Inlet I.R. No. 3.

Geographically, the study area is characterized by a narrow band of coastal floodplain. In some areas along the coastline, the land closest to the ocean is comprised of fill placed for both Port and municipal development. Within this area, several steep mountain creeks and gravel bed rivers drain the North Shore mountains and flow southward to the ocean: these features are typically associated with alluvial fans. As presented in Figure 1-1, low-lying areas are well defined on the North Shore as there is typically a sharp increase in slope inland from the shoreline.

1.3 Project Scope and Phases

The main components of the project scope are to:

- Review sea level rise related hazards, including coastal flooding;
- Assess the likelihood of coastal flooding and consequences from economic, social, and environmental perspectives;
- Identify priorities for adaptation using a risk-informed approach;
- Develop adaptation approaches, concepts, and actions;
- Conduct public and stakeholder engagement; and
- Prepare the strategy.

There are five phases to this project.



Phase 1 (Context for Adaptive Planning and Risk Assessment): documents key project and strategy criteria including context and objectives for the partners, and current provincial and local sea level rise policy and criteria.

Phase 2 (Sea Level Rise Flood Hazard): describes sea level rise hazards and maps coastal flood depths and extents for the following 5 scenarios:

- Current sea level, 200-year return period / 0.5% annual exceedance probability storm;
- 0.5 m sea level rise, 10-year return period / 10% annual exceedance probability storm;
- 1.0 m sea level rise, 10-year return period / 10% annual exceedance probability storm;
- 1.0 m sea level rise, 200-year return period / 0.5% annual exceedance probability storm; and
- 2.0 m sea level rise, 200-year return period / 0.5% annual exceedance probability storm.

Flood maps are prepared by projecting peak water levels, estimated using a joint probability of tide and storm surge analysis, on digital elevation models produced from light detection and ranging (LiDAR) data. Flood mapping produced for the strategy does not include wave effects which vary across the study area.

Phase 3 (Consequence and Risk): identifies, maps, and quantifies the consequences of coastal flooding for 2 scenarios, and discusses priorities for adaptation through a qualitative, risk-based approach. The consequence assessment includes physical, economic, social, and environmental consequence themes.

Phase 4 (Sea Level Rise Adaptation Actions): identifies, describes, and evaluates adaptation approaches and concepts across spatial, temporal, and sectoral scales.

Phase 5 (Sea Level Rise Adaptive Management Strategy): outlines the preferred set of actions to be included in the North Shore Sea Level Rise Adaptive Management Strategy, and documents each phase of the process.

Public and stakeholder engagement with the North Shore community and other specific parties is an important component of the project. KWL's scope includes supporting the partners in conducting public and stakeholder engagement for the three municipal partners, leading stakeholder engagement for the Squamish Nation community, and engaging the Port Authority's North Shore-based stakeholders with assistance from KWL's sub-consultant, Davies Transportation Consulting Inc. Public and stakeholder engagement objectives are discussed in Section 3.1.

1.4 Report Outline

This report is structured as follows:

- Section 1 provides a general introduction to the project;
- Section 2 documents the current provincial and local context of each partner organization with respect to sea level rise, and documents key project and strategy criteria;
- Section 3 describes the community engagement approach, including the input received and how that informed adaptation approaches;
- Section 4 outlines the strategic vision and guiding principles of this project;
- Section 5 presents the results of the hazard assessment, including coastal flood water levels and flood mapping;
- Section 6 presents the results of the consequence and vulnerability analyses and identifies the priorities for adaptation using a risk-informed approach;
- Section 7 describes adaptation approaches and initial adaptation concepts for the identified comprehensive adaptation planning zones;
- Section 8 contains the implementation plan, including the next steps.

1.5 Project Team

DNV is the lead partner for project management and administration. DNV's Nicole Foth and Stephen Bridger are the co-project managers.

DNV retained Kerr Wood Leidal (KWL) as the lead consultant. Davies Transportation Consulting Inc. (DTCI) is a sub-consultant retained by KWL to provide economic impact analysis services for the Port Authority.

The primary consulting team members are listed below:

- Erica Ellis, Project Manager;
- Mike Currie, Principal-in-charge and Senior Technical Reviewer;
- David Sellars, Senior Technical Reviewer;
- Amir Taleghani, Project Engineer / Engineer-of-Record (primary report author);
- Robin Hawker, Environmental Planner;
- Jackie Yip, Consequence Analyst;
- Deanna Shrimpton, Water Resources Analyst;
- Patrick Lilley, Senior Biologist;
- Larissa Low, Junior Biologist;
- David Roche, Senior Engineer (risk assessment advisor);
- Eric Morris, Senior Coastal Engineer (coastal engineering advisor);
- Jack Lau, Senior GIS Analyst;
- Tiffany Soh, GIS Analyst;
- Phillip Davies, Transportation Economist (Davies Transportation Consulting Inc.); and
- Darryl Anderson, Transportation Economist (Davies Transportation Consulting Inc.).

1.6 Technical Steering Committee

Organizations

A Technical Steering Committee of representatives from across the North Shore guided the development of the North Shore Sea Level Rise Adaptive Management Strategy. The organizations represented in the Steering Committee are referred to as project partners, and include:

- District of North Vancouver (DNV);
- City of North Vancouver (CNV);
- District of West Vancouver (DWV);
- North Shore Emergency Management (NSEM);
- Squamish Nation (SN); and
- Vancouver Fraser Port Authority (Port Authority, PA).

These project partners represent many, but not all, of the communities and major interest groups on the North Shore. Other organizations including Tsleil-Waututh Nation, BC Hydro, CN Rail, and Metro Vancouver, and Vancouver Coastal Health were informed of engagement opportunities during development of the Strategy.

The Technical Steering Committee enabled ongoing collaboration over the course of the project to develop a strategy that would meet community needs and priorities across the region. This unique collaborative approach supports the development of adaptation approaches that are coordinated and compatible across the North Shore.

Membership

The members of the Technical Steering Committee representing the partner organizations are:

- Nicole Foth, DNV;
- Stephen Bridger, DNV;
- Julie Pavey, formerly with DNV;
- David Matsubara, CNV;
- Matthew MacKinnon, DWV;
- Heather Keith, DWV;
- Jenn Moller, DWV;
- Fiona Dercole, formerly with NSEM;
- John Chapman, NSEM;
- Ronan Chester, Port Authority;
- Sean Smith, Port Authority;
- Kathleen Callow, formerly with Squamish Nation;
- Bob Sokol, Squamish Nation; and
- Jeff Derer, KWL, on behalf of Squamish Nation.

Additional representatives from each Partner organization have attended meetings and provided input over the course of the project.

Role and Objectives

Technical Steering Committee members provided input on project methodologies and deliverables at key milestones throughout the project timeline. Input was provided through 6 interactive committee meetings:

1. Project Initiation Meeting (June 28, 2018)
2. Context Summary & Hazard Assessment Approach (August 28, 2018)
3. Hazard Summary & Consequence Assessment Approach (October 26, 2018)
4. Consequence Assessment Preliminary Results (March 7, 2019)
5. Risk Assessment & Adaptation Priorities (June 20, 2019)
6. Adaptation Measures & Draft Strategy Review (May 21, 2020)

The Technical Steering Committee established a Terms of Reference early in the project timeline, outlining the committee roles, protocols, and objectives for project outcomes.

The Committee's stated objectives for the North Shore Sea Level Rise Adaptive Management project are as follows:

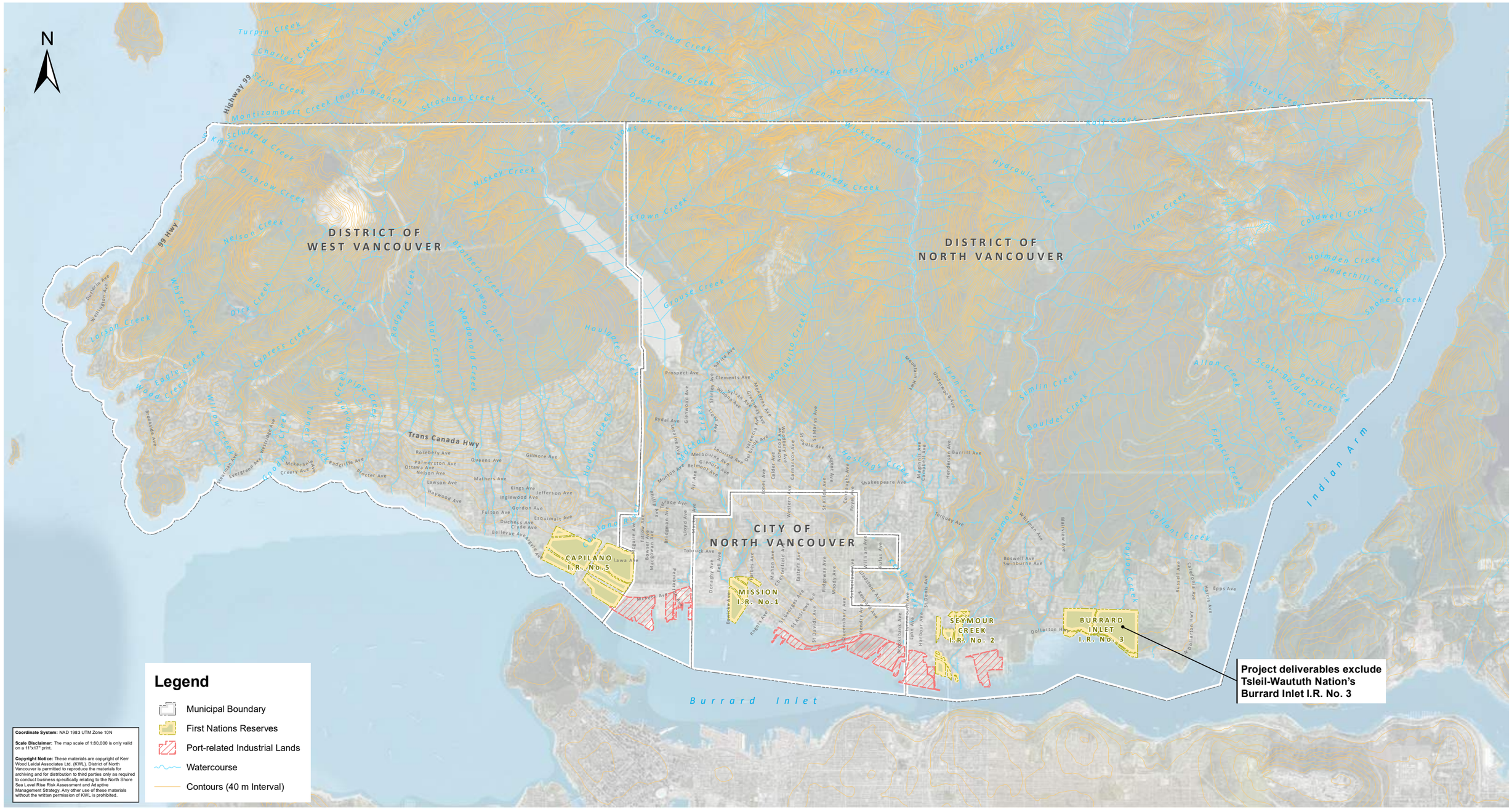
- To map the extent of sea level rise flooding on the partners' jurisdictions based on the scenarios and assumptions agreed upon by the Committee.
- To complete a preliminary assessment of the risks that sea level rise poses to communities (e.g., emergency response, transportation, critical infrastructure) and ecosystems in the partners' jurisdictions.
- To develop a list of recommended action areas and priorities to reduce vulnerability and risk from sea level rise.

- To define policy, process, and engineering options that address top priority risks on affected sites.
- To identify tools and approaches to inform land use planning and development requirements.
- That the above objectives are developed into an integrated Adaptive Management Strategy that responds to high-level goals of the partners' communities, and supports regional collaboration on adaptation.

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adapt

KERR WOOD LEIDAL consulting engineers



Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:80,000 is only valid on a 11"x17" print.

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Project No. 31.548

Date July 2020

Scale 1:80,000

1 0.5 0 1 km

Study Area

Figure 1-1

2. Context

This section introduces the issue of sea level rise, outlines the current provincial policy context, provides the local context of each partner organization with respect to sea level rise, outlines the project timeline and public and stakeholder engagement objectives.

2.1 Sea Level Rise

Sea level is the elevation of the water surface of the ocean at a location and time. Sea level varies due to several processes with a wide range of timescales. This includes tides and storm surges that affect sea level on hourly and daily scales, climate variability patterns (e.g., El Niño Southern Oscillation, ENSO) with seasonal and decadal scales, and geologic processes (e.g., land subsidence or uplift) with scales spanning centuries and longer.

Anthropogenic factors, which are caused or influenced by humans, have led to significantly increased levels of greenhouse gases within the atmosphere, which is resulting in changes to the climate and other processes. These changes include thermal expansion of the oceans, loss of glaciers and land ice, and other factors that are contributing to a gradual and long-term rise in the base sea level. A rise in the base sea level results in overall higher water levels for tides and storm surges.

Sea level rise is one of the indicators of climate change that is monitored and documented by the Province of BC. The following information is summarized from the Province of British Columbia's (Province) 2016 Indicators of Climate Change Report (Ministry of Environment, 2016).

Globally, sea level rose on average 0.17 m relative to land during the 20th century based on tide gauge measurements indicating an average rate of rise of 1.7 mm/year. The average rate of rise has almost doubled in the last 2 decades to 3.2 mm/year.

In Vancouver, relative sea level rose approximately 0.04 m between 1910 and 2014 based on tide gauge observations. In other parts of BC, relative sea level rose more (e.g., 0.13 m in Prince Rupert) and less during the same period (-0.12 m in Tofino where there is a significant ground uplift). Sea level rise projections (discussed below) show an acceleration of the rate of rise beyond the expected rates of land movement resulting in a reduction of the effect of local factors on relative sea level.

Climate Variability and Precipitation Factors

Sea level is affected by local sea surface temperature which is linked to natural climate variability. In the Pacific Northwest region, the two main climate variability patterns are the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). In British Columbia, high sea levels and larger storm surge heights are more likely during the warm phase (El Niño) of the ENSO interdecadal climate variability condition (Abeysirigunawardena et al, 2011).

Freshwater runoff, especially changes in freshwater runoff into and mixing in estuaries can also affect local sea level (Thomson et al, 2008). DNV's Climate Change Adaptation Strategy considers that average annual precipitation is projected to increase by approximately 5% in the 2050s, with increasing high precipitation events. Increasing precipitation, and frequency of high precipitation events, can increase local water levels around estuaries and outfalls during these events.

Land Subsidence and Uplift

Geological processes are also an important consideration for sea level rise planning because they can amplify (land subsidence) or dampen (ground uplift) the effects of global sea level rise. Natural Resources Canada (NRCAN) has conducted research on land subsidence and has published maps of estimated land subsidence rates for the BC coast based on GPS measurements (Lambert et al, 2008). Figure 2-1 reproduces the results from Lambert et al (2008) for the North Shore. The figure shows that land subsidence and ground uplift are both being observed on the North Shore and that there is no single value allowance that can be adopted for the entire study area. Accordingly, the coastal flood depth maps presented in this section do not include an allowance for future land subsidence / ground uplift. However, land subsidence / ground uplift should be considered for site-specific coastal flood hazard assessments and sea level rise adaptation measures. The consideration of land subsidence is particularly important for the determination of site-specific flood construction levels in areas of higher land subsidence rates (e.g., Maplewood Flats).

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 the North Shore (Thomson et al, 2008).

Response to Sea Level Rise – Mitigation versus Adaptation

Sea levels are expected to rise despite efforts being taken now and contemplated around the world to reduce and/or stabilize greenhouse gas emissions. This is due to the slow response signal between ocean thermal expansion and atmospheric temperature, which means the effects may become evident years later. There are two ways to respond to anticipated rising sea levels: mitigation and adaptation. Climate change mitigation refers to efforts made to limit climate change by reducing or preventing greenhouse gas emissions; this may help to reduce the long-term rate of sea level rise. Sea level rise adaptation involves anticipating the changes to sea levels as a result of climate change, and taking action to minimize or prevent the impacts of rising sea levels. This project focuses on sea level rise adaptation, while climate change mitigation would be addressed in other plans or policies of the project partners.

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KERR WOOD LEIDAL consulting engineers

N

DISTRICT OF WEST VANCOUVER

DISTRICT OF NORTH VANCOUVER

CITY OF NORTH VANCOUVER

CAPILANO I.R. No. 5

MISSION I.R. No. 1

SEYMOUR CREEK I.R. No. 2

BURRARD INLET I.R. No. 3

Burrard Inlet

Indian Arm

Project deliverables exclude Tsleil-Waututh Nation's Burrard Inlet I.R. No. 3

Legend

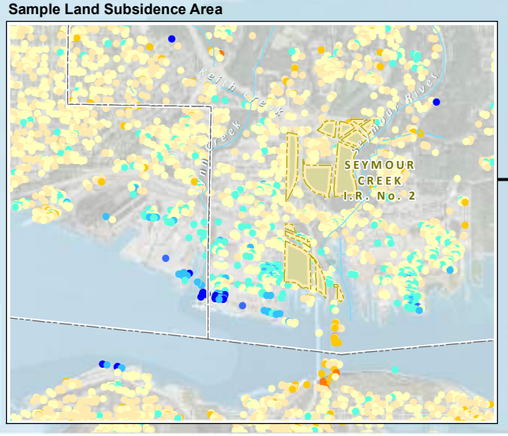
- First Nations Reserves
- Watercourse
- Contours (100 m Interval)

Ground Uplift / Land Subsidence Rates

Uplift Rate (mm/year)

- < -3.5
- - 3 to -3.5
- -2 to -3
- -1 to -2
- 0 to -1
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 3.5

Sample Land Subsidence Area



Source:
Lambert, A., Mazzotti, S., van der Kooij, M., & Mainville, A. (2008). Subsidence and Relative Sea Level Rise in the Fraser River Delta, Greater Vancouver, British Columbia from Combined Geodetic Data. Geological Survey of Canada Open File 5698.

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:80,000 is only valid on a 11"x17" print.

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Project No. 31.548
Date July 2020
Scale 1:80,000

1 0.5 0 1 km

Ground Uplift / Land Subsidence Rates on the North Shore

Figure 2-1

2.2 Province of BC Sea Level Rise Planning Policy

Uncertainty in the magnitude and timing of sea level rise presents a challenge for governments working to adapt to sea level rise. This is particularly true for local governments, which create multi-year plans, review development applications, and manage infrastructure with multi-decadal life cycles.

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

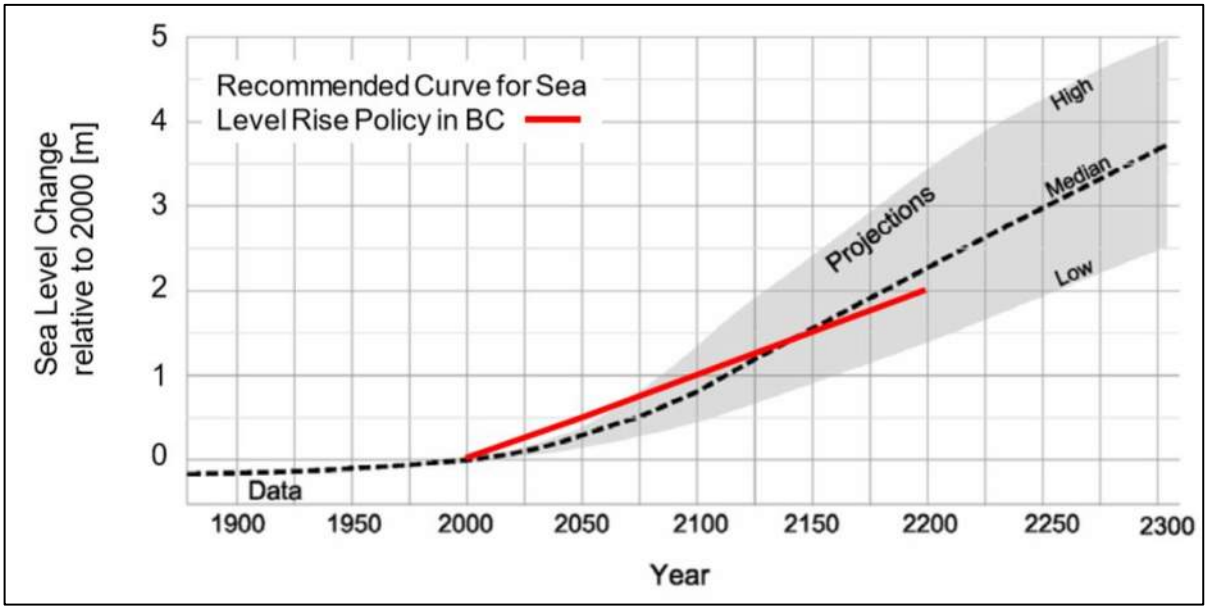


Figure 2-2: Recommended Curve for BC Sea Level Rise Policy (Ausenco Sandwell, 2011)

Using the Year 2000 as a baseline, the Province recommends planning with a linear rate of sea level rise resulting in 1 m of global sea level rise by the Year 2100 and 2 m by the Year 2200. 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.

This project adopts the Province of BC's sea level rise policy, with the following caveats:

- The specific years in which the three levels of sea level rise are anticipated (based on the Province of BC's sea level rise policy) are de-emphasized to avoid implying certainty;
- 2.0 m of sea level rise is viewed more as an accelerated sea level rise scenario than strictly a Year 2200 condition; and
- While not quantitatively assessed, this project will qualitatively consider the effects of further sea level rise (i.e., beyond 2 m) in the development of adaptation measures.

This approach is intended to maintain flexibility in the Strategy, should rising sea levels or policy direction change in the future. An additional intention is to encourage consideration and discussion of which adaptation concepts will be effective across a range of scenarios, and which concepts may be effective only up to a certain threshold and may increase risk above a threshold.

By considering sea level rise scenarios of up to 2.0 m, the project is consistent with approaches used by other municipalities within the Lower Mainland (e.g., City of Vancouver (NHC, 2014)) and other comparable jurisdictions, such as San Francisco (San Francisco, 2016).

In addition to the policy on the rate of sea level rise for planning, the Province has published or contributed to the following documents to provide guidance to local governments and other organizations for sea level rise adaptation planning:

- Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use (Ausenco Sandwell, 2011a; 2011b; 2011c);
    - updated Provincial Guidelines for sea dike design and coastal flood hazard land management to address climate change factors in coastal waters of BC.
- Coastal Floodplain Mapping Guidelines and Coastal Flood Hazard Areas (KWL, 2011);
    - standardized methodology to produce floodplain maps that account for sea level rise for coastal communities.
- EGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC (EGBC, 2018);
    - guides professional practice for flood assessments, to help identify the circumstances when risk assessments are needed and to emphasize the need to consider climate change and land use changes in such assessments.
- Sea Level Rise Adaptation Primer – A toolkit to Build Adaptive Capacity on Canada's South Coasts (Arlington Group, 2013); and
    - offers a toolkit for coastal management authorities to help identify, evaluate and compare options for adapting to the impacts of sea level rise and associated coastal hazards (the Government of Canada published a related document supporting climate change adaptation via Canadian case studies titled Land use planning tools for local adaptation to climate change in 2012).
- Amendment Section 3.5 and 3.6 - Flood Hazard Area Land Use Guidelines (BC MFLNRORD, 2018).
    - offers updated guidance on the consideration of sea level rise and wave effects for flood hazard land use management.

2.3 Regional Context

The Fraser Basin Council (FBC) initiated the Lower Mainland Flood Management Strategy (LMFMS) in 2014 to promote collaborative, regional flood management on the lower Fraser River and the coast of the Lower Mainland. Partners include all levels of government, non-governmental organizations, and the private sector. DNV, CNV, DWV, and the Port Authority are partners on the LMFMS.

The LMFMS is being completed in three phases. Phase 1, completed in 2016, focused on flood hazards, vulnerabilities, and existing structural and non-structural flood protection measures. Phase 1 produced mapping and analysis of flood scenarios (current sea level (0 m of sea level rise), and 1 m of sea level rise by year 2100), regional assessment of flood vulnerabilities, Lower Mainland dike assessment, and a review of flood management policies and practices. This information is available on the FBC website (www.fraserbasin.bc.ca/water_flood.html).

Phase 2, currently underway, is expected to include an assessment of regional flood mitigation options, and an assessment of decision-making models and cost-sharing options. Phase 3 is expected to focus on LMFMS implementation.

2.4 Local Context Statements

The project partners bring varying contexts to the project as they represent different jurisdictions and coastal shoreline areas across the North Shore.

The following context statements have been provided by partner organizations. Relevant local background documents are identified within the statements.

District of North Vancouver

Key DNV plans provide strong direction and support for taking proactive action on climate change. The Official Community Plan (2011) includes objectives and policies to adapt proactively to climate change, to manage shoreline areas, and to integrate climate change perspectives into infrastructure design and maintenance, ecosystem management and emergency preparedness. The Climate Change Adaptation Strategy (2017) recommends strengthening the District's capacity to respond to extreme weather events and climate change - including sea level rise -- and taking steps to protect people, property, and foreshore ecosystems from coastal impacts. Related technical work completed to date includes a Creek Hydrology and Floodplain Mapping assessment for MacKay Creek, Lynn Creek and the Seymour River (Kerr Wood Leidal, 2014) which also examined the impacts of sea level rise to these areas.

City of North Vancouver

The City's OCP (2015) recognizes that including climate adaptation measures to adjust decision-making and activities in response to climate change is central to the City's future. The City continues to investigate and apply updated methods of incorporating climate change considerations into infrastructure design, lifecycle planning, and maintenance that account for the climatic conditions through to the end of the lifespan. The City's Climate Change Adaptation Plan (2013) recognizes that flooding and inundation of coastal, creek and low lying lands due to more intense precipitation and sea level rise presents one of the greatest risks to the City. This plan calls for an ongoing commitment to climate adaptation as an ongoing process, incorporating the best available science and regularly reviewing the City's vulnerabilities, policies, and adaptation actions.

District of West Vancouver

West Vancouver's Official Community Plan (2018) identifies climate change adaptation and mitigation as key issues for the District's future and includes proactive policy directions on both. Specifically related to sea level rise the OCP calls for updating shoreline protection strategies and flood construction level requirements (including the creation of a foreshore development permit area) to further increase protection from sea level rise, reduce shoreline erosion, preserve and enhance habitat and improve public access. The West Vancouver waterfront is unique both in terms of its coastal morphology (including various low-lying areas) and its land uses (which are primarily single-family residential buildings but also include beaches, parks, seawall, civic infrastructure, and natural systems), which require particular policy responses and adaptation strategies. In recent years, West Vancouver's waterfront has experienced severe damages from wave action and erosion including a historical event in 2012. Coastal flooding and other damages to the shoreline are anticipated to be further exacerbated by rising sea levels and increasingly more severe and frequent storm events. Left unchecked, these

processes acting in concert will continue to cause increased capital costs to repair and maintain West Vancouver's waterfront. West Vancouver has developed and is implementing a Shoreline Protection (Adaptation) Plan to maintain and enhance the foreshore to mitigate impacts from wave action and to manage erosion. Implementation involves ongoing efforts to work with the owners of waterfront property to guide involvement in foreshore enhancement and protection. This work has taken on greater urgency with the increasing occurrence of severe storm events and wave action.

North Shore Emergency Management

North Shore Emergency Management is an inter-municipal agency that provides emergency management services for the City of North Vancouver, District of North Vancouver, and District of West Vancouver, with the vision of a disaster-resilient North Shore. NSEM is committed to understanding disaster risk, the vulnerability of our communities to sea level rise and coastal flooding, using this information to strengthen disaster risk governance, and investing in disaster risk reduction for resilience.

Squamish Nation

For the Squamish Nation, descendants of the Coast Salish Aboriginal peoples who lived in the present day Greater Vancouver area, Gibson's landing and Squamish River watershed, the risk from sea level rise are significant. The Nation's present-day reserve locations, on the waterfront, adjacent to the North Shore of Burrard Inlet is occupied by member housing, community facilities, Nation-owned businesses, and urban economic development from which the Nation draws revenue to sustain a thriving community, makes the Nation particularly vulnerable to sea level rise. Understanding potential vulnerabilities and levels of risk from sea level rise is a critical step needed to inform future planning and to ensure ongoing community resiliency and adaptability over time in response to changing climatic conditions.

Vancouver Fraser Port Authority

The Vancouver Fraser Port Authority is Canada's largest port, and the third-largest in North America in terms of annual tonnes of cargo. The port is home to 27 major marine cargo terminals and three Class 1 railroads, offering a full range of facilities and services to the international shipping community. A number of the Port's marine terminals and tenants are located on the North Shore of Burrard Inlet, including, for example, Neptune Terminal, Lynnterm Terminal, Cargill Terminal, and Richardson Terminal.

The Vancouver Fraser Port Authority is responsible for managing federal lands and waters of the Port of Vancouver on behalf of Canadians and in support of national trade objectives. The Port Authority is a non-shareholder corporation established by the Government of Canada in January 2008, under the Canada Marine Act, and is accountable to the Federal Minister of Transport. The Vancouver Fraser Port Authority's vision is to be the world's most sustainable port. The Port Authority maintains a suite of strategic initiatives to advance its vision that include an emphasis on long-term planning and climate change.

2.5 Multi-sector Perspective

Sea level rise adaptation is a multi-decade endeavour that involves various levels of government, many different sectors, and has challenges and opportunities for all members of society. Due to the complexity of sea level rise adaptation in an urban and industrial context, the project is being conducted through the perspective of the six sectors presented in Figure 2-3.

A multi-sector approach to risk assessment and adaptation considering direct and indirect impacts across economic, social, and environmental themes is in line with the United Nations Sendai Framework for Disaster Risk Reduction and supporting guidelines (UNISDR, 2017).

The high-level categories of economic, social, and environmental were refined into six sectors specific to the North Shore by KWL with input from the Technical Steering Committee members. The six sectors reflect the local context of the North Shore and will be considered in the development of adaptation measures. This approach has been used in other jurisdictions, including Tsleil-Waututh Nation (KWL, 2019), the City of Vancouver (NHC, 2014) and the Coast Salish First Nation community of the Swinomish Tribe in Washington state (Swinomish, 2009).

The use of sectors and elements also builds on the Source-Pathway-Receptor model (HR Wallingford, 2005), which is commonly used in flood risk assessments to categorize hazard sources (e.g., sea level rise), impact pathways (e.g., overland flooding), and impact receptors (e.g., buildings).

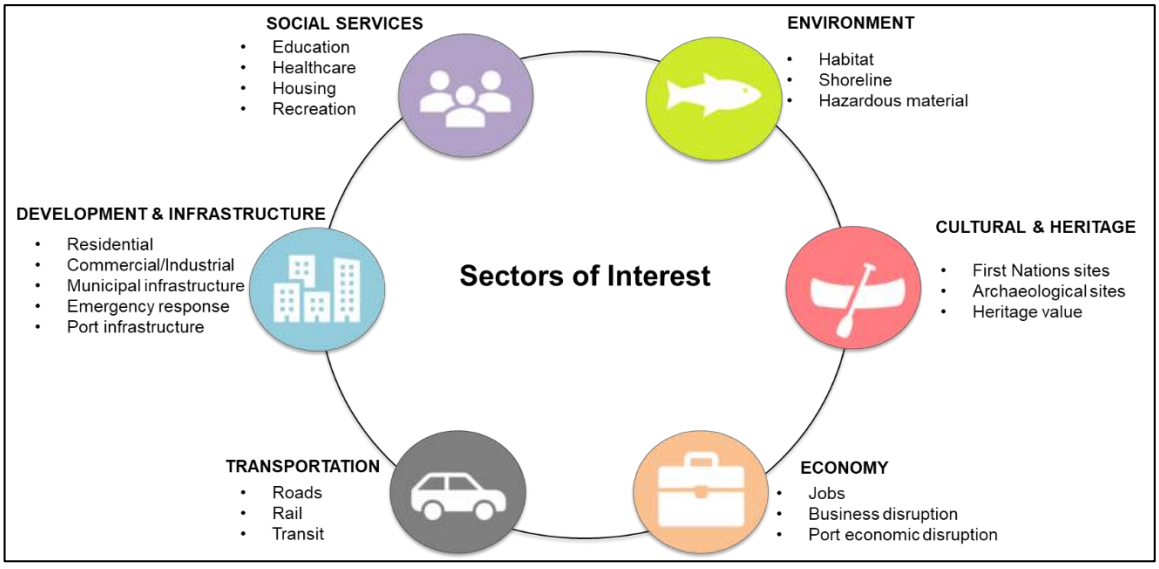


Figure 2-3: Sectors of Interest

The six sectors were used in the risk assessment (Phase 3) and the development of adaptation concepts (Phase 4) as follows:

- **Phase 3** describes the impacts to the sectors from sea level rise related coastal flood events and uses a risk-based approach to identify which sectors and particular elements within the sector are high priorities for adaptation.
- **Phase 4** identifies adaptation approaches, concepts, and actions to manage risks across the sectors, including concepts that benefit all sectors and others that target specific sectors.

2.6 Project Timeframe

The partners acknowledge that this project and resulting Strategy are an initial step in what will likely be a multi-decade collaborative initiative.

The Strategy informs actions over a 10-year period.

The project aims for a flexible Strategy for changes to sea level rise science and public policy. However, the Strategy may need to be revised earlier than 2030 if unforeseen conditions arise.

3. Community Engagement

Community engagement plays a critical role in any planning process to build an understanding of the drivers for action and to gather input on proposed approaches to align with community values and priorities.

Sea level rise has the potential to affect communities on the North Shore in broad and diverse ways and will require ongoing decision-making to consider trade-offs and opportunities for North Shore collaboration. A range of different policy and structural approaches will be needed to address coastal flood hazards, which would be implemented gradually and may have significant associated costs.

Building community awareness and understanding of sea level rise risks and adaptation enable informed community input, adaptation approaches that reflect community priorities and values, and buy-in for future states of planning and implementation.

Community members, businesses, and other key stakeholders across the North Shore were invited to provide input on the impacts of sea level rise and adaptation approaches. All information presented through engagement was drawn from the Draft Strategy and posted on the project website (https://www.dnv.org/sea level-rise-strategy).

This section presents the engagement approach taken for this Strategy, outlining the objectives of engagement, the initiatives taken and their associated timelines, input received over the course of the project, and how that input informed the development of adaptation approaches proposed in this Strategy.

3.1 Engagement Approach

The community engagement approach was coordinated among North Shore partners to 'speak with one voice' with the public and stakeholders (e.g. port operators) within their jurisdictions.

Objectives

The community engagement objectives for this project are as follows:

- **Raise awareness, inform, and educate** about sea level rise and North Shore coastal flood risks by translating results of the project's technical work into publicly-accessible information;
- **Gather input from public**, internal and external stakeholders by providing opportunity to
    - learn about North Shore coastal flood risks,
    - review potential adaptation approaches and measures, and
    - comment on potential adaptation concepts and measures, and share their ideas, concerns, issues, and priorities;
- **Foster discussion of potential trade-offs and co-benefits** from managing coastal flood risk, while acknowledging each partners' unique coastal areas and land uses; and to
- **Communicate Strategy development**, project progress, and engagement opportunities and results

Initiatives & Schedule

Engagement initiatives included a combination of North Shore-wide initiatives administered by the District of North Vancouver on behalf of all North Shore partners, and individual initiatives led by each partner within their jurisdiction. Initiatives and associated timeframes are shown in Table 3-1, with shared initiatives shown in bold.

Table 3-1: Initiatives and Associated Timeframes

Engagement Phase	Engagement Initiatives
Internal Introduction (April – Dec 2019)	• Presentations to staff • PA meetings with port terminal operators
Engagement #1 Concerns & Priorities (Jan – Mar 2020)	• **Website with project video and details on project progress** (launched Jan 21, 2020) • **Online survey #1** (Jan 21 – Mar 9, 2020) • Present progress to Councils • Communications including newsletter articles (Squamish Nation), social media, letters to landowners and emails to stakeholders • Local workshops for residents, owners, Squamish Nation Elders, and key community groups, including feedback on approach (DNV: Feb 11 – Mar 8, 2020, SN: Nov 2019 – Mar 2020)
Engagement #2 Draft Strategy Review (Sep – Dec 2020)	• **Online survey #2** (Sep 1 – 22, 2020) • Communication with previous participants (e.g. email list) and stakeholders • Present draft Strategy to staff, Councils, and Boards
Final Strategy (Feb – Apr 2021)	• Present final Strategy to Councils and Boards

Note: shared engagement initiatives by the partners in bold. Initiatives not in bold were optional, individually led by each partner

3.2 Input Received

Input and feedback from members of the public and key stakeholder groups have been summarized and used to inform the adaptation approaches defined in this Strategy. Each project partner gathered and summarized feedback from the individual engagement initiatives they led in their jurisdiction. Themes from engagement, by phase, are described in this section with engagement summaries compiled in Appendix A: Engagement Summaries

Details on feedback provided by port terminal operators are outlined in Section 6.3 and Appendix E.

Engagement #1 – Concerns & Priorities

This phase of engagement aimed to introduce the project, build community understanding of sea level rise concepts and potential consequences on the North Shore, learn about community concerns and priorities, and get feedback on preliminary adaptation approaches and principles.

More information on the topics discussed as part of this engagement is provided on the project website (https://www.dnv.org/sea level-rise-strategy) and in Section 6 (Consequence and Risk Assessment) and Section 7 (Adaptation Approaches) of this Strategy.

Community input during this phase was gathered from the following engagement initiatives:

- Online survey #1 (77 responses received);
- District of North Vancouver Community Workshops (48 attendees across 3 workshops);
- Squamish Nation Elders Meetings (three meetings with approximately 20 people per meeting); and
- Squamish Nation Community Members Open House (1 meeting with 6 attendees).

Feedback received during this phase through the survey and workshops is grouped under four topics:

General Awareness & Process

Adapting to sea level rise is a public high priority, with almost 50% of survey respondents reporting being somewhat or much more concerned about it relative to other issues. There is a general understanding of the challenges at hand and the need for ongoing, long-term planning.

Many people highlighted that this project is important and noted that we need to begin preparing for sea level rise now, while also continuing to build community awareness and understanding of climate change and sea level rise.

Respondents felt that community members hold knowledge to contribute to decision-making and should continue to be involved in coastal adaptation planning, with information shared in a relatable way.

Respondents also agreed that groups across the North Shore need to continue working together, including municipalities, industry, utilities, and the Province. Though building political consensus may be difficult, Partners should be accountable and offer “their best effort”. There can’t be any gaps.

What Matters Most

Engagement #1 initiatives asked community members to share information on how sea level rise could affect their lives, including what coastal areas are most important to them and what concerns they have about potential sea level rise impacts.

Survey respondents selected their “top three places” on the North Shore. The most frequently selected places were Homes and residences (53%), Nature and coastal ecosystems (39%), and streets and ways of moving around (32%).

District of North Vancouver workshop attendees were particularly concerned about sea level rise impacts to people (e.g., health and homes), transportation & infrastructure (e.g., roads), and the economy (e.g., shops, businesses, industry, access, and jobs). Workshop attendees were also concerned about impacts to natural areas (erosion, habitat impacts, and potential contamination), and there was particular concern about the need to protect the Norgate residential area.

Squamish Nation members and Elders noted that protecting members and families is their highest priority. Elders also noted the importance of protecting the cemetery and St. Paul’s Church. The Squamish Nation community also raised concerns about how sea level rise could affect creek water

quality (e.g., salt wedge and cross-contamination from contaminated lands and sanitary infrastructure). Nation members highlighted that It is important that adaptation strategies consider future generations and how conditions and needs may change over time.

Feedback on High-Level Adaptation Approaches

Workshop attendees and survey respondents were asked to comment on which approaches to adaptation they preferred. The adaptation approaches proposed were adapted from those in the Province of BC's Sea Level Rise Adaptation Primer (2013) and include:



Resist: Focus on structural measures such as building dikes to reduce the likelihood of flooding.



Accommodate: Focus on non-structural adaptation measures, including consciously acknowledging flood risk, defining how much risk we are willing to tolerate, and raising livable spaces in areas vulnerable to flooding.



Avoid: Focus on land use planning to avoid building or adding more in areas that are vulnerable to flooding, or by gradually relocating buildings and infrastructure away from areas at risk of flooding.



Advance: Reclaim land to make space for structures such as dikes, which can reduce the likelihood of flooding in coastal areas. Reclaimed land could be used for wildlife habitat, recreation, or other purposes.

More detail on these four approaches is described on the project website and in Section 7.1.

Responses to the survey were the primary source of feedback on adaptation approaches.

Survey respondents were asked to rank which criteria should be most important for designing adaptation measures (survey question 8). The criteria most frequently ranked as "important" or "very important" were low environmental impact (53%), effectiveness (53%), and adaptability (52%).

A key theme in comments throughout the survey and workshops was that adaptation should be proactive and provide other benefits to natural systems and communities e.g., habitat enhancement, nature-based solutions, creating new areas for recreation and greenspace.

Survey respondents were also asked to provide input on which of the four adaptation approaches they preferred, with comments on key considerations for implementation (survey question 9). Results suggest that respondents preferred "avoid" approaches overall (47% support), followed by "resist" and "accommodate" (23% support each), and with "advance" as the least preferred (1% support). Table 3-2 shows additional feedback provided on the four approaches, based on feedback received during workshops led by the District of North Vancouver and Squamish Nation.

Table 3-2: Feedback Provided on the Four Approaches

Approach	Survey Results	Concerns and Questions (Workshops)	Possible Strategies (Workshops)
Avoid	14 of 30 respondents support this (47%)	costs and implementation, limited availability of land to move to, equity issues of who should move, impacts to property values and privacy, and policy changes required.	Importance of preventing new development in high-risk areas.
Resist	7 of 30 respondents support this (23%)	land requirements, lifecycle costs, environmental impacts, potential impacts to neighbouring properties, and policy changes required.	Particularly suitable in waterfront industrial areas. Consider a sea dam, raising the existing seawall and CN railway, flood gates on creeks.
Accommodate	7 of 30 respondents support this (23%)	How to implement with limited property space or non-building assets (e.g., roads), how it works with other natural hazards and policy changes required. Emergency response and management is important so people have a safe place to go.	Consider wet flood-proofing, working with land owners (e.g. PA) and regulatory agencies (e.g. Province), and raising or floating houses.
Advance	2 of 30 respondents supported this (1%)	Environmental impacts, costs, and implementation approaches.	Particularly in waterfront industrial areas or where filling has already occurred:

Who Should Pay?

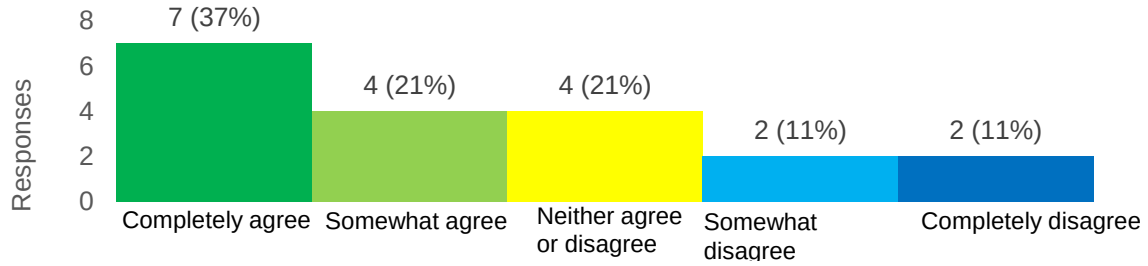
Managing costs and responsibilities (e.g., who should pay) was raised as an important discussion topic in all meetings and workshops. 65 respondents ranked which groups should cover a higher proportion of adaptation costs. Of the 38 respondents who live within the planning area, the highest proportion (63%) suggested that senior levels of government should cover the highest proportion of adaptation costs. In contrast, the highest proportion of respondents living outside of the planning area (17 of 27, 63%) felt that land owners in flood risk areas should pay the highest proportion of adaptation costs.

Engagement #2 – Draft Strategy

This phase of engagement aimed to gather feedback from the public on the draft Strategy document to inform updates to the final Strategy. This phase of engagement occurred in September 2020 and focused on an online survey to gather feedback in a way that was accessible under the Government of BC Public Heath Orders related to the coronavirus pandemic.

The survey was hosted on the project website (https://www.dnv.org/sea level-rise-strategy) for a period of three weeks between September 1 – 22, 2020. The online survey was accompanied by summary information highlighting key aspects of the draft Strategy, and a copy of the complete document. Each project partner was responsible for advertising the survey (e.g. through notification emails) and encouraging responses from their constituents. The survey was also distributed to key community partners, including Metro Vancouver, Tsleil-Waututh Nation, and infrastructure asset owners.

Overall, 19 residents responded to the survey, all from the District of North Vancouver. More than half of respondents felt that the strategy points the region in the right direction for sea level rise adaptation. Results from this question in the survey are shown below:



Survey respondents also shared feedback through open-ended questions, with comments emphasizing support for a range of adaptation approaches described in the draft Strategy, including:

- implementing sea level rise regulations for new and existing development (3 comments);
- leading more education and awareness about the sea level rise (2 comments);
- supporting “avoid” or “accommodate” approaches (1 comment);
- supporting nature-based adaptation measures (1 comment);
- prioritizing the protection of the natural environment as the most cost-effective long-term solution (1 comment);
- supporting dikes in Maplewood (1 comment);
- *not* supporting dikes or building close to waterways (1 comment).

Open-ended feedback on whether sea level rise planning should continue to be a priority was mixed. While 3 respondents emphasized general support for ongoing sea level rise adaptation planning, 1 respondent expressed concern that sea level rise impacts were too far in the future to plan for today, 1 suggested that earthquake preparedness was a more immediate priority, and 2 respondents noted that they didn't feel like much sea level rise would happen. On the other hand, 1 respondent noted that some properties on Indian Arm already experience flooding during storms.

Further detail on results from the survey are provided in Appendix A.

3.3 Informing Adaptation Approaches

Input received through community and port operator engagement has directly informed the development of adaptation strategies in the following ways:

- General comments and feedback on what matters most informed the development of the strategic vision (Section 4.1) and adaptation measures listed in the toolkit (Section 7.2) (e.g., the importance of ongoing education, engagement, and regional collaboration);
- Feedback from survey respondents on the strategic principles led to the refinement of the principles (Section 4.2), which will also inform measuring implementation progress and monitoring success (Section 8.4);
- Feedback provided during workshops with port terminal operators informed the adaptation measures toolkit (Section 7.2) and comprehensive adaptation planning zone concepts (Section 7.4) (e.g. land raising balanced with industrial access to water needs and infrastructure lifespans);
- Specific areas identified as highly important and survey responses ranking design criteria have been reflected in comprehensive adaptation planning zone concepts (Section 7.4) (e.g., protecting the Norgate neighbourhood and residential areas);
- General comments on adaptation approaches and preferences and survey responses ranking design criteria informed the balance of measures included in the adaptation toolkit (Section 7.2);
- Concerns raised about adaptation approaches have been reflected as pros/cons in the "adaptation approaches" section of the Strategy (Section 7.1);
- Comments regarding who should pay have been considered in the funding section of the Implementation Plan (Section 8.3).

4. Strategic Vision & Principles

This section states the strategic vision for sea level rise adaptation on the North Shore, as well as outlining guiding principles for adaptation planning.

The strategic vision and principles set a shared direction to support ongoing coordination and implementation of sea level rise adaptation measures moving forward. They were developed based on community priorities and guidance from the project Steering Committee and informed the development of adaptation measures and concepts in this Strategy. The vision and principles will also guide the ongoing measurement and evaluation of Strategy implementation over time.

4.1 Strategic Vision

The strategic vision for adapting to sea level rise across the North Shore is:

"To work together to reduce risk and strengthen community resilience to sea level rise across the North Shore."

The vision is about more than working together; it's about respecting the unique priorities and contexts of each community while setting a commitment to coordinate approaches so that actions in neighbouring communities are compatible over the long term.

4.2 Guiding Principles

The guiding principles for adaptation planning and implementation are below. The guiding principles draw on the UN's Sendai Framework for disaster risk reduction.

Proactive	**Sea level is rising and we have time to prepare if we begin planning now.** Areas at risk of flooding due to sea level rise will be affected unless we take proactive steps to minimize the impact.
Adaptive	**Flexibility in the face of uncertainty and adaptive to the needs of future generations.** New scientific and technical information informs our decisions. Adaptation should prepare us for a range of scenarios in the future, including changes in the pace and height of sea level rise over time.
Risk-Based	**Decisions are risk-based and consider impacts to different sectors: environment, economic, and social.** Adaptation actions aim to strengthen resilience across the North Shore to reduce existing risk, prevent new risk, and increase preparedness for response and recovery.
Coordinated	**Collaboration across all levels of government and industry.** Each actor has a shared commitment and is accountable to build resilience across the region.
All-of-Society	**Everyone has a role**. Adaptation actions are implemented in an equitable way, with an effort to support vulnerable groups and consider multiple values wherever possible (e.g., environment, social, economy, culture, recreation, residents).
Informed Decision-Making	**Education and awareness building allows the public to provide informed input into decision-making processes.** Openly communicating flood risks, and being transparent about adaptation planning as it evolves, helps ensure our communities have a shared awareness.

5. Hazard Analysis

This section describes the primary sea level rise-related hazards which are relevant for risk assessment and adaptation planning.

Sea level rise affects many aspects of the built and natural environment on the North Shore. In this study, the effects are described through a series of hazard pathways, including:

- Tides and intertidal area change (coastal squeeze) (Section 5.1);
- Coastal overland flooding (Section 5.2);
- Riverine backwater flooding (Section 5.3);
- Drainage system surcharge (Section 5.4);
- Wave effects and shoreline erosion (Section 5.5); and
- Tsunami flooding and erosion (Section 5.6).

The main analytical focus of the hazard analysis is on the coastal stillwater (no waves) overland flooding pathway (Section 5.2), but other hazard pathways are included for completeness and are discussed qualitatively and/or with reference to an existing analysis by others. Other hazards that may be impacted by sea level rise, such as groundwater impacts and linkages to liquefaction vulnerability, are not discussed in the Strategy but may need to be included in future revisions of the Strategy as these topics emerge further.

Knowledge gaps, and potential future actions to address them, are summarized at the end of the sub-section for consideration in the development of the adaptive management Strategy.

5.1 Tides and Intertidal Area Change

The intertidal zone is the area of marine foreshore that is exposed at low tide and inundated at high tide. Rising sea levels affect the location and extent of the intertidal zone depending on the shoreline topography.

The impact of sea level rise on tides is important to consider because sea level rise increases where the high tide and low tide are located on the shoreline, and therefore can change the intertidal zone.

The Strait of Georgia and Burrard Inlet experience a mixed, semi-diurnal tidal regime meaning that 2 high tides and 2 low tides of varying sizes are experienced each day. The highest and lowest tides of the year are experienced during the periods of November to January and July to August; the tides in these periods are known as spring perigean tides, or popularly ‘king tides’.

Tides within the study area are described by the following two tide gauges operated by the Canadian Hydrographic Services (CHS):

1. Pt. Atkinson (CHS station # 7795); and
2. Vancouver (CHS station # 7735).

Table 5-1 provides the tidal statistics for Pt. Atkinson and Vancouver, which describe average and extreme tide conditions.

Table 5-1: North Shore Tidal Statistics

Tide Statistic	Description	CHS Station, Elevation (m, CGVD28)	
		Vancouver	Pt. Atkinson
Lower Low Water Large Tide (LLWLT)	The average of the lowest low waters, one from each of 19 years of predictions.	-2.9	-3.0
Lower Low Water Mean Tide (LLWMT)	The average of all the lower low waters from 19 years of predictions.	-1.8	-1.9
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	1.4
Higher High Water Large Tide (HHWLT)	The average of the highest high waters, one from each of 19 years of predictions. Typically considered the extreme upper end of the tide cycle.	2.0	1.9
		Range (m, not an elevation)	
Extreme Tide Range	Difference in LLWLT and HHWLT.	4.9	
Average Tide Range	Difference in LLWMT and HHWMT.	3.3	

The tidal regime is generally similar throughout the study area. Tidal elevations within Burrard Inlet (Vancouver station) are slightly (0.1 m) higher than outside of the inlet (Pt. Atkinson). This is likely due to the shape of Burrard Inlet as well as river inflow (from Indian River, Seymour River, Lynn Creek, etc.).

The majority of the study area is located within Burrard Inlet and therefore the Vancouver CHS station has been used as the basis for water levels used in the hazard assessment. The lower 0.1 m tide height for the Pt. Atkinson CHS station should be reflected in the development of adaptation measures for areas located west of the Lions Gate Bridge (District of West Vancouver and a portion of SN's Capilano I.R. No. 5).

The intertidal area is defined by temporary inundation and exposure during the tide cycle by the limits of low tide and high tide. Intertidal areas provide a variety of ecosystem and societal benefits, including habitat for aquatic species and recreational/cultural spaces (e.g., Ambleside beach).

Sea level rise shifts the intertidal area up in elevation, which often is further inland.

Table 5-2 presents the tidal elevation range for a range of sea level rise scenarios using the average high and low tide statistics in Table 5-1.

Table 5-2: Intertidal Area Elevation Bounds With Sea Level Rise

Intertidal Area Bounds	Vancouver CHS Station, Elevation (m, CGVD28)			
	Current Sea Level	0.5 m Sea Level Rise	1 m Sea Level Rise	2 m Sea Level Rise
Average Lower Bound of Intertidal Area (LLWMT)	-1.8	-1.3	-0.8	0.2
Average Upper Bound of Intertidal Area (HHWMT)	1.5	2.0	2.5	3.5

Flooding from sea level rise increases gradually over time. High tide flooding is the first and most frequently experienced sign of sea level rise. For example, sea level rise may initially cause shallow, infrequent flooding during only the highest tides of the year. As the sea rises, flooding would increase in depth, frequency, and could cover a larger area potentially causing greater damage and access issues throughout the stormy season that could amount to potentially deep sub-daily tidal flooding. This range of high tide flooding impacts is presented conceptually in Figure 5-1. For the sake of simplicity, the levels in the figure show the water levels caused by astronomical tide alone (excluding other factors affecting water levels like storm surge, wave effects, etc.).

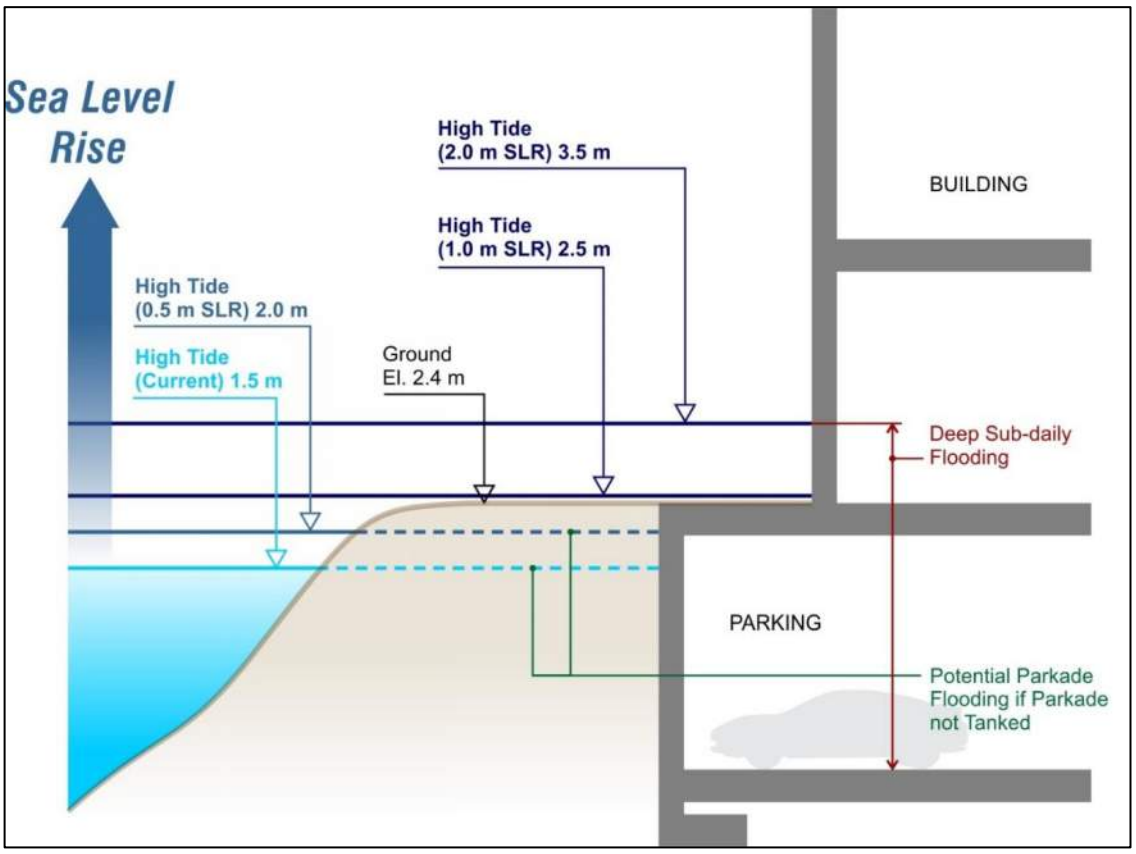


Figure 5-1: Illustrative Example of High Tide Flooding Impacts as Sea Level Rises

Intertidal Area Change (Coastal Squeeze) Analysis

As described above, the intertidal area is defined by low tide and high tide elevations. As sea level rises, the low tide and high tide elevations increase and where they intersect with the land changes as well, shifting 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” as depicted in Figure 5-2.

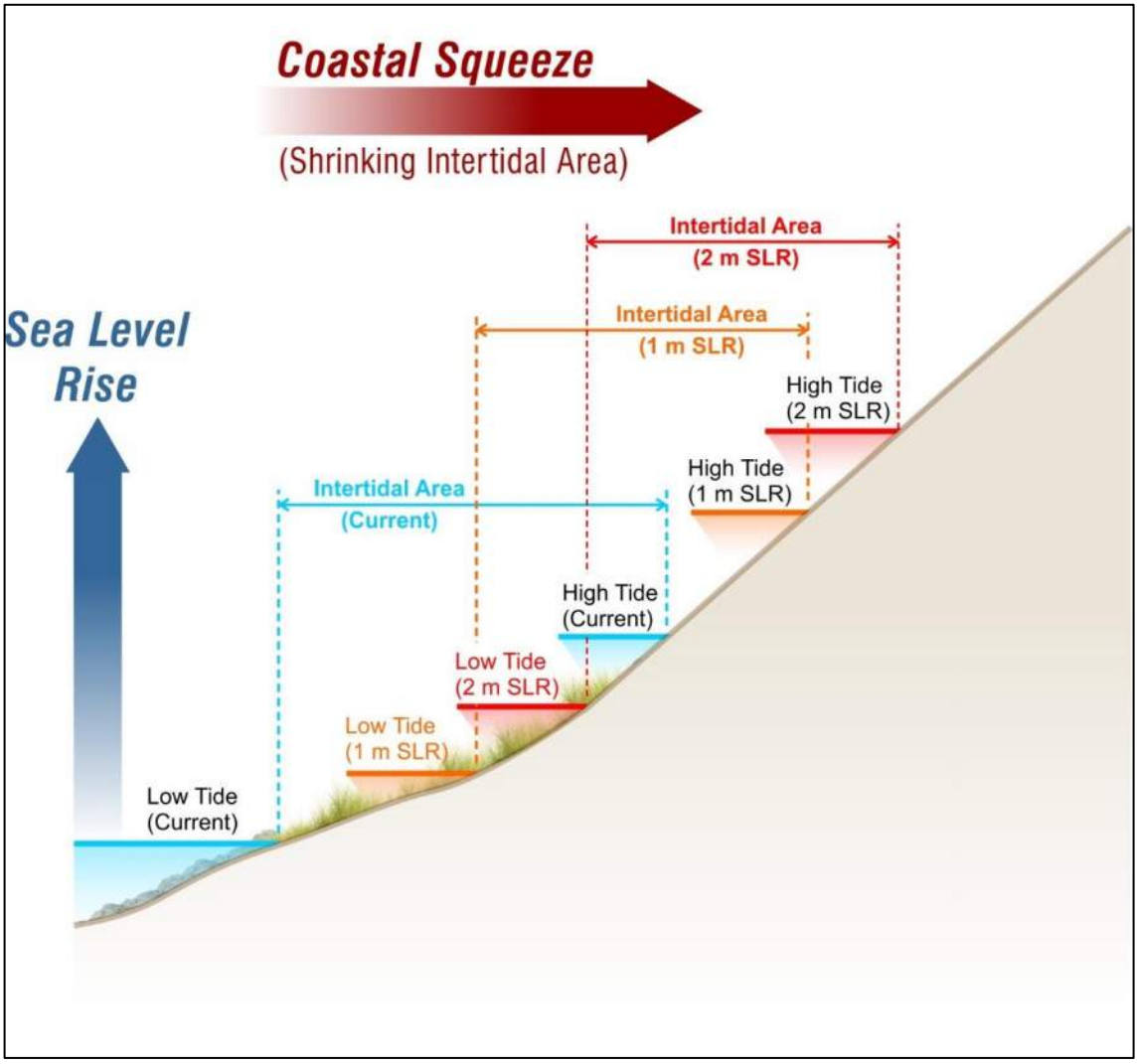


Figure 5-2: Illustration of Coastal Squeeze (Intertidal Area Change)

A high-level intertidal area change analysis was conducted using available topographic data to indicate the potential for coastal squeeze on the North Shore. The North Shore has a variety of shoreline typologies ranging from steep, rocky shorelines (e.g., along Indian Arm) to low-lying relatively flat creek/river alluvial fan areas (e.g., Mackay Creek fan in Norgate). In the low-lying relatively flat areas, the extent of future intertidal areas is closely linked with future shoreline land-use decisions.

In areas where the future average high tide elevation (refer to Table 5-2) exceeds the elevation of the existing shoreline top of bank, the intertidal area would theoretically expand into current inland areas. A range of land-use adaptation responses are possible, including implementing land uses that would welcome the intertidal area expansion through managed retreat and naturalization (e.g., parks and habitat conservation areas) and constructing vertical barriers (e.g., seawalls, dikes, etc.) to prevent land from tidal inundation; the latter approach resulting in coastal squeeze.

In this high-level analysis, the two extreme ends of the spectrum in response options are considered: a managed retreat approach (allowing high tide expansion into inland areas) and a prevent approach (vertical walls to keep the high tide line where it is now). Other response options are discussed in Section 7.

Table 5-3 presents the results for estimated intertidal area change under each approach for 1 m and 2 m sea level rise scenarios. These scenarios are separate from Scenarios A through E used for the broader hazard assessment, as intertidal area change isn't tied to temporary inundation during an extreme storm; rather, it is governed by the gradual upward shifting of the tidal range.

Due to topographic data limitations, the analysis area was limited to between Point Atkinson in the District of West Vancouver to North Woodlands along Indian Arm in the District of North Vancouver. It is important to note that this analysis approach has limitations and is intended only as a high-level indication to show that coastal squeeze is an important topic to consider in adaptation planning.

One of the key limitations is that the analysis approach assumes that shoreline and floodplain topography is stationary in the future, whereas, in reality, it is possible that shoreline geomorphology changes in response to sea level rise.

Table 5-3: Predicted Intertidal Area Change Under Different Coastal Adaptation Scenarios for 1 m and 2 m of Sea Level Rise

	Current Intertidal Area (2009, m^2)	Managed Retreat and Naturalization – Allow High Tide Expansion Into Inland Areas		Resist - Vertical Walls at Current High Tide Line	
		Net Change in Intertidal Area (m^2)	Future Intertidal Area (~Year 2100) (m^2)	Net Change in Intertidal Area (m^2)	Future Intertidal Area (~Year 2100) (m^2)
1 m SLR	1,906,340	-690,100 (-36%)	1,216,240	-950,890 (-50%)	955,450
2 m SLR	1,906,340	+497,300 (+26%)	2,403,640	-1,540,620 (-81%)	365,720

Note: Areas rounded to nearest 10 m^2

The results show that under a "managed retreat" approach, 1 m of sea level rise would result in a net loss of intertidal area of 36% and 2 m of sea level rise would result in a net gain of 26%. The latter reflects that additional inland areas that would become intertidal areas in the future under 2 m of sea level rise under a managed retreat and naturalization approach. This is due to the topography of the North Shore at the waterfront, an example of which is a steep overhang directly at the water's edge, followed by a flat area behind. The results show that in many areas, the flat area is inundated by average high tide in the 2 m sea level rise scenario, but not in the 1 m sea level rise scenario.

Under a "resist" approach, there is a net loss of intertidal area in both scenarios: 50% for 1 m of sea level rise and 80% for 2 m of sea level rise. Such a significant loss of intertidal area would have wide-ranging impacts on ecosystems and recreational/cultural areas. This is discussed further in the intertidal area consequence assessment sub-section in Section 6 of the report.

The analysis described above utilizes an extreme application of two sea level rise adaptation approaches (managed retreat and resist). Other response approaches are discussed further in Section 7 of the report. As discussed later, it is anticipated that a variety of approaches will be applied along the North Shore shoreline. The net change in intertidal areas on the North Shore will depend on the balance between opportunities to apply managed retreat to accommodate or encourage new intertidal areas and areas where development and/or industry will result in coastal squeeze.

5.2 Coastal Overland Flooding

Coastal flooding occurs when a combination of tide and storm surge causes the ocean water level to exceed the elevation of the top of the shoreline and floodwaters to flow overland onto the coastal floodplain. Figure 5-3 depicts the water level components of a coastal flood event.

Storm surge is a moderately short (i.e., days to weeks) rise in water level, measured above the tide water level, due to offshore or near-shore storm processes including pressure changes and wind. The maximum recorded storm surge height on the North Shore is approximately 1 m (recorded at Pt. Atkinson in 1965).

Stillwater levels are the water levels observed during a flood, which are the combination of tide and storm surge. Tide and storm surge are physically separate processes, and there is no correlation between them (i.e., their combinations are random). However, the highest stillwater levels on the North Shore typically occur in the winter period when storm surge weather events are more likely to occur.

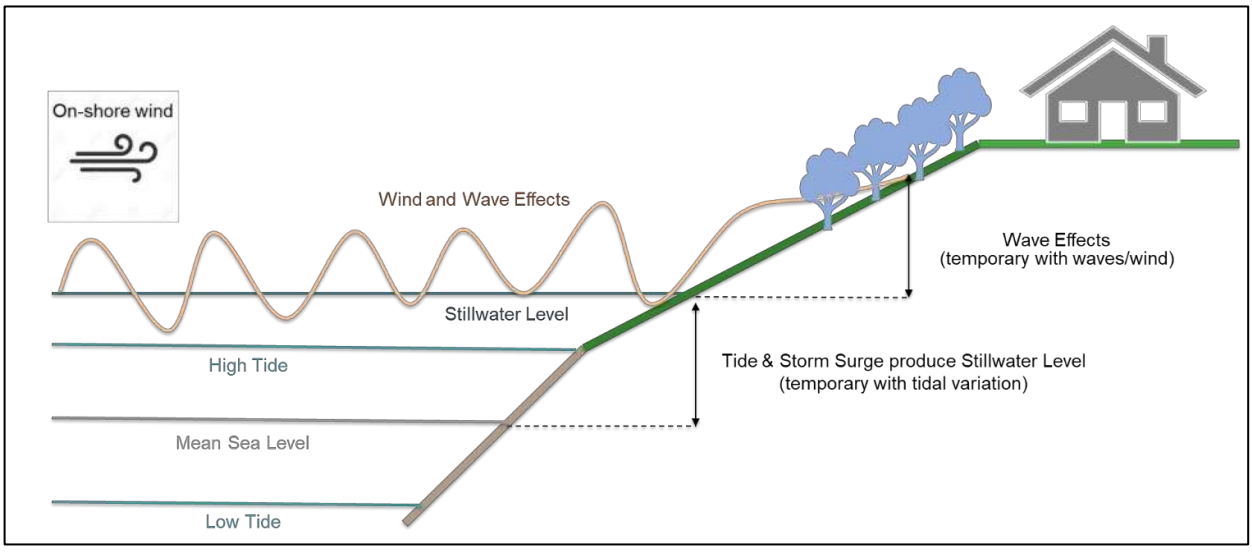


Figure 5-3: Coastal Flood Water Level Components

In addition to the stillwater level, there are wave effects, including wave setup and wave runup. Wave effects are an important consideration for the design of waterfront structures that could be directly impacted by waves. On wider coastal floodplains, wave effects may gradually diminish further inland due to reduction in wave energy. Wave effects are discussed further in Section 5.5.

Stillwater Level Analysis

The frequency-magnitude relationship for stillwater levels has been assessed using KWL's in-house joint coastal water level frequency analysis tool. The analysis was previously used to support Phase 1 of the Fraser Basin Council's Lower Mainland Flood Management Strategy and additional detail on the analysis is provided in the associated report (KWL, 2015). Table 5-4 presents a summary of results for the North Shore, using the CHS Vancouver station, which is generally representative of the study area.

Table 5-4: North Shore Coastal Flood Stillwater Level Frequency and Magnitude (without sea level rise)

Return Period	Annual Exceedance Probability	Water Surface Elevation[1] (m, CGVD28)
Annual Average Maximum Stillwater Level		2.3
10-year	10%	2.5
50-year	2%	2.6
100-year	1%	2.7
200-year	0.5%	2.8

Notes:
1. Based on joint coastal water level analysis using Vancouver (CHS station # 7735). Water levels for Pt. Atkinson are typically 0.1 m lower. Values are based on recorded water levels and do not include projections of sea level rise, which is discussed later.
2. Refer to (KWL, 2015) for additional discussion.

The stillwater level analysis results presented above are based on historic data and do not reflect projected climate change impacts such as sea level rise. Sea level rise amplifies the coastal flood hazard by increasing the base sea level above which the stillwater level occurs. Accordingly, sea level rise can be factored into the analysis by addition of an assumed sea level rise height (e.g., the 200-year return period stillwater surface elevation is 2.8 m CGVD28 based on historic data and would be 3.8 m CGVD28 under a 1 m sea level rise scenario).

There are other potential impacts of climate change on coastal flooding, such as increased storm surge magnitude, frequency, or both, however, there is currently no relevant planning guidance on this subject. A brief literature review was conducted confirming that there are no local projections of future storm surge available at this time. Some projections for New York City were found (Garner et al, 2017), which indicates that there could be a future local research direction. While not directly related to storm surge height, Hagos et al (2016) project a 35% increase in the number of landfalling 'atmospheric river' type storm days between 1980 and 2080 for western North America. Their research focuses on future precipitation projections; other researchers have found that atmospheric rivers contribute to high sea water levels along the U.S. West Coast. Khouakhi and Villarini (2016) found that atmospheric rivers are associated with 15% to 50% of the annual sea level maxima before (and 22% to 65% after) removing tidal oscillations. Therefore, there may be an increase in storm surge frequency with climate change due

to atmospheric rivers. Further local research on this topic would be beneficial to sea level rise adaptation planning on the North Shore.

Storm surge pattern changes were also investigated through trend analysis of observed water levels: increasing trends were found, but they are not statistically significant. Observed water level datasets were assessed to investigate statistical trends in storm surge. The historic annual maximum storm surge height datasets for Pt. Atkinson (1950 to 2013) and Vancouver (1940 to 2017) were analyzed for trends using the Mann-Kendall test (Gilbert, 1987). The calculated storm surge height datasets (observed water level minus predicted tide) were corrected for sea level rise and ground uplift / land subsidence by using an assumed linear relative sea level rise rate; this was based on the 0.04 m relative sea level rise value reported by the Province for Vancouver from 1910 to 2014 (Ministry of Environment, 2016).

The topic of climate change impacts to storm surge magnitude and frequency is important for adaptation planning, and the sea level rise hazard assessment may need to be revised if research emerges showing potential increases in storm surge height that significantly change predicted stillwater levels.

Coastal Stillwater Flood Scenarios and Flood Depth Mapping

Coastal flood scenarios and associated flood depth mapping included in the Strategy focus on stillwater flooding, i.e. do not incorporate wave effects. Wave effects were not included in the flood mapping due to limited scope that did not include ocean wave modelling to determine wave heights and wave effects. This is discussed further in Section 5.5. While not appropriate for detailed assessments, coastal stillwater flood mapping does provide a representative product that can be used for risk assessment and identification of sub-areas for site-specific adaptation planning.

Five theoretical coastal stillwater flood scenarios describing different levels of sea level rise and flood hazard were identified to be used in preparing flood maps. The scenarios are described in Table 5-5.

Table 5-5: Coastal Flood Stillwater Scenarios and Levels

Scenario ID	Sea Level Rise	Coastal Flood Intensity (Return Period) (% annual exceedance probability)	Peak Stillwater Surface Elevation without Freeboard (m, Elevation CGVD28)	Peak Stillwater Surface Elevation with Freeboard (m, Elevation CGVD28)
A	Current (0 m)	200-year (0.5%)	2.8 m	3.4 m
B	0.5 m	10-year (10%)	3.0 m	3.6 m
C	1.0 m	10-year (10%)	3.5 m	4.1 m
D	1.0 m	200-year (0.5%)	3.8 m	4.4 m
E	2.0 m	200-year (0.5%)	4.8 m	5.4 m

The five scenarios were selected in consultation with the Technical Steering Committee to capture the full range of sea level rise heights considered in this project and to include both relatively frequent

(10-year return period) and infrequent (200-year return period) flood intensities. By including both relatively frequent and infrequent flood events, the consequences of flooding (presented and discussed in Section 6) can be contextualized in terms of likelihood of occurrence, which supports a risk-based approach to flood management. This is discussed further in Section 6.

Flood Depth Mapping

Appendix B (Coastal Stillwater Flood Maps) contains flood depth maps with five sets of maps, one for each scenario.

The following is mapped for each scenario:

- Stillwater flood depth (without freeboard[1], does not include wave effects);
- Additional area that would be flooded with 0.6 m of freeboard (this is designated on the maps as "additional area flooded with 0.6 m freeboard"); and
- Average high tide (HHWMT) elevation contour (based on the sea level for the scenario) for context.

A sample portion of the flood depth map focused on the Norgate neighbourhood of North Vancouver (District and City) is presented in Figure 5-4.

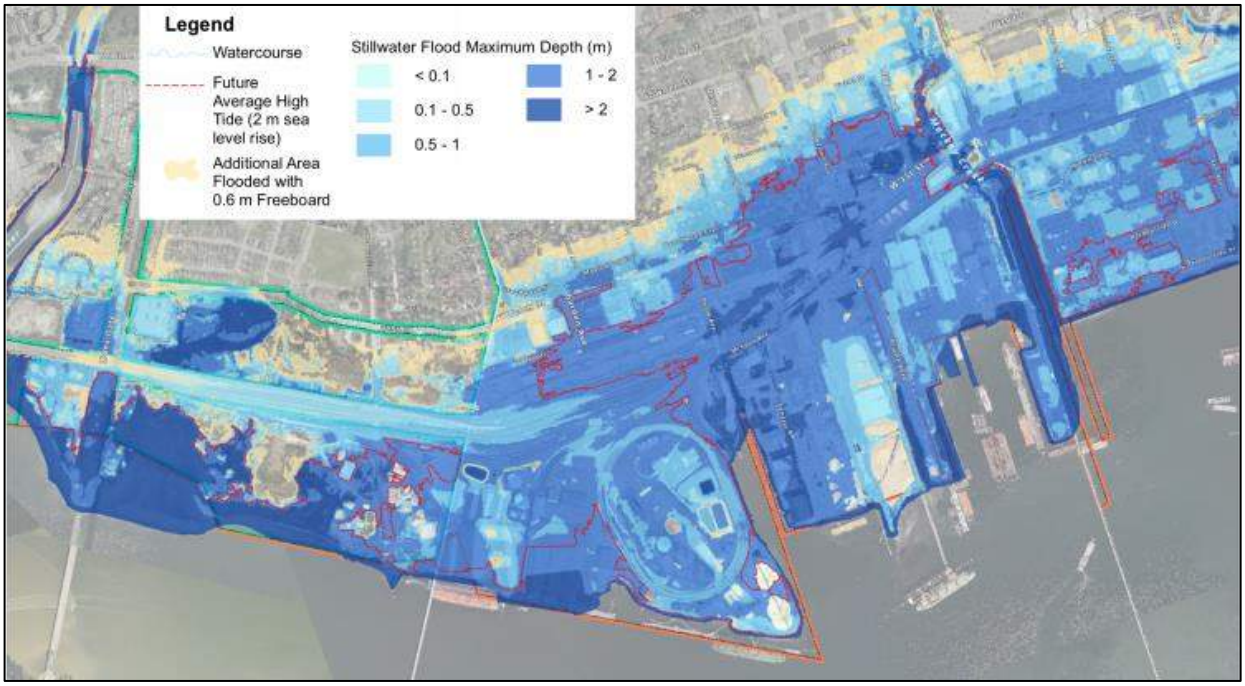


Figure 5-4: Sample of Flood Depth Map: Scenario E in Norgate Area of North Vancouver

[1] Freeboard is a vertical distance added to water surface elevations to account for scientific uncertainty. A typical value of 0.6 m is used in British Columba for flood hazard assessment. The flood maps present depths using the peak water surface elevation without freeboard and separately present a 'freeboard zone' which shows the additional area that would be inundated if a 0.6 m freeboard is included.

The coastal flood maps provided in Appendix B show that across all scenarios, there are 9 areas where the coastal flooding would extend beyond individual waterfront properties and would cover a wider area. These are identified in Figure 5-5.

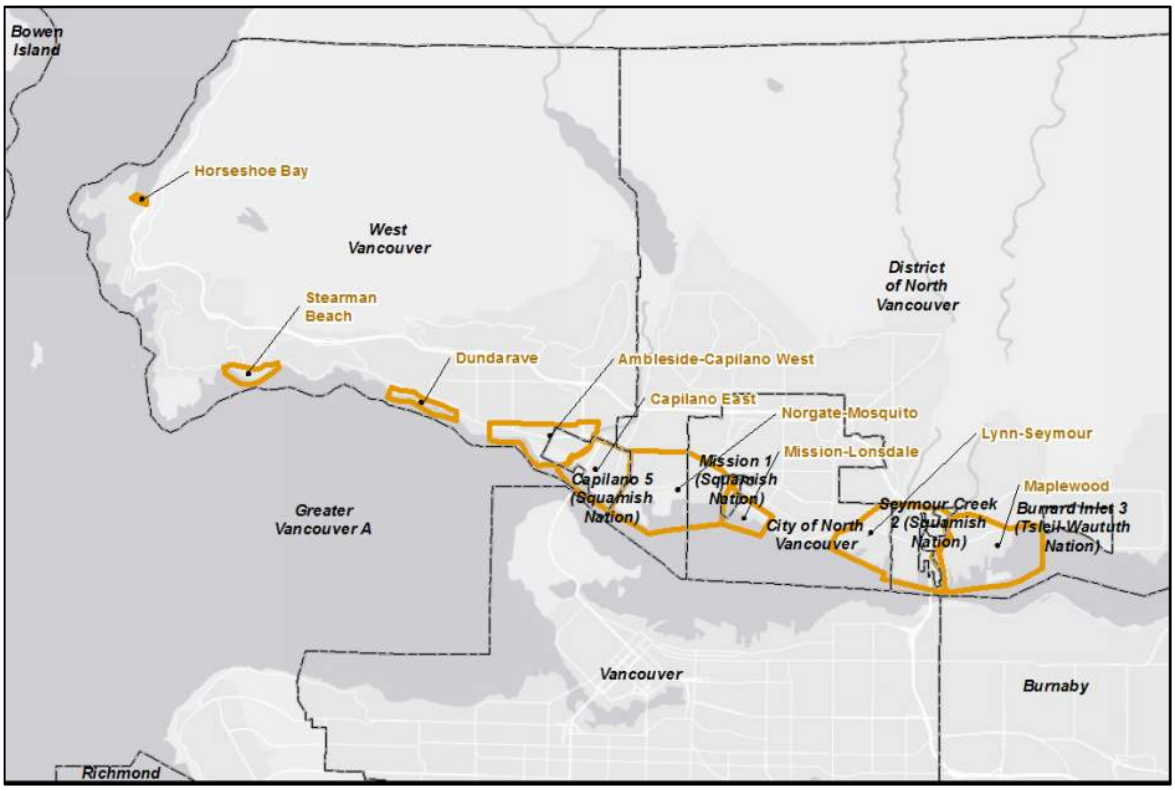


Figure 5-5: North Shore Comprehensive Adaptation Planning Zones (orange areas)

In each of these 9 areas, a higher degree of adaptation planning effort will be required than other areas where flood extents are limited to individual waterfront properties where adaptation can be primarily implemented through the development and building controls. These 9 areas are introduced as "comprehensive adaptation planning zones" and are discussed further in Section 7.

Flood Depth Mapping Methodology and Limitations

The flood depths are calculated by projecting the peak stillwater flood water surface elevation without freeboard (refer to Table 5-5) over a digital elevation model derived from LiDAR elevation data to determine maximum flood depths. LiDAR data is typically collected by airplane and the data is processed to remove buildings, tree canopy, and other vegetation impacts to produce a 'bare earth' interpretation of the topography. Both the approach to flood mapping and the LiDAR itself, are subject to uncertainty, as discussed below.

This is a simplified flood mapping approach that assumes that the temporal aspect of hydrodynamic conditions (i.e., how far the floodwaters reach inland before the tide recedes) is negligible and, as such, that all areas below the peak water level would be inundated. This is a reasonable assumption in the study area based on KWL's experience with analyzing coastal flood hazards on the North Shore's relatively narrow coastal floodplain.

The mapping was conducted primarily by using 2016 LiDAR data obtained from the Province (EMBC LiDAR for floodplain mapping) and was supplemented by additional LiDAR data from the District of West Vancouver (2016) and the District of North Vancouver (2013) to cover the remainder of the study area not included in the Province's LiDAR (north of Horseshoe Bay and northern portions of Indian Arm). The need for multiple LiDAR datasets to cover the study area results in a datum discrepancy as the 2016 provincial LiDAR dataset is in the Canadian Geodetic Vertical Datum of 2013 (CGVD2013), whereas the municipal LiDAR datasets are in the Canadian Geodetic Vertical Datum of 1928 (CGVD28). CGVD2013 is an emerging datum that will eventually become the accepted datum across the Lower Mainland. However, at this time there is no precise conversion method available to convert all the LiDAR sources into one consistent datum[2] over such a large study area. The stillwater levels used to create the mapping (Table 5-5) are in CGVD28 datum and there is an approximately 3 cm conversion for water levels at the Canadian Hydrographic Services' (CHS) Vancouver Harbour station used for the water level mapping. This is viewed as a minor discrepancy and within the level of uncertainty acceptable for the high-level coastal stillwater flood mapping.

As described earlier, the flood maps show coastal stillwater flood potential only and do not include wave effects. Additional future work on numerical wave modelling is required to update the maps to include wave effects. The flood maps also do not include the potential flood impacts of concurrent riverine and stormwater sewer flow. These are qualitatively discussed separately in Sections 5.3 and 5.4. The maps also do not reflect the impact of land subsidence and ground uplift on flood depths due to the variability on the North Shore as discussed in Section 2.1.

The flood maps have been prepared with consideration of relevant guidelines, including the Engineers and Geoscientists BC Professional Practice Guidelines on Flood Mapping in BC (EGBC, 2017). In accordance with the guidelines, a flood mapping assurance statement is included in Appendix B.

Flood Duration

In addition to flood depth, flood duration is an important factor in understanding coastal flood consequences and for developing adaptation measures.

The tide cycle governs coastal flood durations on the North Shore given that the average tidal range (LLWMT to HHWMT) is approximately 3 m while the maximum recorded storm surge height is approximately 1 m. Additionally, as discussed earlier, the local tide cycle includes 2 high tides and 2 low tides every 24 hours. During a flood event, the lows of the tide cycle can provide flood relief twice per day, while the highs of the tide cycle can cause repeated flood peaks twice per day. The number of flood peaks depends on the storm surge pattern.

As an example, Figure 5-6 presents the interaction of predicted tide, calculated storm surge height, and recorded stillwater level for the December 2012 coastal flood event which impacted the North Shore, including flooding in the District of West Vancouver's John Lawson Park.

[2] Personal communication between Amir Taleghani (KWL) and Tyson Altenhoff (Province of BC, MASCOT program) May 27, 2019.

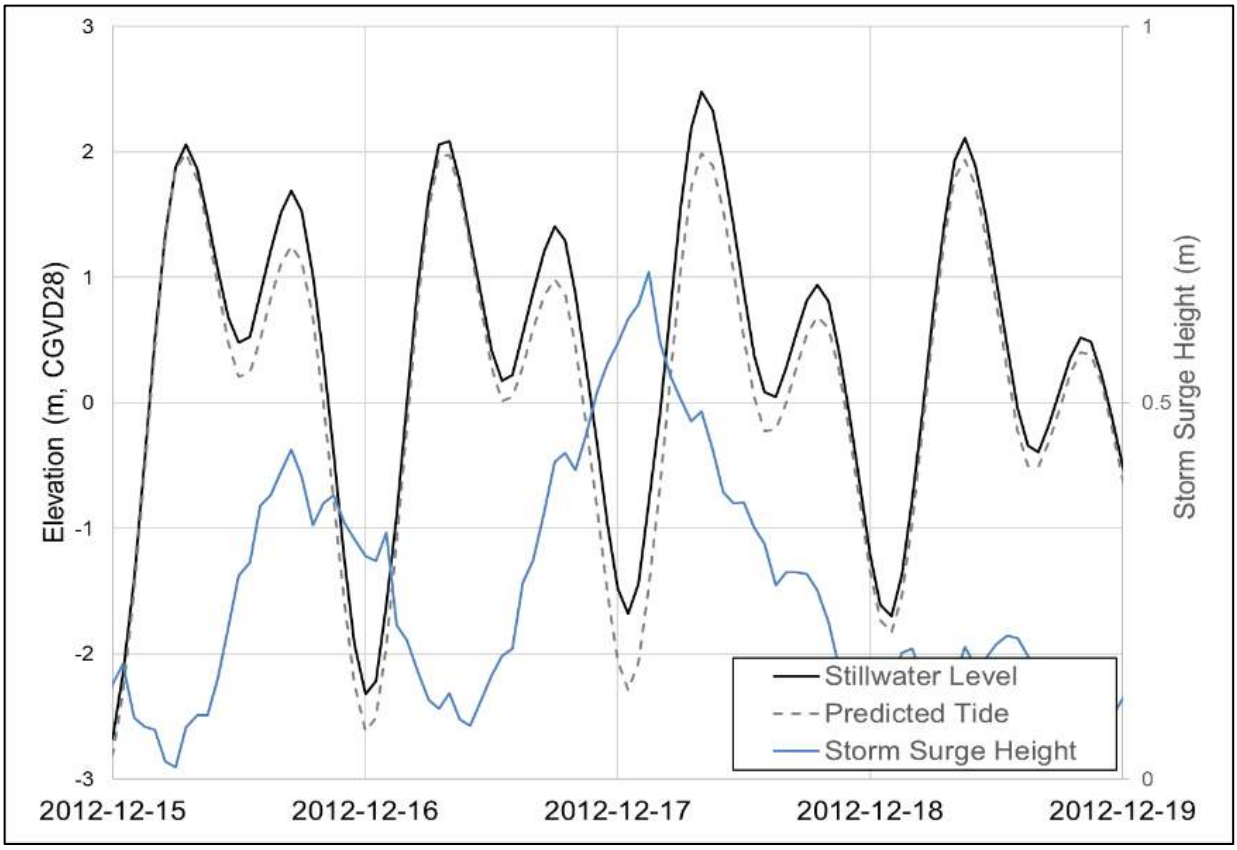


Figure 5-6: December 2012 Coastal Flood Components Timeseries

Table 5-6 shows that the storm surge event (blue line, right vertical axis) lasted approximately 4 days and had peaked during December 15, 2012, and December 17, 2012. The storm surge peaks did not line up with the predicted tide peaks (dashed grey line, left vertical axis). The peak stillwater level (~2.5 m CGVD28) was recorded in the morning of December 17 when the peak tide combined with a ~0.5 m storm surge height on the falling limb of the storm surge peak.

Flood durations can be estimated by calculating the total length of time when the stillwater level time series exceeds an elevation threshold of interest.

Theoretical stillwater level time series were produced for the five coastal flood scenarios to estimate flood durations. For scenarios B and C (each with a 10-year return period flood intensity), the December 2012 event described earlier was used because it has a recorded peak stillwater level approximately matching the estimated 10-year return period magnitude. The December 2012 event was modified to add sea level rise.

For scenarios A, D, and E (each with a 200-year return period flood intensity), a theoretical event was created by modifying predicted tide data to achieve a 5-day duration stillwater event with a 1-hour peak that matches the 200-year return period level. This is presented in Figure 5-7.

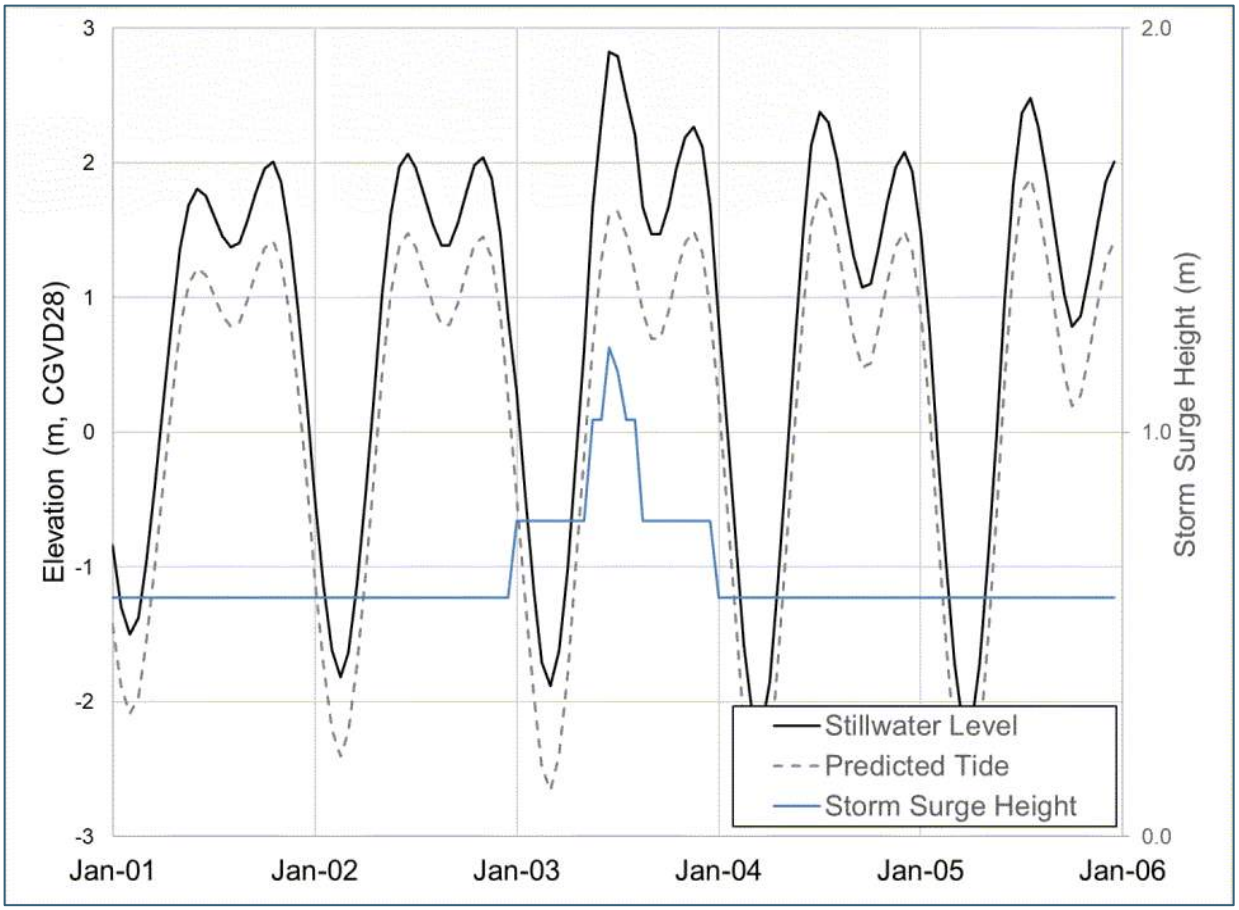


Figure 5-7: Theoretical 200-year Return Period Stillwater Timeseries Without Sea Level Rise

The theoretical storm surge event contained within the stillwater level time series is built using 1-hour, 2-hour, 6-hour, 24-hour, and 120-hour duration storm surge heights with a 0.5% annual exceedance probability. This is a conservative approach akin to the Chicago rainfall distribution used in urban stormwater management. The shape of the storm surge event is not necessarily realistic, but the conservative approach is appropriate due to a lack of recorded local extreme storm surge events. The theoretical event time series was modified to add sea level rise for each scenario.

Flood durations were estimated for each scenario by counting the number of hours when the stillwater level (without and with freeboard) exceeded the extreme high tide (HHWLT) level. Results are presented in Table 5-6.

Table 5-6: Coastal Flood Scenarios and Stillwater Level Exceedance Hours

Scenario ID	Sea Level Rise	Coastal Flood Intensity (Return Period) (% annual exceedance probability)	Total Number of Hours When Stillwater Level (without freeboard) Exceeds Extreme High Tide (HHWLT)
A	0 m (current)	200-year (0.5%)	14
B	0.5 m	10-year (10%)	6
C	1.0 m	10-year (10%)	6
D	1.0 m	200-year (0.5%)	14
E	2.0 m	200-year (0.5%)	14

These durations can generally be considered upper bounds as they are representative of the lowest-lying, non-intertidal areas within the floodplain. Areas located higher in elevation would be inundated for a shorter duration. The results show that in more frequent flood events such as the 10-year return period event, the flood duration could be as short as 6 hours in low-lying, non-intertidal areas. Extreme flood events such as the 200-year return period event could inundate low-lying, non-intertidal areas for a total of 14 hours (without freeboard). Areas without positive drainage (e.g., underground parkades, basements, ponds, etc.) would likely be flooded for longer and may require pumping to remove water.

It should be noted that the above analysis is only appropriate for the current floodplain configuration (i.e., no potential flood infrastructure or coastline changes). For sea level rise scenarios (B to E), the flood durations only include areas above the future extreme high tide elevation (HHWLT). If measures are implemented to prevent intertidal area change (e.g., dikes or seawalls), then areas located below the future extreme high tide elevation would likely be inundated for significantly longer durations in the event of a breach of the measures prior to repairs.

5.3 Riverine Flooding Impacts

Sea level rise can exacerbate riverine flood hazards by reducing the flow conveyance of river channels at their mouth and correspondingly increasing water levels, also referred to as backwatering. The backwatering effect is particularly important for rivers and creeks with shallow sloped alluvial fans located partially on the coastal floodplain. On the North Shore, examples include Mackay Creek and Capilano River. The backwatering effect is less significant for the many smaller creeks which enter Burrard Inlet or the Strait of Georgia at a steep grade where the creek bed is above the high tide elevation within several metres of the shoreline.

The backwatering effect is most severe during periods of concurrent high flow and high stillwater level. However, given that river flow and tidal elevations are physically independent processes and that the tidal cycle governs the stillwater level, no direct correlation is expected between flow and stillwater level.

KWL (2014) analyzed the backwatering effect for Mackay Creek, Mosquito Creek, Lynn Creek, and Seymour River for the following scenarios:

- 200-year return period flow matched with a high tide (HHWLT) without sea level rise, with 1 m of sea level rise, and with 2 m of sea level rise; and
- Mean annual flood flow matched with a 200-year return period storm surge and a high tide (HHWLT) without sea level rise, with 1 m of sea level rise, and with 2 m of sea level rise.

It is understood that Capilano River backwatering effects are currently being investigated as part of flood hazard studies being conducted by Metro Vancouver and the Squamish Nation. This project is not aware of any other riverine backwater effects analysis within the study area.

Sea level rise may also impact riverine flood and erosion hazards by altering sediment transport and deposition characteristics of low-lying alluvial fans. This is analogous to the intertidal area change process discussed earlier. If the intertidal area moves upstream in a river channel, then the depositional area of the river channel and alluvial fan may also change. A potential change in depositional areas could increase riverine flood levels, cause sediment deposition and potential channel instability, impact habitat, and impact sediment management programs. This project is not aware of any local studies of sea level rise impacts to alluvial fan depositional areas.

5.4 Drainage System Impacts

Similar to rivers, urban drainage systems (i.e., stormwater pipe networks) can be backwatered by coastal water levels. Sea level rise can increase the potential for backwater flooding in low-lying areas.

In general, stormwater outfalls that are susceptible to backwatering with sea level rise may require measures in the future to prevent backwatering and to maintain the desired level of performance.

The DNV's recent drainage system model development and assessment project (NHC, 2017) assessed the impact of sea level rise on stormwater outfalls throughout the DNV and rated several outfalls as 'severely backwatered'. The scenarios assessed were 2-year and 10-year return period rainfall events occurring at the same time as an approximate 10-year return period stillwater level with and without 1 m sea level rise and ground uplift of 0.12 m. Since rainfall events and tides are not physically related processes, this combination of events represents a more conservative scenario.

This project is not aware of other community-wide drainage assessments within the study area which have assessed outfall performance with sea level rise.

Drainage system impacts are important considerations in the development of sea level rise adaptation measures. On the North Shore, the minor drainage system comprising catch basins and stormwater pipes are designed for the 10-year return period (10% annual exceedance probability) rainfall event based on the standard at the time of construction. More extreme rainfall events are conveyed via the major drainage system (typically creeks, roads and right-of-ways). Hard protective sea level rise adaptation infrastructure, such as sea dikes or seawalls, could interrupt overland flow paths causing internal drainage flooding, often referred to as the 'bathtub effect' where water depth builds up due to a barrier that prevents conveyance, for rainfall events above the 10-year return period intensity. This can trigger the need for flood management infrastructure to mitigate the risk (e.g., additional outfalls, flapgates, pump stations with storage, or other alternative measures).

5.5 Wave Effects and Shoreline Erosion

Waves generated by wind and vessel movement also impact flood and erosion risks to waterfront lands and development. Consideration of waves is important for developing and assessing adaptation measures.

Wave effects include the following components:

- wave setup; and
- wave runup.

Wave setup is a local increase in water level near the shoreline caused by the momentum of breaking waves. The magnitude of wave setup depends on the available wind fetch and water depth. Because of its site-specific nature, a “typical” value for wave setup cannot be defined for the entire North Shore.

Wave runup is the vertical distance between the mean water level (stillwater level plus wind and wave setup) and the highest point that a broken wave reaches on a shoreline. Since wind-generated wave heights are not constant during a wind event, wave runup is often expressed in terms of the vertical distance between the mean water level and the point on the shoreline above which only 2% of waves reach.

Wave runup is dependent on shoreline geometry (including waterfront site grade) and deep-water wave height. In general, steep, smooth slopes (e.g., concrete walls) result in higher runup while shallow, rough slopes (e.g., cobble beach) result in lower runup for the same deep-water wave height. It is not possible to calculate a single representative wave runup for the whole study area due to the variability in the shoreline. Additionally, potential future waterfront development may change shoreline geometry and site grading, which would affect the calculation for future wave runup.

Wave effects generally diminish with increasing distance from the shoreline.

SNC-Lavalin (2013) assessed wind-generated wave effects for a portion of the study area between the Lions Gate Bridge and Maplewood Flats as part of the DNV and CNV floodplain study (KWL, 2014). SNC-Lavalin (2013) estimate wave effects for seven representative shoreline cross-sections during a combination of a high tide (HHWLT) and a 200-year return period storm surge, under varying sea level rise scenarios (current, 1 m, and 2 m). The results indicate total run-up heights in the range of 0.5 m to 1.5 m, measured above the stillwater level. However, the stillwater level exceeded the existing top of shoreline in several sections and an assumption was made that at a certain distance set back from the shoreline there would be a 1.5H:1V slope extending to above the wave effects, to represent potential future development land raising. The utility of the wave effects values is limited to the conditions of this assumption. This underscores the necessity of assessing site-specific wave effects at the time of development (or other landscape change) since a general assumption of what the future site grade maybe is not appropriate for the diversity of landscapes and developments that are possible on the North Shore.

Wave effects analysis is currently not available for the study area west of the Lions Gate Bridge. The existing analysis by SNC-Lavalin (2013) is only appropriate for areas east of the bridge which are generally sheltered from open ocean conditions. A wave modelling study is required to estimate deep-water wave heights for the shoreline west of the Lions Gate Bridge to support the calculation of wave effects for existing and future shoreline geometries. It is understood that the District of West Vancouver has retained a consultant to study wave hazards in support of coastal floodplain development controls, including flood construction levels.

Sea level rise raises the stillwater level and allows waves to reach higher on the shoreline. Climate change may also impact the magnitude and frequency of winds that generate wave effects; however, there is a lack of local projections and policy guidance on this subject at this time.

In low-lying areas, sea level rise may elevate the stillwater level for a particular event above the existing shoreline. In this case, wave effects would be significantly altered and could pose a more severe damage risk to waterfront structures as waves could break directly on them as opposed to the adjacent shoreline.

Wave effects also have an important role in shaping shoreline geometry. For natural shoreline areas, it is assumed that the current shoreline geometry along the North Shore is in a state of quasi-equilibrium that is linked to previous storm events and their associated wave effects. Sea level rise is likely to trigger a transition to a different state of quasi-equilibrium through shoreline erosion and retreat. Without adaptation measures, this could result in the loss of waterfront land and changes to intertidal and riparian habitats. Environmental impacts are explored in Section 6.

Shoreline geometry impacts from sea level rise are also linked to the concept of the 'natural boundary' which is defined by the BC Land Act[3] and is used in the management of development in floodplains to measure flood and erosion setback distances for structures. The legal definition of 'natural boundary' does not lend itself well to a changing climate and shoreline.

Sea level rise will also impact vessel-generated wave hazards by increasing the base water level over which vessels generate waves. Vessel-generated waves are a major consideration in harbours and the geometry of shoreline areas with heavy adjacent marine traffic (e.g., tugboats, etc.) may be governed by vessel-generated waves, instead of wind-generated waves. Vessel-generated wave hazards have not been assessed in this study, and the partners may wish to consider investigating this as part of future work.

5.6 Tsunami

While not a focus of this study, sea level rise also impacts tsunami hazards by increasing the base sea level above which tsunami waves move and run up the shoreline. A brief literature review was conducted to determine the tsunami hazard to the North Shore.

NSEM commissioned a 2005 study (Clague and Orwin, 2005) to examine the tsunami hazard for North and West Vancouver which determined that there are five main sources for tsunami waves:

- Large earthquakes at subduction zones around the Pacific Rim;
- Large earthquakes at the Cascadia subduction zone;
- Shallow local earthquakes from faults within the North America plate;
- A landslide at the front of the Fraser River delta west of Richmond; and
- A landslide into Howe Sound or Indian Arm.

Clague and Orwin (2005) state that "the small risk to Lions Bay, Sunset Beach, and parts of Deep Cove derives entirely from local, landslide-triggered tsunamis in Howe Sound and Indian Arm [but] this risk is very low. The risk to the North and West Vancouver waterfronts derives largely from tsunamis triggered by large, shallow earthquakes beneath the Strait of Georgia. The largest possible tsunami of this type could produce run-ups of more than 2 metres on the North Shore, but this is a worst-case scenario with a very low likelihood of occurrence. Tsunamis triggered by great earthquakes at distant North Pacific

[3] The Land Act defines natural boundary as "the visible high water mark of any lake, river, stream or other body of water where the presence and action of the water are so common and usual, and so long continued in all ordinary years, as to mark on the soil of the bed of the body of water a character distinct from that of its banks, in vegetation, as well as in the nature of the soil itself" (Source: www.bclaws.ca).

subduction zones pose no risk to North Shore communities. Tsunamis triggered by great earthquakes at the Cascadia subduction zone would result in run-ups of less than 2 metres on the North Shore."

They concluded by stating that "the tsunami threat to the Fraser delta lowlands and by extension the North Shore, is very small," and that "severe storms pose a greater risk to North Shore coastal infrastructure than tsunamis."

The Clague and Orwin (2005) study concludes that severe storms pose a greater risk because coastal flood stillwater levels (described in Section 5.2) are generally higher in elevation than the tsunami wave runup if it is assumed that a tsunami occurs at mean sea level. For example, at current sea level, a (~0 m CGVD28) a 2 m tsunami wave runup would reach up to a shoreline elevation of approximately 2 m CGVD28 which is well below the current 0.5% annual exceedance (200-year return period) stillwater coastal flood level (2.8 m CGVD28 as presented in Section 5.2).

A more recent national tsunami hazard assessment (Lucinda et al, 2014) states that the largest risk for the Georgia Strait region is near-field earthquakes (including nearby continental slope landslides, as they would likely be triggered by a local earthquake) and that the probability of exceedance in 50 years is slightly higher than 10% for a 1.5 m run-up and less than 1% for 3.0 m runup. However, due to the sheltered location of the North Shore within Burrard Inlet, these values are likely conservative and wave run-up heights would be lower.

In the future, tsunamis may become a more significant flood hazard if new scientific knowledge emerges and/or sea level rise accelerates beyond 2 m. The North Shore partners, primarily through NSEM, continue to support and be involved in emerging research, primarily led by NRCAN, on earthquake and tsunami hazards.

5.7 Summary of Knowledge and Potential Future Hazard Analyses

Table 5-7 presents a summary of the state of knowledge of major sea level rise-related hazard components discussed in this section. For each component, the table includes a discussion of potential future analyses.

Table 5-7: Summary of Knowledge on Various Sea Level Rise Related Hazard Components

Component	Adequacy of Knowledge	Potential Future Analyses
Sea level rise rate	Acceptable	Future updates to be triggered by provincial / regional (Fraser Basin Council) shifts in sea level rise policy in response to emerging scientific consensus (e.g., United Nations Intergovernmental Panel on Climate Change's next assessment).
Land subsidence / ground uplift	Acceptable	Future updates to be triggered by provincial / federal (Geologic Survey of Canada) shifts in land subsidence science and policy.
Intertidal area change	Incomplete	Update intertidal area change analysis with more complete bathymetric survey information.
Storm surge and stillwater levels	Acceptable	Consider collaboration with research institutions at a regional level to better understand how climate change will impact storm surge magnitude and frequency.

Component	Adequacy of Knowledge	Potential Future Analyses
Riverine flood impacts (backwatering and increased erosion)	Incomplete	Capilano River flood hazard analysis (underway, by SN) Lynn Creek flood hazard analysis (underway, by DNV and CNV) Screen other riverine systems for potential need to assess backwatering.
Drainage system impacts	Incomplete	Consider updating drainage master plans and integrated stormwater management plans to include a sea level rise impact assessment for low-lying catchments and outfalls. DNV has recently completed this. Drainage analyses can be coordinated with conceptual-level planning of potential structural adaptation measures (e.g., dikes).
Wind-generated waves	Incomplete	Consider a wave hazard analysis for DWV and the Indian Arm area of DNV. Consider preparing updated flood maps that incorporate wave effects.
Vessel-generated waves	Minimal	Consider assessing potential wave heights and related shoreline erosion hazards from vessel traffic, particularly within high traffic Port areas adjacent to natural shoreline (e.g., Maplewood Flats).
Shoreline erosion	Minimal	Consider undertaking a North Shore-wide shoreline erosion screening assessment to identify areas with the highest vulnerability to sea level rise and prioritization of shoreline adaptation measures.
Tsunami	Acceptable	Continue to collaborate with the federal government (Natural Resources Canada / Geologic Survey of Canada) through NSEM on earthquake and tsunami hazard and risk assessments.
Dike breach	Not applicable at this time because there are no formal dikes on the North Shore	Undertake dike breach hazard analysis as part of consideration of any future structural adaptation measures.
Liquefaction vulnerability	Minimal	Consider additional literature review and/or seek advice from local earthquake research community on the potential for sea level rise to increase liquefaction hazard probability/intensity in low lying areas.

6. Consequence and Risk Assessment

This section describes the sea level rise consequences and risk that the North Shore partners can expect to face if steps are not taken to adapt to sea level rise. Consequence and risk assessments were conducted based on existing conditions and land use and with the assumption that no adaptation measures have been implemented. Accordingly, the results are intended to explain the need for sea level rise adaptation planning and to guide the development of adaptation measures and the adaptive management Strategy.

Three different consequence assessments were conducted:

1. Coastal flood consequence assessment (Section 6.1) for 24 variables representing major elements of 6 sectors across the North Shore for 2 coastal flood scenarios;
2. Economic disruption assessment for the Port Authority's terminals on the North Shore to identify the wider economic impacts associated with coastal flooding for 3 coastal flood scenarios (Section 6.3); and
3. Environmental habitat consequence assessment (Section 6.4) related to intertidal area change.

The coastal flood consequence assessment results were used to conduct a semi-qualitative flood risk assessment (Section 6.2) to identify which sectors and elements have a relatively higher risk and can be considered as priorities for coastal flood adaptation planning.

6.1 Coastal Flood Consequence Assessment

Assessment Approach

The consequence assessment uses coastal stillwater flood scenarios, and a range of variables across 6 sectors to describe the consequences if no adaptation measures are undertaken. The following coastal stillwater flood scenarios were used:

- Scenario C: 1 m sea level rise, 10% annual exceedance probability stillwater level (10-year return period), and
- Scenario E: 2 m sea level rise, 0.5% annual exceedance probability stillwater level (200-year return period).

Annual Exceedance Probability (AEP) refers to the probability of a flood of a certain intensity or larger occurring in any year.

Scenarios C and E were selected by the Technical Steering Committee for the following reasons:

- A 0.5 m sea level rise scenario was considered, but not selected because it was found to have generally limited impacts.
- A 1 m of sea level rise scenario (horizon year 2100) would capture the lifespan of buildings constructed now as per provincial sea level rise planning guidelines (Ausenco Sandwell, 2011b), and would be in line with assessments conducted by other local governments and the Fraser Basin Council's Lower Mainland flood management strategy;

- A 2 m of sea level rise scenario would consider long-range land use planning as per provincial guidelines (Ausenco Sandwell, 2011b), and to acknowledge the uncertainty in the magnitude and pace of sea level rise should it occur more rapidly than the currently projected horizon year 2200;
- Include a large, rare/extreme flood event (i.e., 0.5% annual probability / 200-year return period) to capture the upper end of consequences; and
- Include a more frequent event than the rare/extreme flood events typically used in flood management studies to show that sea level rise will also have more frequently occurring consequences (i.e., 10% annual probability / 10-year return period).

There are 24 variables selected to represent flood consequences across the 6 sectors (described in Section 2) on the North Shore (Table 6-1).

The following methods were used to assess flood consequences:

- Census-based consequence modelling using the Canadian version of the Hazus model for population displacement, building and contents damage, and building and contents debris generation;
- Prolonged power outage assessment based on analysis of BC Hydro's substation network;
- Business disruption modelling based on work by Chang et al (2008); and
- Spatial identification of other variables within the scenario flood extent using GIS.

Appendix C (Flood Consequence Assessment) describes the above methods including theory, data inputs and sources, and associated limitations/uncertainty.

Table 6-1: Consequence Assessment Variables (By Sector)

Sector	Consequence Variable	Unit
Social Services	1. Population displaced by inundation	persons
	2. Vulnerable population (age <16 and >65, income <$20,000) exposed to inundation and/or power outage	persons
	3. Healthcare facilities (hospital, clinic, pharmacy) exposed to inundation and/or power outage	facilities
	4. Education/daycare facilities (public/private schools and daycares) exposed to inundation and/or power outage	facilities
	5. Social services facilities (churches, meal providers, education centres, and community centres) exposed to inundation and/or power outage	facilities
Environment	6. Hazardous waste generating/storage sites exposed to inundation	sites
	7. Contaminated sites exposed to inundation	sites
	8. Debris generated by building and contents damage	tonnes
	9. Parks exposed to inundation	area (ha)

Sector	Consequence Variable	Unit
Culture and Heritage	10. Registered archaeological and historic sites exposed to inundation	sites
	11. Heritage buildings exposed to inundation	buildings
Buildings and Infrastructure	12. Buildings exposed to inundation	buildings
	13. Emergency service (fire, police, ambulance) and municipal operations facilities exposed to inundation and/or power outage	facilities
	14. Squamish Nation-owned buildings exposed to inundation and/or power outage	buildings
	15. Wastewater and stormwater pump stations exposed to inundation	pump stations
	16. Port terminal operators exposed to inundation	sites
	17. Population impacted by power outage	persons
Economy	18. Building damage and contents replacement cost ($)	$
	19. Temporary non-port business disruption due to inundation and/or power outage	businesses
Transportation	20. Emergency routes (roads) exposed to inundation (km)	route length (km)
	21. Major routes (roads) exposed to inundation	route length (km)
	22. Bus routes (roads) exposed to inundation	route length (km)
	23. Bus stops exposed to inundation	bus stops
	24. Gas stations exposed to inundation or power outage	gas stations

Results

The flood consequence assessment results are discussed below by sector for the North Shore as a whole.

A full breakdown of the results, including by partner jurisdiction, are presented in tabular, bullet point summary, and spatially (figures) in Appendix C: Flood Consequence Assessment.

Social Services

Without adaptation, sea level rise-related coastal flooding is expected to have direct and indirect impacts on the North Shore population and the social service facilities that support the population. In general, a small proportion of the population will be impacted by inundation, but the proportions increase when power outages related to flooding are considered.

Consequence results across the North Shore overall are summarized in Table 6-2 and are discussed below the table.

Table 6-2: Social Services Sector Consequence Results (North Shore)

Consequence Variable	Scenario C (1 m SLR, 10% AEP[1] event)		Scenario E (2 m SLR, 0.5% AEP event)	
	Value (unit)	*% of North Shore Total*	*Value (unit)*	*% of North Shore Total*
Population displaced by inundation	1,340 people	0.8%	2,770 people	1.6%
Vulnerable population (age <16 and >65, income <$20,000) exposed to inundation or power outage	540 people	0.8%	12,620 people	20%
Schools (public/private) and daycares exposed to inundation	8 facilities	2.3%	75 facilities	22%
Healthcare facilities (hospital, clinic, pharmacy) exposed to inundation or power outage	0 facilities	0%	9 facilities	43%
Social service facilities (churches, meal providers, education centres, and community centres) exposed to inundation or power outage	1 facility	0.9%	31 facilities	27%

1. Annual Exceedance Probability (AEP) refers to the probability of a flood event occurring in any year.
Note: Population variables are rounded.

Consequence results under Scenario C suggest that inundation and power outages would affect 1% of general and vulnerable populations across the North Shore. This is a small proportion of the total population as most residential areas on the North Shore are located at higher elevations. However, displacement of more than 1,000 people would still be a significant consequence on the North Shore and would require significant local, regional, and provincial resources to coordinate emergency response and recovery efforts. The population displaced under Scenario C doubles in Scenario E.

The number of vulnerable people exposed to inundation and/or power outage notably increases between Scenario C and Scenario E to 20%. The increased exposure in Scenario E is primarily due to significant power outages resulting from inundation and damage of two BC Hydro power substations (BC Hydro's John Lawson sub-station in DWV and Norgate Substation in DNV) that service a large portion of residential and commercial lands in the District of West Vancouver (Dundarave, Hollyburn, Ambleside, Park Royal, Cedardale, Sentinel Hill and the British Properties), Squamish Nation (Capilano I.R. No. 5, and Mission I.R. No. 1), and the District of North Vancouver (Norgate and Pemberton Heights). The substations outages extend under Scenario E to residential areas with a large percentage of seniors. In addition to the people represented in the vulnerable population variable, it is important to note that coastal flooding has the potential to displace homeless people and people at risk of homelessness who may frequent areas near the waterfront, which are likely not included in the census-based population data.

Schools and daycares are expected to be comparatively the most exposed facility type within the social services sector. The North Shore's primary hospital (Lion's Gate Hospital) is not exposed to inundation or power outage. However, under Scenario E, more than 40% of the North Shore's clinics and pharmacies would be exposed to inundation or power outage which would put a strain on other facilities during the recovery period.

Environment

Coastal flooding under future sea level rise scenarios without adaptation would negatively impact the receiving environment through the release of pollutants from hazardous-material-generating and/or storage sites and contaminated sites. This would threaten ecological and human health. Building and infrastructure damage from flooding will also generate debris that would require proper disposal, which could pose a challenge as it may be contaminated. Parks facilities, trails, and landscape spaces within inundation zones would also be damaged resulting in reduced recreational opportunities for the community during the recovery period.

Consequence results across the North Shore overall are summarized in Table 6-3 and are discussed below.

Impacts on environmental habitat from sea level rise are likely to occur gradually as opposed to consequences of extreme coastal flood events. Accordingly, these impacts on habitat have been assessed using a different approach presented in Section 6.4.

Table 6-3: Environment Sector Consequence Results (North Shore)

Consequence Variable	Scenario C (1 m SLR, 10% AEP event)		Scenario E (2 m SLR, 0.5% AEP event)	
	Value (unit)	*% of North Shore Total*	*Value (unit)*	*% of North Shore Total*
Hazardous-waste-generating and storage sites exposed to inundation	73 sites	25%	135 sites	46%
Contaminated sites exposed to inundation	43 sites	3.8%	86 sites	7.6%
Debris generated by building and contents damage	18,900 tonnes	-	51,900 tonnes	-
Parks exposed to inundation	81 ha	0.5%	106 ha	0.7%

A notable proportion of provincially and federally registered hazardous-waste-generating and storage sites on the North Shore are exposed to coastal flooding under both scenarios, reflecting the industrial and commercial land use along the Port lands and in the Norgate and Maplewood areas of North Vancouver. The number of exposed sites does not reveal the complete consequence profile as the analysis did not investigate the relative vulnerability of the sites to flooding (e.g., an open-air bulk material handling site vs. a chemical contained within a sealed tank) or the public/environmental health risk associated with the release of different contaminants. However, in general, the results show that there is a large number of sites where flooding could lead to potential release of contaminants.

In addition to registered hazardous-waste-generating and storage sites, registered contaminated sites exposed to inundation were are also counted. The potential impact of flooding of contaminated sites is also uncertain given that some sealed, underground sites may not interact significantly with coastal flooding while other sites along the waterfront could potentially be eroded during the flood leading to the release of contaminated soils into the floodwaters.

A relatively small proportion of parks on the North Shore would be impacted, but the impacts would be focused on more urban parks, particularly in the City of North Vancouver and in Squamish Nation reserve lands.

The amount of debris generated from flood damage is approximately 1.5 times higher in Scenario E than Scenario C, reflecting the increased flood extent and the increased number of damaged buildings (discussed further under the Buildings and Infrastructure sector).

Culture and Heritage

Many cultural and heritage sites are located within Scenario C and/or E sea level rise flood inundation areas. Damage to these cultural assets can have cascading effects by limiting opportunities for cultural practices and education, preservation of history, as well as potentially impacting tourism, should these sites also be tourist attractions.

Consequence results across the North Shore overall are summarized in Table 6-4 and are discussed below.

Table 6-4: Culture and Heritage Sector Consequence Results (North Shore)

Consequence Variable	Scenario C (1 m SLR, 10% AEP event)		Scenario E (2 m SLR, 0.5% AEP event)	
	Value (unit)	*% of North Shore Total*	*Value (unit)*	*% of North Shore Total*
Archaeological sites (registered) exposed to inundation	21 sites	58%	23 sites	64%
Heritage buildings exposed to inundation	6 buildings	1.1%	10 buildings	1.8%

The exposure of cultural and heritage sites to inundation was assessed using spatial analysis of designated archaeological sites, historic sites, and municipal heritage buildings (heritage data received only from CNV and DNV).

Archaeological site exposure to coastal flooding is notable with 58% to 64% of designated archaeological sites exposed under Scenario C and Scenario E, respectively, as there are many sites along the shoreline. This assessment did not consider erosion of archaeological sites, which could impact shoreline sites that may experience more frequent tidal and wave action under sea level rise.

The relative exposure of historic sites and heritage buildings is low (1.1% to 6.4% of North Shore totals), but the exposed sites and buildings represent the majority of waterfront historic sites and heritage buildings.

Buildings and Infrastructure

Much of the North Shore's coastal floodplain areas have been developed. They support a variety of land uses including commercial centres (e.g., Park Royal), high-density mixed-use areas (e.g., Ambleside and Lonsdale Quay), low-density residential, and active industrial and Port lands.

The differing development types are also reflected in the variety of buildings found on the North Shore which range from single-family wood-construction houses to high-density reinforced concrete buildings, industrial processing plants, and Port terminal warehouses. Major municipal and third-party infrastructure systems including water/wastewater, transportation, and electrical networks, service the developed lands.

Consequences to buildings and infrastructure were assessed through a combination of approaches involving building damage, power outages, and flood exposure of infrastructure and emergency service/operation facilities. The building damage assessment considered building type, material, and the relationship between flood depth and damage. Additional information on the methods is provided in Appendix C.

Consequence results across the North Shore overall are summarized in Table 6-5 and are discussed below.

Table 6-5: Buildings and Infrastructure Sector Consequence Results (North Shore)

Consequence Variable	Scenario C (1 m SLR, 10% AEP event)		Scenario E (2 m SLR, 0.5% AEP event)	
	Value (unit)	*% of North Shore Total*	*Value (unit)*	*% of North Shore Total*
Buildings exposed to inundation	219 buildings	0.5%	594 buildings	1.4%
Emergency service (fire, police, ambulance) and municipal operations facilities exposed to inundation or power outage	2 facilities	7.1%	6 facilities	21%
Squamish Nation band-operated buildings exposed to inundation or power outage	6 buildings	26%	15 buildings	65%
Wastewater and stormwater pump stations exposed to inundation	37 pump stations	46%	53 pump stations	66%
Port terminal operators exposed to inundation	5 operations	46%	11 operations	100%
Population affected by power outage	430 people	0.2%	31,270 people	18%
Note: Population variable rounded.				

Hundreds of buildings are estimated to be damaged by coastal flooding in Scenario C and Scenario E. However, because the North Shore's overall development extends far beyond the coastal floodplain areas, these buildings represent a very low proportion of all buildings on the North Shore. It should be noted that the number of buildings does not include the number of individual units within each building (which would be a higher number).

Building damage would create indirect impacts on the community and the economy, and recovery time would vary due to several factors including the extent of damage, insurance, government aid, and the rebuilding regulatory process. Replacements costs associated with building damage are presented under the economy sector consequence results, below.

While two emergency service facilities (City of North Vancouver Operations Centre and Community Operations Squamish Nation) are exposed under Scenario C, Scenario E has 7 facilities inundated or exposed to power outage, including 2 fire halls, 2 police stations, 1 ambulance centre, and a total of 2 operations centres. Together, these 7 facilities account for 25% of all emergency service facilities on the North Shore, with 4 of the facilities (fire, ambulance, and police) located in the District of West

Vancouver. If no adaptation measures are taken, this exposure may limit flood emergency response efforts on the North Shore and may strain the capacity to respond to non-flood-related emergencies on the North Shore during the recovery period. Furthermore, flooded roads would also impact emergency response, compounding the difficulty.

Squamish Nation band-operated buildings are separated as an individual variable to highlight the high proportion of Squamish Nation government service facilities that would be impacted by inundation (over 20% in Scenario C and over 60% in Scenario E).

Approximately half of all wastewater and stormwater pump stations on the North Shore are exposed to flooding under Scenario C, and 66% under Scenario E. Nearly all the pump stations are wastewater pump stations as there are few municipal stormwater pump stations on the North Shore. The large exposure of wastewater pump stations is not surprising because pump stations are typically required in the lowest elevation areas of a sanitary sewer system, which, on the North Shore, overlaps with the coastal floodplain. Although the assessment did not consider the likelihood of pump station failure, exposure to flooding is an indicator of potential failure given the wide range in pump station size, type, and age on the North Shore, and potential for a power outage (caused by flooding), unless they have standby backup power systems.

Although this study did not assess the consequence of system backups, potential failure of wastewater pump stations could result in sewer backups and if mixed with floodwaters, which could result in health impacts for people, and aquatic and riparian habitats, exposed to contaminated floodwater. Recovery efforts would be more complicated if buildings remain contaminated following the recession of floodwaters (e.g., drywall may need to be removed and disposed of).

Power outage is the consequence of BC Hydro infrastructure inundation. As discussed in Appendix C, the assessment methodology involved two components: assumed de-powering of flooded areas by BC Hydro to avoid dangerous conditions and the flood-related failure of sub-stations resulting in power outages. Measured by the impacted population, the assessment shows that there is a large increase in the impact under Scenario E as compared to Scenario C. This is related to the predicted outage for the service area of BC Hydro's John Lawson sub-station located in West Vancouver as well as the Norgate Substation in the District of North Vancouver, which are both only inundated in Scenario E.

Under Scenario E, most of the Port Authority's North Shore terminals experience inundation as previously summarized in the flood mapping discussion (Section 5.2). The potential economic disruption associated with this exposure was assessed separately by a transportation economist and is presented in Section 6.3 below. The impacts would be less under Scenario C as some terminals would not be inundated.

Economy

Widespread coastal flooding would have an economic impact on North Shore residents, employers, and employees. The North Shore economy is integrated into the wider Lower Mainland, provincial, and national economic systems, and there would also be measurable indirect economic impacts. Furthermore, the Port plays an important role in the local, provincial and national economy, acting as a western gateway to global markets.

For residents and employers, flooding could result in damage to buildings and contents. This assessment provides an estimate of total building-related replacement costs, which were found using the HAZUS model (see Appendix C for methodology). It does not investigate flood insurance penetration and the issue of insurable vs. non-insurable losses. Residential overland flood insurance is an emerging product in Canada.

For employers and employees, flood damage and power outages may result in the temporary closure of the business. A business disruption analysis based on the work by Chang et. al. (2008) was used to assess business disruption for the municipal and Squamish Nation partners in terms of the number of temporary business closures based on flood damage and power outage. The analysis was supported by business information from business licenses. The business disruption assessment does not consider Port terminal operators, which are assessed as a wider economic disruption associated with flooding of the Port Authority's North Shore operations (see Section 6.3). Additional factors not included in the assessment that may impact business closure following a flood can include disruption of other services (e.g., water, wastewater, and transportation), insurance administrative requirements, and regulatory health and safety requirements related to the overall recovery. The duration of temporary business closure has not been estimated as it is difficult to predict, but the timeline of weeks to months may be likely for a major flood. While not included in the assessment, businesses experiencing temporary closure have indirect impacts including revenue and wage loss.

Consequence results across the North Shore overall are summarized in Table 6-6 and are discussed below.

Table 6-6: Economy Sector Consequence Results (North Shore)

Consequence Variable	Scenario C (1 m SLR, 10% AEP event)		Scenario E (2 m SLR, 0.5% AEP event)	
	Value (unit)	*% of North Shore Total*	*Value (unit)*	*% of North Shore Total*
Building damage and contents replacement cost	$915 million	2.4%	$2.71 billion	7.2%
Temporary (non-Port) business disruption due to inundation or power outage	468 businesses	3.6%	1,902 businesses	15%

Under Scenario C, building damages across the North Shore are expected to exceed $900 million. The cost of damages is expected to almost triple to nearly $3 billion under Scenario E. These values include estimates for building damage within Port lands.

While the Scenario E damage cost estimate is a larger number, the Scenario C estimate is a significant finding because it has a 10% probability of occurring in any given year (annual exceedance probability, AEP) after 1 m of sea level rise is reached, anticipated by the Year 2100. Unlike Scenario E with an AEP of only 0.5% and a longer timeline (Year 2200), the Scenario C event is not rare or extreme.

For comparison, the North Shore has experienced multiple 10% AEP rainfall events over the last several years and damages have generally been minimal in comparison to these estimates; this is partly because rainfall management infrastructure on the North Shore is generally designed to convey 10% AEP events without surface flooding.

The business disruption analysis shows a significant increase in impacts between Scenario C and Scenario E. This is again linked to the BC Hydro sub-stations that are only inundated under Scenario E and further emphasizes the importance of power outages in the overall consequences.

Table 6-7 presents a breakdown of the building damage and contents replacement cost by building type. These results are based on census results and include all buildings in all partner jurisdictions (including the Port and Squamish Nation).

Table 6-7: Building Damage and Contents Replacement Cost by Building Type (North Shore)

Building Type	Scenario C (1 m SLR, 10% AEP event)		Scenario E (2 m SLR, 0.5% AEP event)	
	Cost	*% of Total for All Building Types*	Cost	*% of Total for All Building Types*
Residential	$53.3 million	0.2%	$143 million	0.6%
Public/Governmental	$10.8 million	1.0%	$26.2 million	2.3%
Commercial	$719 million	6.6%	$2.25 billion	21%
Industrial	$129 million	12%	$292 million	27%
Agricultural	$3 million	23%	$4 million	30%
Total	$915 million	2.4%	$2.71 billion	7.2%

Under both scenarios, the most significant losses are from commercial and industrial buildings (combined $848 million in Scenario C, and $2.54 billion in Scenario E). This reflects inundation of the North Shore's waterfront commercial, industrial, and Port land uses. Note that the agricultural building type category includes agri-food related buildings.

Table 6-8 presents a breakdown of the business disruption assessment results by business type.

Table 6-8: Temporary Non-Port Business Closure by Business Type (North Shore Totals)

Business Type	Scenario C (1 m SLR, 10% AEP event)		Scenario E (2 m SLR, 0.5% AEP event)	
	Number of Temporary Closures	*% of Total for All Business Types*	Number of Temporary Closures	*% of Total for All Business Types*
Finance and real estate	18	0.6%	62	2.0%
Health services	19	2.2%	151	18%
Manufacturing	37	16%	65	29%
Mining, construction, transport, and utilities	72	3.6%	257	13%
Service industry and others	204	4.0%	941	18%
Wholesale and retail	118	7.5%	426	27%
Total	468	3.6%	1,902	15%

The business disruption assessment reveals that most business closures would be in the service, and wholesale and retail industries (combined 322 in Scenario C and 1367 in Scenario E). This reflects the major commercial shopping areas and business parks located in the floodplain on the North Shore, including at Ambleside, Park Royal, Norgate (Capilano Mall and Auto Mall area), and Maplewood.

Transportation

Transportation on the North Shore impacts and influences all other sectors. Inundation of transportation routes could have wide-reaching impacts on North Shore residents and workers if their travel routes, and goods movement routes, are inundated.

The North Shore is home to major regional transportation corridors for multiple transportation modes. Several of these corridors overlap with the coastal floodplain for both scenarios as apparent on the Appendix B flood maps, including:

- The Trans-Canada Highway (Highway #1)
- Phibbs Exchange transit hub;
- The major east-west arterial road network comprising Marine Drive, Dollarton Highway, Main Street, and Dollarton Highway;
- Major transit routes along east-west routes and Translink's Sea Bus terminal at Lonsdale Quay; and
- The east-west rail network that services the Port Authority's North Shore operations.

As sea level rises, transportation impacts will vary by the scale and severity of flooding.

A large, rare coastal flood could damage transportation infrastructure and limit the access of emergency responders. There would likely be a period of reduced economic productivity following a flood as transportation infrastructure is repaired and reinstated.

Without adaptation, smaller but more frequently-occurring flood events and high tides can result in flooding of important routes requiring temporary closures until the low tide when the water level lowers. The repetitiveness of shallow, nuisance flooding can result in loss of economic productivity through increased traffic congestion.

Transportation consequences were assessed using spatial analysis to identify segments of major transportation corridors, emergency response routes, bus routes, and bus stops exposed to inundation. The number of gas stations exposed to inundation and power outage was also assessed.

Consequence results across the North Shore overall are summarized in Table 6-9 and are discussed below.

Table 6-9: Transportation Sector Consequence Results (North Shore)

Consequence Variable	Scenario C (1 m SLR, 10% AEP event)		Scenario E (2 m SLR, 0.5% AEP event)	
	Value (unit)	*% of North Shore Total*	*Value (unit)*	*% of North Shore Total*
Emergency routes exposed to inundation	2 km	3.2%	5 km	6.7%
Major routes exposed to inundation	36 km	4.4%	57 km	7.1%
Bus routes exposed to inundation	30	13%	31	14%
Bus stops exposed to inundation	21	2.3%	36	4.0%
Gas stations exposed to inundation or power outage	8	21%	12	32%

Transportation consequences on the North Shore are primarily concentrated in higher density commercial areas around Lonsdale Quay (Seabus terminal), Norgate (Capilano Mall), and Park Royal, with the exception of Phibbs Exchange which is also impacted.

As previously discussed, the Scenario C event is a more frequently (10% AEP) occurring event after 1 m of sea level rise, and, without adaptation, the potential for repeated impacts could strain the economic productivity of the impacted commercial and business areas, including Norgate and Maplewood, the liveability of the residential areas, including Ambleside and Squamish Nation neighbourhoods, and access for North Shore residents and workers travelling through these areas.

While the relative proportion of affected emergency response routes exposed to inundation under Scenario C (3.2%) and Scenario E (6.7%) are small, these are the main emergency routes for the coastal floodplain areas. As presented on the transportation sector consequence map in Appendix C, the major east-west response route along Marine Drive to Dollarton Highway are partially disrupted under both scenarios. Other emergency routes that are impacted include portions of Lonsdale Ave., the Trans-Canada Highway, and 15th Street in West Vancouver. A detailed assessment of alternative emergency response routes was not conducted, and the redundancy of the emergency response system was not studied.

A notable proportion of gas stations on the North Shore are expected to be exposed to inundation or power outage under Scenario C (21%) and Scenario E (32%). A power outage for gas stations means that gas cannot be pumped. Temporary closure of these gas stations would limit available supply on the North Shore. Furthermore, inundation could cause contamination of neighbouring properties, with potential risk to public and ecological health (not assessed in this section).

6.2 Qualitative Flood Risk Assessment

A high-level, qualitative risk assessment was conducted using the coastal flood consequence assessment results (above) to identify elements in each sector that are perceived as a higher concern compared to other elements, and therefore can be considered a higher priority for adaptation planning.

The assessment uses the coastal flood consequence assessment results (Scenario C and Scenario E); elements are generally physical assets or populations from the consequence assessment variables discussed previously.

Risk is a function of the probability and severity of a consequence occurring. An overall risk profile encompasses the full spectrum of potential events, from extremely rare events which may have very high consequences to much more frequent events with minor consequences. It is important to note that both rare and frequent events can be key risk contributing events depending on the severity of consequences. This is conceptually described in Figure 6-1 where relatively higher risk is defined by red areas and relatively lower risk is defined by green areas, and yellow represents moderate relative risk. The figure shows that the overall risk contribution from a rare event with high consequences can be similar to a frequent event with small consequences as both areas are yellow coded.

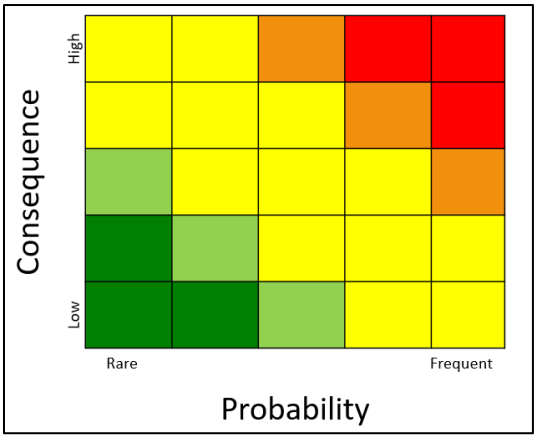


Figure 6-1: Example of a risk matrix.

In the flood risk context, the probability is generally dictated by the hazard and the performance of flood protection infrastructure.

A qualitative risk assessment exercise was conducted with the Technical Steering Committee members to enable discussion and identification of which sectors and elements as reflected in the flood consequence assessment results may be considered priorities for adaptation planning. Elements are the subject of the variables that were measured in the flood consequence assessment (e.g., "vulnerable population" is the element that was the subject of the variable which counted the number of people aged less than 16 or over 65, or having an annual income less than $20,000 who were exposed to inundation and/or power outage).

The qualitative assessment is not considered a comprehensive risk assessment, which would require an assessment of a larger number of flood scenarios across different sea level rise time horizons.

The assessment involved a two-step process, with a preliminary questionnaire distributed to all Technical Steering Committee members in March 2019 requesting their input and relative rating of the severity of the consequences under Scenario C and Scenario E. This was followed by a Risk Assessment Workshop in June 2019 to confirm risk ratings and discuss implications across the region overall.

The consequence severity ratings for Scenario C and Scenario E were used to create simplified risk matrices, using the template provided in Figure 6-2.

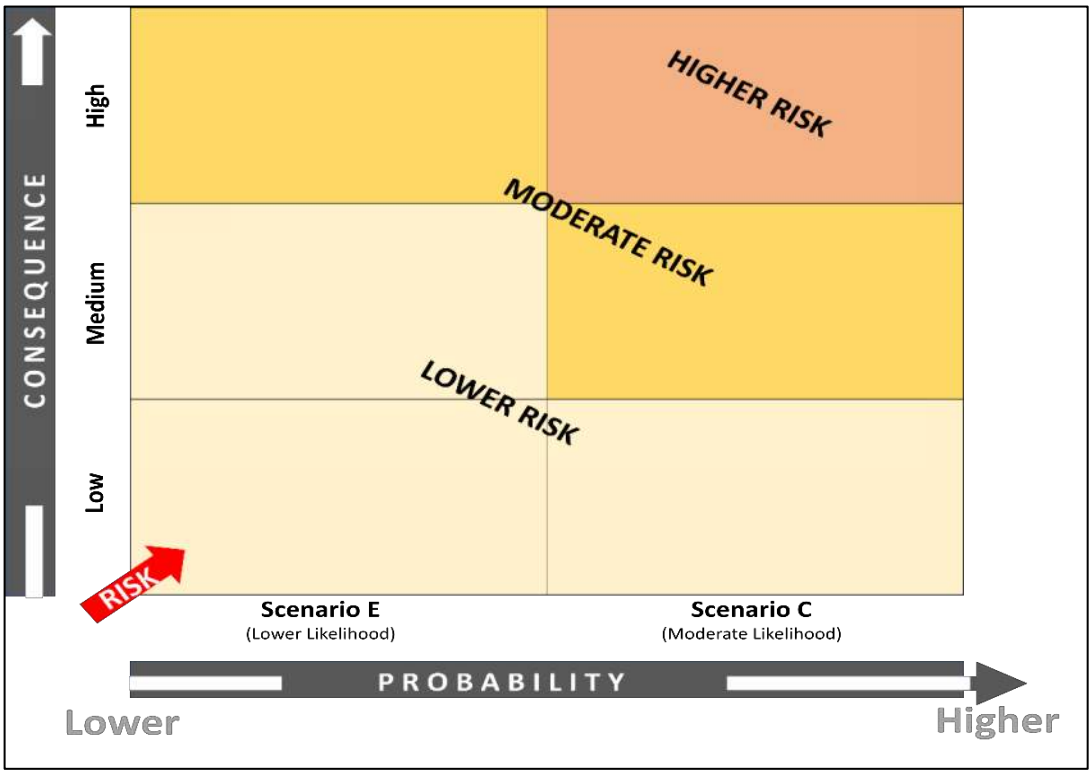


Figure 6-2: Qualitative Risk Assessment Template

The matrix was applied to each sector where the relative consequence severity (low, moderate, high) was plotted against the scenario probability. To enable the exercise, it was assumed that Scenario C and Scenario E are directly comparable regardless of the fact that Scenario C involves 1 m of sea level rise and Scenario E involves 2 m of sea level rise. Accordingly, Scenario C was treated as the higher probability event (a 10% AEP event) and Scenario E (0.5% AEP event) as the lower probability event.

The risk matrix results were averaged for all partners and an overall risk rating was applied to each element based on its maximum risk rating in the matrix template.

Table 6-10 presents a summary of the major sector elements categorized by relative risk based on the qualitative risk assessment workshop for the North Shore.

Table 6-10: Summary of Qualitative Risk Assessment Results (North Shore)

Higher Relative Risk Elements	Moderate Relative Risk Elements	Lower Relative Risk Elements
• Buildings • Wastewater and stormwater pump stations • Businesses • Emergency routes	• General population • Vulnerable population • Healthcare facilities • Social services • Receiving environment (related to hazardous waste sites, contaminated sites, and debris from damage) • Archaeological and heritage sites • Emergency services and operations • Electrical network • Economic impact (specifically related to building damage) • Major road routes • Bus routes • Gas stations	• Schools and daycares • Parks • Heritage buildings

Based on this assessment, the most concerning and more immediate issues to consider for adaptation planning for the North Shore as a whole are: building damage, wastewater infrastructure (pump station) damage, business impacts, and flooded emergency routes. Buildings and businesses may feature prominently given the large commercial/industrial land use exposure as compared to residential area exposure. Pump stations and emergency routes may stand out because of the concern risk assessment workshop participants may have regarding the impact on the level of service and the potential for slow recovery. It is important to note that this is only single, initial, regional averaged snapshot of risk. Moderate and lower risk elements are considered important as well and may have been ranked as higher risk by individual partners and communities.

With only 2 flood scenario consequence results available, the risk assessment is limited in its ability to reflect that risk is formed by a spectrum of events ranging from very rare flood events with very severe consequences to more frequently occurring events with much lower consequences. Additionally, the qualitative assessment only highlights elements perceived to be of ***relatively*** higher or lower risk as compared to other elements in the same sector.

It should also be noted that the assessment does not rate risk in absolute terms. This would require the definition of tolerable and non-tolerable risk in the form of a consequence rating system (for example, defining what percentage of a community's population displaced should be considered a "high" consequence). Such definitions (at a local, regional, or nation scale) do not currently exist for the variables included in the consequence assessment. Future flood risk assessment guidelines forthcoming from the Government of Canada's flood mapping guidelines initiative may help start to fill this gap.

Appendix D provides a more detailed breakdown of the qualitative risk assessment methodology and results, including separate results for each North Shore partner.

6.3 Port Economic Consequence Assessment

DTCI was retained to provide economic impact analysis for the North Shore port terminal or industrial operations. The purpose of this section is to provide a brief summary of this analysis. The full report is contained in Appendix E.

The DTCI analysis considered three of the five coastal flood scenarios developed for the project, as the Port:

- Scenario B: 0.5 m sea level rise, 10% annual probability stillwater level (10-year return period)
- Scenario C: 1 m sea level rise, 10% annual probability stillwater level (10-year return period)
- Scenario E: 2 m sea level rise, 0.5% annual probability Stillwater level (200-year return period)

In addition to Scenarios C and E (which were used in the broader consequence assessment), the Port Authority elected to also use Scenario B in its fact-finding site visits to present a near-term scenario within their planning horizons of 30 to 40 years.

For each of Scenarios B, C and E, the estimated physical impacts of coastal flooding for each major operator were used to develop key economic impact indicators including cargo losses, equipment losses, supply chain costs, traffic diversion and labour income lost. The physical impacts on operations were estimated through individual meetings with staff for each major operation. Vulnerable assets identified in the research include marine terminals, low-lying electrical infrastructure and transportation infrastructure such as rail lines and roads.

Major port terminal or industrial facilities on the North Shore include:

- Kinder Morgan Vancouver Wharves,
- Fibreco,
- Vancouver Shipyards,
- Vancouver Drydock,
- Richardson International,
- Cargill,
- Neptune Bulk Terminals,
- G3 Canada,
- Lynnterm,
- Univar Canada, and
- Chemtrade Chemicals.

Table 6-11 provides a summary of the commodity traffic moving through the Port Authority North Shore Trade Area in 2017.

Table 6-11: North Shore Trade Area Commodity Traffic 2017 (000 Tonnes)

Commodity Group	Imports	Exports	Total
Animal Products, Dairy & Produce	0	0	0
Chemicals, Basic Metals and Minerals	2651	1537	4188
Coal	0	7618	7618
Consumer & Related Goods	0	0	0
Fertilizers	0	8298	8298
Forest Products	0	2283	2283
Grain, Specialty Crops & Feed	0	11186	11186
Machinery, Vehicles, Construction & Materials	112	3	115
Petroleum Products	46	126	172
Grand Total	2810	31052	33862

Trade Value

The value of trade moving through the North Shore Trade Area reached approximately $15 billion in 2017.

Vessel Calls

The number of vessel calls to the facilities listed above was 956 in 2017. Vessel traffic is expected to grow in the coming years.

Economic Impact Methodology

This assessment is based on a methodology developed for the U.S. Transportation Research Board (TRB) and consists of a sequential five-step process:

1. Identifying the direct and immediate physical effects of a network disruption;
2. Identifying current and future affected network flows by facility and link;
3. Identifying supply chain characteristics and parameters;
4. Modelling the response of the supply chain to disruptions and delays; and
5. Modelling the economic impacts of network disruptions.

Economic Impact Findings

Table 6-12 provides a summary of the impact findings for each scenario.

Table 6-12: Summary of Economic Impacts on Current Port Operations by Scenario

Coastal Flood Scenario	Impacts on Current Operations
B (0.5 m SLR, 10% AEP event)	Not significant – any disruption is within the bounds of current variability due to weather. Minor issues that occur today will worsen, including but not limited to: • Flooding of parking areas & storm systems • Flooding & contamination (with seawater) of underground storage chambers and conduits • Difficulty for certain vessels loading at high tides due to height • Periodic flooding of Mountain Highway underpass at CN rail during heavy rain events
C (1 m SLR, 10% AEP event)	Moderate – any disruption is within the bounds of current variability due to weather, apart from specific vulnerable locations where disruptions in operations could occur due to site access flooding, such as: • Rail and road access to Kinder Morgan Vancouver Wharves (KMVW), Fibreco, and employee access and parking at Seaspan Shipyards as a result of flooding at the eastern edge of the KMVW site along McKeen Avenue. • Road access to Lynnterm and Univar as a result of flooding overland from the Lynnterm marina site onto local streets and/or the Mountain Highway underpass. There are also facilities which are vulnerable to extended disruptions of operations at this level of sea level rise, including: • Allied Shipbuilders could experience major damage to the upland works yard and building shops, and there could be major damage to the machine shop and fabrication shops, with loss of heavy equipment at ground level that would render the shipyard inoperable for a long period.
E (2 m SLR, 0.5% AEP event)	Severe: overall, the economic impacts of Scenario E would disrupt operations at all facilities for an extended period of time. Potential flooding impacts and costs for the North Shore for this scenario (assuming a 7-day business disruption period): • Cargo losses (mainly potash at Neptune Bulk Terminals, as other bulk commodities, are not seriously affected by short-term immersion): total loss would be 480,000 tonnes or 1.5% of total (2017) North Shore tonnage. • Equipment losses, mainly sub-surface dumping pits and underground conveyors at multiple bulk terminals and low-lying electrical substations and other infrastructure. • Traffic diversion to other ports to avoid losses: would result in a loss of 140,000 tonnes, approximately 0.4% of total (2017) tonnage. • Lost labour income: $2.2 million. • Supply chain losses of $220 million.

6.4 Habitat Consequence Assessment

As described in Section 5.1, the size and extent of the intertidal area will change in response to sea level rise and future shoreline land-use decisions. A high-level intertidal area change analysis considered land-use decisions ranging from managed retreat to welcome intertidal area expansion, to preventing tidal inundation of inland areas through vertical barriers (e.g., seawalls and dikes).

The intertidal area change analysis results showed that:

- A managed retreat approach would result in a 36% reduction in intertidal area under 1 m of sea level rise and a 26% increase under 2 m of sea level rise when inland areas would be converted into intertidal areas; and
- A prevent approach would result in a 50% reduction in intertidal area under 1 m of sea level rise and an 81% reduction under 2 m of sea level rise.

Additional analysis was conducted to describe the ecosystem consequences that would result from these intertidal area change projections. To explore the impact of intertidal area change on intertidal and marine riparian habitats, the current habitat types were mapped and compared to the projected future intertidal areas. The methodology and limitations are described further in Appendix F. Results are summarized below and are further described in the appendix as well.

As the low tide line moves inland under sea level rise, existing intertidal habitat that is located below the future low tide line will be lost (converted to sub-tidal). If the high tide line moves inland (i.e. if no vertical barriers are constructed), additional upland areas will be converted to intertidal areas.

The analysis only focused on existing habitat types that would be lost as it is not possible to predict if and what types of habitats would be established in future intertidal areas.

Across the analysis area (between Point Atkinson in the District of West Vancouver to North Woodlands along Indian Arm in the District of North Vancouver), bull kelp habitat will have the greatest percentage habitat loss under 1 m of sea level rise (-98.6%) and black felt mat habitat will have the greatest percentage habitat loss (-100%) under 2 m of sea level rise. Sea lettuce and fucus habitats are found abundantly along the North Shore shoreline and were found to be greatly impacted, with more than 50% of the habitat type area lost under 1 m of sea level rise and more than 80% under 2 m of sea level rise. Sea lettuce and fucus habitats are significantly impacted because they are often found at the lower elevations of the intertidal area, and are therefore more susceptible to intertidal area change.

As stated above, the analysis does not predict what future habitats will establish or how existing habitats within the intertidal zone may change. Accordingly, the primary value of this analysis is a screening-level review of potential impacts and justification for adaptation measures to enable future habitat, discussed in Section 7.

Impact on Marine Riparian Zones

While the focus of the analysis was on intertidal habitats, it's important to note that intertidal area change may also impact marine riparian habitat.

The marine riparian zone is defined as the terrestrial land cover located immediately above the current high tide and is influenced by its proximity to the ocean but is not subject to daily inundation. On the North Shore, the marine riparian zone is a mix of urban development areas, Port lands, park spaces, and natural areas.

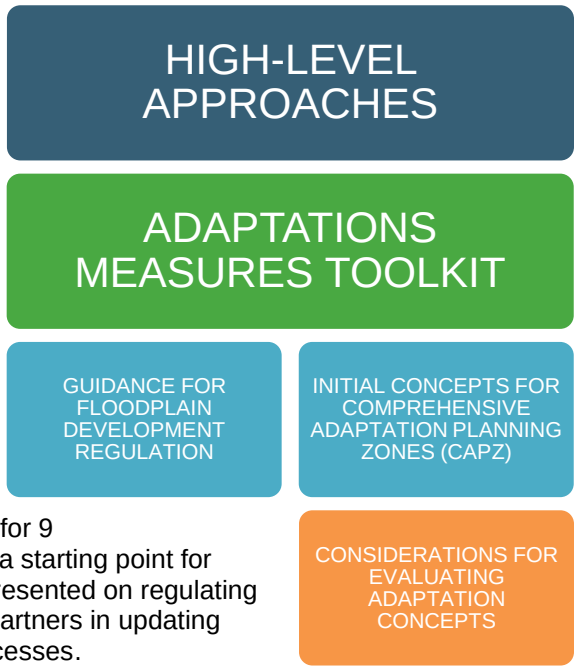
Under a managed retreat and naturalization approach, the inland movement of the high tide line would result in a loss of marine riparian land cover type as this area becomes part of the intertidal zone. It is estimated that under this approach, approximately 360,000 m^2 of coniferous and deciduous tree land cover would become part of the intertidal area under 1 m of sea level rise, with the value increasing to approximately 420,000 m^2 under 2 m of sea level rise. Additional results for other land cover types are presented in Appendix F.

For both the intertidal area and marine riparian habitat consequence assessment, the analysis shows that there is a strong link between shoreline land-use decisions and habitat impacts and opportunities for future habitat creation/preservation.

7. Adaptation Approaches and Concepts

In the context of sea level rise, adaptation is an umbrella term for all of the approaches, measures, and actions that communities undertake to adjust and be resilient to a changing sea level and all of the associated hazards and risks.

This section provides an introduction to and resources for sea level rise adaptation for the North Shore. This is intended as a foundation to support on-going adaptation planning by the North Shore partners. Specific actions to advance collaborative planning efforts are provided in Section 8.



The resources in this section are organized in a layered format as presented in the adjacent graphic. High-level adaptation approaches were used to guide the development of a toolkit of adaptation measures to support site-specific planning on the North Shore. Initial adaptation concepts are presented for 9 comprehensive adaptation planning zones to serve as a starting point for future planning zone level projects. Guidance is also presented on regulating development in the floodplain to support North Shore partners in updating their individual development review and regulation processes.

7.1 High-level Adaptation Approaches

Sea level rise adaptation is often discussed in terms of high-level approaches, typically described using the following terms:

- Resist;
- Accommodate;
- Avoid or Retreat; and
- Advance.

These high-level approaches were most prominently introduced in British Columbia via the Ministry of Environment's Sea Level Rise Adaptation Primer (Arlington, 2013). These approaches have been used to frame adaptation in the North Shore's neighbouring communities throughout Metro Vancouver.

The list of high-level approaches is presented below in terms that are most relevant to the North Shore. A brief description and an example are provided for each approach. Pros and cons listed for each approach reflect input from public and stakeholder engagement, such as February 2020 workshops in DNV neighbourhoods.

Resist

Resist (also known as protect) consists of structural measures to keep tidal and flood inundation out of developed areas. Resist addresses risk by reducing the likelihood of exposure for people, property, infrastructure, and other elements. It is generally the category that has been considered first among the suite of approaches (as the traditional form of flood defence), however as sea levels continue to rise, the cost of this form of adaptation can become excessively expensive to construct, given the height needed and the overall footprint of the dike necessary to reach that height. Without careful planning, the resist approach can also be inflexible in the face of changing sea level rise projections.

Examples of 'resist' strategies include traditional hard-engineered solutions like sea dikes, seawalls, storm surge barriers, and breakwaters, as well as nature-based measures such as mudflats and marsh building which can be combined with traditional engineering measures to create hybrid measures that provide environmental and social co-benefits.

Given that it is the conventional approach for coastal flood protection, there are many examples of adaptation concepts based on a resist theme. Possibly the most prominent local example is the City of Richmond's Lulu Island perimeter dike. The 49-km dike is the primary measure in managing tidal and coastal storm flood risk and is supplemented by internal drainage infrastructure and policy measures, including flood construction levels and land raising through redevelopment policies. Updated in 2019, the City of Richmond's Flood Protection Management Strategy (City of Richmond, 2019) outlines steps to adapt its perimeter dike to rising sea levels and increasing risk, including moving towards a higher level of protection such as the 10,000-year return period (0.01% annual exceedance probability) for dike performance.

Pros of the resist approach include:

- The ability to implement large-scale, standalone projects and pursue potential development opportunities.
- Could have less reliance on external measures such as redevelopment pace and proportion of property owners with flood insurance that is not fully within the control of communities.
- Pursues 'status quo' – neighbourhood boundaries remain the same and existing land uses can remain in place.
- Can be linked with recreational trails and/or other linear corridor works (e.g., roads, railways etc.).

Cons of the resist approach include:

- Complex implementation including land tenure issues, and lack of right-of-ways or space for structures.
- Complex interaction with flood management on major creeks and rivers, including the 'bathtub' effect of sea dikes preventing creek / river flood flows out into the ocean. May trigger additional diking along creeks and rivers. Transfer of risk issues would need to be studied carefully.
- Can lead to an overall increase in flood risk by introducing dike breach hazard for areas immediately behind the dike (which could lead to more hazardous flooding than without a dike), by enabling higher-density development (more people and property in the floodplain) as a means to pay for the measures, and by leading to a false sense of safety (resist reduces the likelihood of exposure, but does not completely eliminate it or risk).

- Major changes and investments required for drainage systems (i.e. potential drainage pump station at each stormwater outfall – this is especially challenging for urban areas without room for drainage storage canals or forebays).
- Environmental impacts including coastal squeeze, habitat impact, and disruption of coastal dynamics (if works are not set back).
- Not an effective approach if sea level rise projections significantly increase (e.g., several meters) as the cost, footprint, and technical factors may outweigh the benefits.
- Potential to limit waterfront access or views for existing waterfront properties (e.g. shoreline dikes).

Accommodate

The accommodate (also known as tolerate) approach allows continued occupation of the coastal floodplain, while also allowing the temporary inundation from tides and/or storm floodwaters into developed areas. The accommodate approach manages risk by reducing the consequences or impacts of exposure. This is achieved through floodproofing of buildings and infrastructure, but also economic and social measures to increase the community's resilience.

A common example measure is dry floodproofing of buildings (i.e. raising the elevation of habitable spaces using fill, structure, or piles). This is most applicable to new construction, but retrofits to existing buildings can also implement and are more common in other jurisdictions (e.g., flood-doors and barriers in the United Kingdom). Another common example measure is household and business flood insurance and general flood preparedness.

The accommodate approach is currently the status quo for most coastal flood risk management on the North Shore where communities use a variety of formal and informal tools to regulate development on the coastal floodplain without the implementation of major structural flood protection works (resist) to date. Key challenges with this approach are the reliance on redevelopment for risk reduction and the reliance on third parties to also implement the approach, particularly for infrastructure (e.g., third-party utilities, transit, etc.).

Land raising through development is another variation of the accommodate approach. Land raising is different than floodproofing of buildings in that it aims to raise the ground elevation of the entire development parcel such that it is lifted out of the floodplain or at least the probability of flooding is significantly reduced. As presented later, there are many opportunities for land raising to be a very effective approach on the North Shore, particularly in industrial floodplain areas where parcel sizes are large and major mixed-used redevelopment areas where lots will be combined and density increased. These situations allow for easier implementation of land raising. In industrial areas where the implementation of shoreline dikes may impede water access, land raising can be an effective solution by enabling individual properties to choose to raise their property elevation based on their flood risk tolerance. The local government can raise the road network to provide safe access/egress during a flood and individual parcels can have more agency in choosing when and how much they want to raise their grade. This approach would also reduce the reliance on the redevelopment of waterfront parcels to enable the implementation of a specific dike alignment. Additionally, land raising can also be advantageous over diking by incorporating new overland drainage routes into the land raising plans instead of dikes that may trigger the need for the construction of drainage pump stations. Finally, another advantage of land raising is that it may be compatible with site capping practices typically involved in the redevelopment of properties with contaminated soils. Disadvantages of the land raising approach include lack of flexibility for further adaptation without redevelopment, reliance on redevelopment for implementation, and a need for detailed coordination of development grades with

adjacent infrastructure. Land raising can also be linked with major redevelopment and land use plans. This can be viewed as an advantage or a disadvantage depending on the perspective applied. In addition to social and political perspectives related to major land-use changes, land raising through redevelopment may encourage an increase-density which increases the number of people and property located within the floodplain area, though they will be raised.

Another aspect of the accommodate approach is tolerate, which involves being informed on and choosing to accept or tolerate a certain level of flood risk, without further interventions for risk reduction. Risk tolerance is discussed further as part of the adaptation measures toolkit in Section 7.2. Conversely, floodplain building regulations (including flood construction levels and other measures falling within the accommodate category) apply everywhere within the floodplain, even if structural measures are built.

Pros of the accommodate approach include:

- Well-suited for gradual implementation in pace with redevelopment and infrastructure upgrades. Most successful when development is higher density allowing for mass raising of land and less practical when development is single-family homes which require significant effort coordinating grading at site boundaries.
- Potential to share responsibility and risk reduction costs with development and private insurance markets.

Cons of the accommodate approach include:

- Implementation pace is limited based on the timing of development and infrastructure upgrades. Risk may not be reduced over time in areas without redevelopment.
- Requires a whole-system approach, including third-party infrastructure, to be flood resilient.
- Difficulty assessing risk tolerance.
- Significant education and household-level responsibility needs (e.g., difficult to enforce how people use areas below flood level within private property).
- Typically requires variances for additional height (to accommodate raising buildings) or other development regulation changes, which could impact neighbourhood character.
- Infrastructure that is not floodproofed may require additional maintenance after a flood event, (e.g. debris clearing on roads designated for floodwater conveyance).

Avoid / Retreat

The avoid/retreat approach focuses on land use planning to limit new buildings and infrastructure within the coastal floodplain (i.e. avoid), as well as gradually relocating buildings and infrastructure away from areas at high risk (i.e. retreat).

This approach is the most effective risk reduction approach over a long timescale, but it faces challenges including other pressures on land use and land availability. Managed retreat is starting to gain traction in Canada as an effective and socially-accepted risk reduction approach, including prominent post-flood property acquisition examples in Grand Forks, British Columbia and Alberta. However, most examples are in lower-density areas and still face implementation challenges including equity concerns related to financial compensation.

Managed retreat is an emerging area of policy that is expected to continue to evolve and receive attention as policy think-tanks encourage governments to consider them (e.g., Thistlethwaite et al, 2020) and different levels of government incorporate them into programs (e.g. the Government of Canada's Disaster Mitigations Adaptation Fund (DMAF) lists property acquisition for natural infrastructure projects such as coastal wetlands as an eligible expenditure).

Pros of the avoid/retreat approach include:

- Highly effective risk reduction approach.
- Opportunity for habitat, cultural, and recreational land uses, and potential for increased public access to waterfront.

Cons of the avoid/retreat approach include:

- Could result in the loss of long-term development potential and related impacts to tax revenue.
- Potential costs associated with relocation may be more than structural risk reduction measures in high-density areas.
- Equity issues regarding who must move versus who has the financial ability to floodproof personal property and remain in place.

Advance

The advance approach (also known as attack) consists of various scales of land reclamation to provide space for implementation of resist and accommodate approach measures. This can include new land for construction of engineered or nature-based shoreline wave attenuation works, dikes, new development on raised lands, and combinations of these measures. A major challenge and disadvantage of land reclamation is the potential for negative impacts to aquatic habitat under the land reclamation footprint and potential for indirect effects to the larger ecosystem. Examples of this approach on a large scale are from Hong Kong, Singapore and the Netherlands, which all have high population densities and small land bases.



Restored shoreline of Cates Park (Whey-ah-Wichen)

A large-scale Canadian example is Waterfront Toronto's Don River mouth improvement project on Lake Ontario that involves filling in a portion of Lake Ontario to create an island for development.

The advanced approach can also include smaller-scale interventions along existing shorelines where only a relatively small amount of additional land is required for the implementation of shoreline erosion or flood protection works. A successful North Shore example of this is the 2013 Cates Park (Whey-ah-Wichen) coastal erosion protection project conducted by the District of North Vancouver in partnership with the Tsleil-Waututh Nation. The project involved the placement of imported sand and gravel on a portion of the existing shoreline, which was eroding resulting in damage to cultural, archaeological, and

physical assets. The placed material advanced the shoreline edge into Burrard Inlet by several meters, restoring its previous location. The project can also be viewed from a nature-based perspective in that, as opposed to a conventional riprap erosion protection revetment, natural shoreline materials were used to mimic ongoing physical processes and reduce the shoreline erosion hazard by re-establishing a shallower slope.

Pros of the advanced approach include:

- Less disruption to existing developed lands to accommodate flood protection measures.
- Potential opportunities for habitat, cultural, and recreational co-benefits.
- Potential linkage to major development opportunities.

Cons of the advanced approach include:

- Potential major impacts to intertidal and marine habitat.
- Complex regulatory and permitting requirements.
- High relative costs and likely low benefit-cost ratio if applied separately from other approaches.
- An impermanent solution that needs rebuilding over time as erosion occurs.
- Can result in increased risk if linked with increased development in the floodplain.
- Potential to limit waterfront access or views for existing waterfront properties.

The high-level ‘resist’, ‘accommodate’, ‘avoid/retreat’ and ‘advance’ approaches described above are most appropriate for framing adaptation planning discussions, and are less appropriate for detailed and area-specific planning. A common misconception is that these approaches are distinct options to choose between. In reality, adaptation concepts may be inspired by the high-level approaches, but they are developed through a combination of various measures that are each related to one or more of these high-level approaches.

7.2 Adaptation Measures Toolkit

A North Shore sea level rise adaptation measures toolkit has been prepared to enable detailed adaptation planning efforts that go beyond the high-level adaptation approaches. The toolkit is presented as a standalone document in Appendix G.

The purpose of the toolkit is to serve as a North Shore tailored adaptation resource which is a comprehensive and consistent starting point for future local area adaptation planning processes.

The multi-sectoral risk assessment and initial community engagement results were used to identify and develop measures that aim to address risk from all relevant perspectives.

The toolkit identifies 26 measures organized across the following 7 administrative categories:

- A – Planning and governance measures,
- B – Building and site measures,
- C – Community-scale structural measures,
- D – Community-scale nature-based measures,
- E – Critical infrastructure resilience,
- F – Response and recovery phase risk reduction measures, and
- G – Community and cultural resilience measures.

The toolkit provides a description for each measure and discusses examples, pros and cons, and applicability on the North Shore. Variations on implementation forms are also identified as sub-measures for each measure.

The adaptation measures are listed by category below. Refer to the toolkit document provided in Appendix G for additional information.

A – Planning and Governance Measures

Planning measures are policies and objectives that North Shore partners can use to regulate and reduce risk levels. They primarily fall under the 'avoid' approach.

The planning and governance measures in the toolkit are:

- A-1 Encourage uptake of private flood insurance,
- A-2 Flood avoidance and risk tolerance policies,
- A-3 Floodplain development management tools (also discussed in Section 7.3),
- A-4 Coastal floodplain urban stormwater management planning,
- A-5 Future intertidal area land preservation, and
- A-6 Formalize North Shore collaborative adaptation planning governance.

B – Building and Site Measures

Building and site measures are measures that are site-specific and reduce risk on an individual building or lot level. They primarily fall under the 'accommodate' approach.

The building and site measures in the toolkit are:

- B-1 Building and site-scale measures for existing properties,
- B-2 Building-scale measures for new construction,
- B-3 Parcel-scale land raising and site grading, and
- B-4 Parcel-scale wave attenuation (shoreline sites).

C – Community-scale Structural Flood Protection Measures

Structural measures are large-scale, engineered measures to reduce flood exposure. They primarily fall under the 'resist' category.

The community-scale structural measures in the toolkit are:

- C-1 Dikes and seawalls,
- C-2 Temporary and demountable flood barriers,
- C-3 Storm surge barriers,
- C-4 Internal urban drainage adaptation, and
- C-5 Nearshore wave attenuation structures.

D – Community-scale Nature-based Measures

Nature-based measures utilize landscape features (i.e. mudflats, beaches, submerged vegetation, etc.) that reduce flood risk, primarily through attenuating wave effects, while providing environmental or social co-benefits. They primarily fall under the 'resist' and 'advance' categories.

The community-scale nature-based measures in the toolkit are:

- D-1 Restoration of naturally resilient environments,
- D-2 Engineered nature-based measures, and
- D-3 Shoreline reshaping for future intertidal habitat.

E – Critical Infrastructure Resilience Measures

Infrastructure upgrading measures are strategies to increase the resilience of existing critical infrastructure. They primarily fall under the 'accommodate' approach.

The critical infrastructure resilience measures in the toolkit are:

- E-1 Municipal pump station resilience,
- E-2 Power transmission infrastructure resilience, and
- E-3 Transportation infrastructure resilience.

F – Response and Recovery Phase Risk Reduction Measures

Response and recovery measures can be planned in advance to make the consequences of flooding less severe and to leverage the recovery phase for effective and long term risk reduction. They primarily fall under the 'accommodate' and 'avoid/retreat' approaches.

The response and recovery phase measures in the toolkit are:

- F-1 Flood forecasting and operational planning, and
- F-2 Recovery phase risk reduction.

G – Community and Cultural Resilience Measures

Community and cultural resilience measures encourage preparedness from other actors and aim to reduce risk to cultural assets. They primarily fall under the 'accommodate' approach.

- G-1 Public awareness and risk reduction empowerment,
- G-2 Protection of cultural sites, and
- G-3 Empowering non-governmental actors to increase resilience.

7.3 Regulatory Tools for Development in the Coastal Floodplain

The coastal flood risk assessment has shown that building damage and potential displacement of occupants are significant risk contributors. Given the multi-decade timeline of sea level rise projections, the regulation of development within the current and future coastal floodplain will play an important role in risk reduction on the North Shore.

This sub-section supplements toolkit measures related to development control by providing a discussion of existing policies, provincial guidelines, and a suggested approach for updating existing policies. This sub-section focuses on the following key topics: flood construction level (FCL), setback distance between shoreline and structures, and permitted uses below the FCL.

Regulatory tools discussed in this sub-section apply to all current and future floodplain areas regardless of whether structural flood protection measures are implemented in wider floodplain areas, as discussed in Section 7.4 which focuses on comprehensive adaptation planning zones. Regulatory tools for managing development are critical for the majority of the North Shore's shoreline length where sea level rise flood impacts will be limited to the first row of development directly adjacent to the shoreline.

Existing Policies

With the exception of NSEM, each of the North Shore partners is responsible for regulating development within the coastal floodplain in their jurisdiction and each takes a slightly different approach.

DWV has currently retained a coastal engineering consulting firm to provide a review of coastal flood construction levels in West Vancouver which may support the development of a coastal development permit area (DPA). Currently (until the DPA is implemented), DWV does not have a formal policy tool, such as a floodplain by-law, for floodplain management. In lieu of a formal policy tool, section 56 of the Community Charter authorizes DWV's chief building official to require a report by a qualified professional (QP) to describe flood hazards and to certify the conditions under which a development may be used safely for the intended use. In conducting flood hazard assessments, QPs and DWV staff consider both provincial flood hazard area land use management guidelines (MWLAP, 2018) and professional practice guidelines for legislated flood hazard assessments issued by Engineers and Geoscientists BC (EGBC, 2019). Provincial guidelines are discussed further below.

DNV uses its creek hazard DPA to regulate most development in the coastal floodplain. While intended for creek flood hazards and steep creek geohazards, the creek hazard DPA does cover some, not all, of the coastal floodplain in DNV (refer to the 2014 North Vancouver floodplain study (KWL, 2014)). Through the DPA, DNV requires flood hazard assessments, determination of a flood construction level and safe for intended use certifications by QPs. The DPA process also typically results in the registration of a restrictive covenant (as per section 219 of the Land Title Act) on title specifying flood hazards and conditions for safe use. The Zoning Bylaw has a setback from Ocean Natural Boundary Line that mostly applies to residential single-family zones, and the streamside protection DPA provides setbacks for watercourses, but not directly for Burrard Inlet or Indian Arm. DNV adopted risk tolerance criteria for natural hazards in 2009, but these apply to landslide and debris flow risks caused by steep slopes and creeks, not coastal flooding.

CNV updated its Sewerage and Drainage Utility Bylaw No. 6746 in 2014 based on information provided in the 2014 North Vancouver floodplain study. The bylaw designates floodplain areas, as per section 524 of the Local Government Act, and incorporates a city-wide coastal flood construction level of 4.5 m CGVD28. The bylaw provides flexibility to require a higher level for site-specific hazard issues (e.g., wave effects) and to allow a relaxation with the ability to require a restrictive covenant.

SN staff review development and building situations on a case-by-case basis and receive consulting engineering support as needed. Various individual flood hazard studies and flood mitigiation planning and implementation projects have been conducted for SN's North Shore reserves, including a Capilano River flood mapping project (KWL, 2020).

The PA has extensive permitting processes for development within its jurisdiction. It is understood that the PA applies internal flood construction level policies on a case-by-case basis and may require a QP flood hazard assessment report, particularly if a development site overlaps Port and DNV/CNV jurisdiction.

Provincial Guidelines

The Local Government Act, under section 524(4), requires local governments to consider provincial floodplain management guidelines in developing bylaws to regulate development in the floodplain. The province maintains flood hazard area land use management guidelines which were amended in January 2018 to include new guidance with respect to coastal areas and sea level rise.

It is important to note that the provincial guidelines are high-level and province-wide, and do not necessarily consider all local context, but rather allow for policy and decision-making flexibility at the local level.

The guidelines specify acceptable methods to calculate coastal flood construction levels, including both the more conservative 'combined' and the more statistically robust 'joint probability' methods for calculating stillwater levels (the latter was used in this Strategy).

For areas without dikes, the guidelines discourage new subdivision of land on coastal floodplains by recommending that lots should have natural ground elevation above the Year 2100 FCL. For the case of the North Shore, there is very little natural ground along the urbanized shoreline due to historic landfilling and reclamation, making this concept difficult to apply. The guidelines similarly discourage new subdivision and development of existing lots through the setback recommendations, particularly for areas without existing dikes.

The guidelines define the "future natural boundary" which is a theoretical boundary to be estimated through a calculation of wave effects associated with an extreme event (200-/500-year return period stillwater level + 200-/500-year wind-generated wave effects).

For areas not protected by dikes within the Strait of Georgia, including Burrard Inlet, the guidelines suggest a minimum setback distance based on the greater of:

- 15 m between the future natural boundary and structures; or
- Landward of the location where the natural ground elevation contour is equal to the Year 2100 FCL.

The latter condition would generally lead to lot sterilization in the coastal floodplain.

For development on existing lots, the guidelines enable relaxations for potential lot sterilization due to the setback requirement by recommending that the local development approval officer may agree to relaxation if recommended by a QP with associated conditions and a restrictive covenant.

For subdivisions, the guidelines enable relaxations for potential lot sterilization due to the natural ground elevation requirement and the setback requirement if the subdivision involves only 2 lots and other conditions.

It is important to emphasize that the above setback requirements do not apply to sites protected by dikes. The guidelines encourage the development of long term flood protection strategies including the consideration of dikes as a path to avoid lot sterilization and to enable greater flexibility in relaxations for FCLs. While not directly mentioned in the guidelines, coordinated land raising plans may be another appropriate consideration in the development of long-term flood protection strategies.

Suggested Approaches on the North Shore

This report suggests the following approaches for consideration when updating regulatory tools for floodplain development management:

1. Incorporate FCL calculation and shoreline treatment guidance into DPAs, bylaws, or other policy tools to enable consistency in FCLs for neighbouring properties:
    a. Select a preferred level of protection for the FCL in terms of a flood event probability / return period and a time horizon for sea level rise.
        i. Selecting either the 200-year return period (0.5% annual exceedance probability) or the 500-year return period (0.2% annual exceedance probability) hazard return period would be in line with provincial guidelines. The City of Vancouver, which has a similar development context to the North Shore, selected the 500-year return period for their floodproofing policies. In reality, the stillwater level difference between the 200-year return period and the 500-year return period events is minor.

ii. A 1 m of sea level rise (Year 2100) time horizon is suggested for all development.

iii. A higher level of protection and/or longer time horizon extending to 2 m of sea level rise (Year 2200) may be appropriate for critical infrastructure and post-disaster facilities.

iv. FCL requirements are independent of whether structural flood mitigation works are implemented (i.e. dike construction should not justify an exemption for FCLs).

b. Identify preferred stillwater flood level calculation method ('joint probability' method is more statistically robust than 'combined' method).

c. Identify preferred (e.g., 10H:1V engineered beach) and acceptable (e.g., 3H:1V armouring) shoreline typologies. This will help achieve consistency in wave effects calculation and calculation of FCLs for the development and neighbouring sites.

2. Encourage and enable land raising where appropriate:

   a. Land raising has multiple potential benefits for application on the North Shore versus diking, including additional robustness by raising the site partially or fully out of the floodplain and by potentially reducing the need for and size of drainage pump stations through incorporating new overland drainage routes into land raising.

   b. Develop minimum site grade land raising guidance for large parcels or special areas of multiple parcels.

   c. Provide guidance on minimum elevation requirements for adjacent road network by balancing access/egress requirements (higher elevation) against maintaining overland drainage routes to Burrard Inlet (lower elevation).

3. Develop a standardized process for requesting and reviewing QP flood hazard assessment reports:

   a. This approach was successfully applied by the Fraser Valley Regional District which partnered with Engineers and Geoscientists BC (EGBC) to develop a customized QP flood and landslide hazard assessment form and guidelines to increase the consistency of QP reports being received.

   b. The process should make direct reference to relevant EGBC professional practice guidelines, including the Legislated Flood Assessments in a Changing Climate in BC guidelines (EGBC, 2018).

4. In cases where FCLs are difficult to achieve, consider alternate means to meet the intent of risk reduction:

   a. Consider specifying tolerable land uses below the FCL if FCL is not achievable. This is preferred over an area-wide FCL exemption. In general, residential land use is the least acceptable land use below the FCL.

5. Enable the implementation of structural flood protection measures through the development process:

   a. Specify land tenure and operation and maintenance responsibility for structural measures implemented through development. In general, it is preferred that the local government be responsible for and access for operation and maintenance.

7.4 Initial Concepts for Comprehensive Adaptation Planning Zones

The coastal stillwater flood mapping described in Section 5 was used to identify 9 comprehensive adaptation planning zones (CAPZ) on the North Shore where flooding could extend well beyond the first row of development/properties (including major parks and public spaces).

Adaptation in these areas will require a combination of measures and coordination between North Shore partners and stakeholders.

Table 7-1 lists the planning zones, describing general boundaries and North Shore partner jurisdictions included in the zones. Figure 7-1 shows the locations of the zones. The majority of the zones involve more than one North Shore partner which emphasizes the need for continued collaboration in adaptation planning.

Table 7-1: Comprehensive Adaptation Planning Zones

Comprehensive Adaptation Planning Zone	Boundaries (Generally West to East)	North Shore Partners Jurisdiction
Horseshoe Bay	Bay Street from Nelson Avenue to Highway 1	DWV
Stearman Beach	Marine Drive from Piccadilly N to Sherman Street	DWV
Dundarave	Bellevue Avenue from 29th Street to 23rd Street	DWV
Ambleside-Capilano West	19th Street to Capilano River (west bank)	DWV, SN
Capilano East	Capilano River (east bank) to McGuire Avenue	SN, DWV
Norgate-Mosquito	McGuire Avenue to Mosquito Creek (west bank)	DNV, CNV, SN, Port
Mission-Lonsdale	Mosquito Creek (east bank) to St. Georges Avenue	SN, CNV, Port
Lynn-Seymour	Heywood Street to Seymour River (west bank)	DNV, CNV, SN, Port
Maplewood	Seymour River (east bank) to Tsleil-Waututh Nation I.R. No. 3	DNV, Port

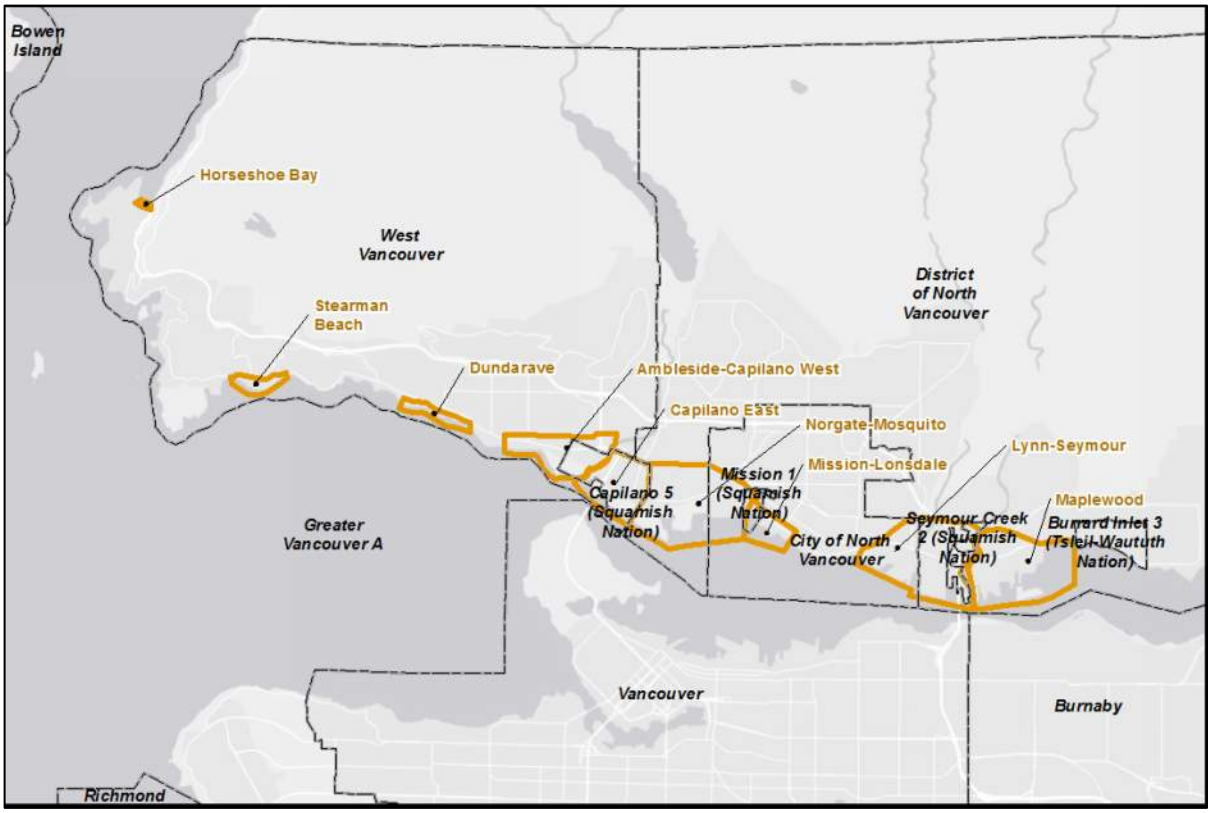


Figure 7-1: North Shore Comprehensive Adaptation Planning Zones (outlined in orange)

These areas were divided into different planning zones to provide a balance between planning zone scope and size. Major watercourses were generally used as natural topographic boundaries between these zones. Some of the planning zones are adjacent to each other and adaptation efforts should be coordinated across the zones (Ambleside-Capilano West, Capilano East, Norgate-Mosquito and Mission-Lonsdale; and Lynn-Seymour and Maplewood).

This sub-section provides a foundation for adaptation planning for each zone. For each zone, the existing context, probability of flooding, and initial integrated adaptation concepts are presented. The planning zone concept figures presented in this Strategy are illustrative only and intended to provide a starting place for further planning and analysis. They do not represent preferred or the final selection of approaches and measures by the North Shore partners. As the planning zones are developed, preferred options may include the concepts presented in the Strategy, alternative concepts and measures, or a combination. These concepts and future concepts to be developed involve large land use and infrastructure decisions. To help guide the evaluation of options and implementation timing, an "adaptation pathways" approach is suggested. This is introduced and discussed in Section 7.5.

The initial concepts generally focus on various configurations for integrating structural and non-structural flood protection measures. It should be noted that development regulatory tools and building floodproofing measures apply in all floodplain areas regardless of potential structural measures unless otherwise noted (e.g. special higher flood risk tolerance areas). Additionally, minimal commentary is provided on 'avoid'-themed concepts as reviewing future land use planning is not in the scope of the Strategy. However, it should be noted that an 'avoid' approach involving density restrictions, land use

restrictions, and other measures are relevant for the CAPZ. It is expected that future CAPZ projects will develop concepts involving avoid measures for consideration.

The North Shore partners involved in each planning zone can conduct future planning and engagement work for each zone to further explore concepts and advance towards preferred concepts and implementation. This is reflected in the implementation section of the Strategy (Section 8). Additional guidance to support advancing planning zone level work is provided in separate sub-sections, including initial criteria for future evaluation of concepts and commentary on the decision-making process and timelines.

High-level guidance is provided for the Horseshoe Bay, Stearman Beach, and Dundarave zones where there are already adaptation planning processes underway or adaptation effort is expected to be limited to park upgrades and on-going floodplain development regulation. Additional guidance and initial concepts including potential structural measures are provided for the remainder of the planning zones.

Wave effects have not been assessed due to a lack of updated numerical wave modelling. This is an important knowledge gap in West Vancouver (Horseshoe Bay, Stearman Beach and Dundarave zones) where the shoreline is more exposed to ocean waves than the rest of the North Shore. Currently, the District of West Vancouver is working to address this information gap through their sea level rise work. Further analysis to include wave effects in addition to the coastal stillwater flood level may expand the identified adaptation planning zones.

Horseshoe Bay

Coastal stillwater flood exposure in Horseshoe Bay is generally limited to the waterfront park and marina (Horseshoe Bay Park and Sewell's Marina). Under all coastal flood stillwater mapping scenarios (refer to Section 5), flooding does not extend beyond the primary waterfront road: Bay Street.

Onset of Flooding Probability

Table 7-2 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Horseshoe Bay area for different sea level rise scenarios. The onset of probability is estimated by applying linear interpolation to the coastal flood stillwater (i.e. combination of tide and storm surge) levels (with freeboard) presented in Section 5. The onset of flooding probability can be considered as the probability for very shallow flooding.

Table 7-2: Horseshoe Bay Annual Probability for the Onset of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
Horseshoe Bay Park lawn area between playground and marina building (4.8 m CGVD28)	< 0.5% (>200)	< 0.5% (>200)	< 0.5% (>200)	14% (7)
Bay Street at Royal Avenue (6.4 m CGVD28)	< 0.5% (>200)	< 0.5% (>200)	< 0.5% (>200)	< 0.5% (>200)

Adaptation Guidance

Given the relatively low onset of flooding probabilities in the short and long term at Horseshoe Bay and the relatively low stillwater flood exposure of development, the Horseshoe Bay zone does not appear to require community-scale structural flood protection measures at this time or in the near future. However, the waterfront park is exposed to flooding and erosion. As previously mentioned, wave effects may also increase the onset of flooding probabilities for the park and upland areas.

The primary adaptation concept for Horseshoe Bay at this time is to incorporate accommodate-themed measures into forthcoming park upgrades.

DWV initiated the Revitalizing Horseshoe Bay Park project in 2017 which led to a park upgrading concept that was approved by DWV Council in July 2019. The concept plan, presented below, includes a continuous waterfront path, a boat launch, water's edge access, seating, and play features.



Horseshoe Bay Park Concept (District of West Vancouver, 2019)

The park upgrading project presents an ideal opportunity to incorporate sea level rise adaptation into the park. Given the recreational land use, adaptation concepts may be themed based on the accommodate/tolerate approach. Proposed structures and infrastructure in the park could be designed with materials that can withstand temporary flooding, including wave impacts. Mechanical, electrical, and lighting equipment should be sufficiently elevated or tanked.

DWV may also wish to consider intertidal area change and coastal squeeze issues in the forthcoming detailed design of the park and explore opportunities to have the park maintain existing intertidal habitat in the future, or increase the habitat. However, this may require landscaping and topographic changes that may conflict with usable park space.

The existing marina building (Sewell's Marina) may benefit from retrofits and temporary/demountable flood barriers, particularly in the winter high tide period, to reduce flood exposure as sea level rises.

In addition to the park, BC Ferries' Horseshoe Bay Terminal may have facilities that are more vulnerable to sea level rise-related flooding. The flood hazard and risk assessments did not involve a detailed review of coastal flood impacts on this specific facility. The North Shore partners, or DWV individually, may wish to engage with BC Ferries to learn what sea level rise adaptation issues and plans may exist for the terminal and how it will interact with the Horseshoe Bay area. It is understood that BC Ferries is currently completing a Horseshoe Bay terminal development plan (BC Ferries, 2020), which would be an ideal opportunity to incorporate sea level rise adaptation measures.

In the very long term, or if sea level rise projections accelerate, DWV may wish to consider Bay Street as a long term potential dike corridor. A separate comprehensive adaptation planning area process may not be required in the short term for Horseshoe Bay given the forthcoming park upgrades. However, the need can be reassessed after knowledge gaps around wave effects are addressed with numerical wave modelling.

Stearman Beach

The Stearman Beach zone comprises single-family houses and the Department of Fisheries and Oceans Pacific Science Enterprise Centre, a research facility with vessel water access. Under current sea level, the 200-year return period (0.5% annual exceedance probability) stillwater flood extent is generally limited to shallow (< 0.5 m) flooding along the shoreline properties. As sea level rises, the flood extents increase and under 1 m of sea level rise, 200-year return period flood depths of 0.5 m to 1 m are estimated for the majority of waterfront lots and, in a few instances, the second row of development from the shoreline. Under 2 m of sea level rise, the extreme flood scenario depths increase to the 1 m to 2 m range and cover approximately half of the zone with shallow flooding across the portion of Marine Drive adjacent to the fisheries research facility.

Onset of Flooding Probability

Table 7-3 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Stearman Beach area for different sea level rise scenarios.

Table 7-3: Stearman Beach Annual Probability for the Onset of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
Ross Crescent at Stearman Avenue (4.4 m CGVD28)	< 0.5% (>200)	< 0.5% (>200)	0.5% (200)	47% (2)
Marine Drive at Pacific Science Enterprise Centre (3.9 m CGVD28)	< 0.5% (>200)	< 0.5% (>200)	13% (8)	100%

Adaptation Guidance

Floodplain development regulation and building floodproofing measures are the most relevant for Stearman Beach where the majority of risk is related to single-family homes and there is no existing right-of-way for shoreline flood protection works. Given the exposure to wave effects, parcel-scale shoreline wave attenuation measures (e.g., engineered beaches, GreenShores, seawalls, and/or small breakwaters/groynes) are also relevant because they can be used to reduce required flood construction levels for floodproofing. Parcel-scale land raising as a part of redevelopment is also an option in this area. Separately from this Strategy, DWV is currently conducting a wave hazard modelling project in support of developing coastal floodplain development measures such as a coastal development permit area. Refer to Section 7.3 for high-level guidance on floodplain development regulatory tools and suggestions for incorporation into new regulatory tools.

While the Pacific Science Enterprise Centre facility is federal property and DWV regulatory tools do not apply, these measures are generally also applicable to the site. However, the site may also require special considerations related to the scientific equipment and vessels stored at the facility. DWV may wish to engage with the Department of Fisheries and Oceans to provide flood hazard information and discuss sea level rise adaptation for the facility.

In the interim before redevelopment of exposed properties, relevant adaptation measures include education and education about overland flood insurance options, household-level resilience (e.g., relocating valuables to higher levels), and retrofitting of homes with flood barriers (e.g., manual and/or passive flood barriers at doors).

Finally, the low section of Marine Drive will need to be addressed in the long term as the probability of flooding increases significantly beyond 1 m of sea level rise. Gradual road raising could be incorporated into road asset management. However, additional analysis would be required to determine the feasibility of raising the road. Alternatives would be hazard signage (“road subject to coastal flooding”) or a short section of setback seawall along the road edge.

Dundarave

The Dundarave zone is centred on Dundarave Park and pier in West Vancouver and also covers the adjacent mixed-use and residential areas to the east and west. Under current sea level, 200-year return period (0.5% annual exceedance probability) stillwater flooding in Dundarave is limited to low-lying park areas and is generally very shallow (< 0.5 m). Flood extents and depth increase with sea level rise, and under 1 m of sea level rise 200-year return period shallow flooding impacts waterfront structures to the east and west of Dundarave Beach, including a restaurant, a single-family house, and a mid-rise residential building lot. A portion of the townhouse complex at the foot of 23rd Street is located within the shallow flood-impacted area but is disconnected from the shoreline by the rail embankment. Shallow flooding is possible if floodwaters pass through the rail embankment via seepage and/or drainage pipes. Under 2 m of sea level rise, flood extents are generally limited to the same areas, but flood depths increase by 1 m.

Onset of Flooding Probability

Table 7-4 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Dundarave area for different sea level rise scenarios.

Table 7-4: Dundarave Area Annual Probability for the Onset of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
Dundarave Beach sand area west of pier (2.8 m CGVD28)	14% (7)	69% (1.5)	100%	100%
Foot of 25th Street (5.2 m CGVD28)	<0.5% (>200)	<0.5% (>200)	<0.5% (>200)	2% (60)
Railway in line with 23rd Street (4.8 m CGVD29)	< 0.5% (>200)	< 0.5% (>200)	< 0.5% (>200)	14% (7)

Adaptation Guidance

The onset of flooding probability shows that Dundarave Beach and its associated pier and other waterfront structures are the most exposed to sea level rise impacts. As with Horseshoe Bay Park, accommodate-themed adaptation measures can be incorporated into future park upgrading plans to make the park resilient to flooding. The viability of the sandy beach under high sea levels would require additional analysis including wave hazard and sediment transport assessment. Additional wave attenuation works (e.g., groynes) may be required to maintain the same-sized beach into the future. Beach raising and reshaping may also be required to maintain the beach under a shifting intertidal area. Alternatively, the beach could be transformed into future intertidal habitat. These topics are best addressed through a future master planning process for the park.

In the interim, DWV may wish to review and/or inspect existing infrastructure within the park (e.g., utilities, lighting, furniture) to determine the need for any replacements.

As with other areas in West Vancouver, a wave hazard modelling study would help better understand wave effects in the Dundarave area and the need for community-scale and parcel-scale wave attenuation measures.

Ambleside – Capilano West

The Ambleside-Capilano zone includes the major waterfront mixed-use district adjacent to John Lawson Park and Ambleside park in the District of West Vancouver and the Park Royal shopping mall on SN's Capilano I.R. No. 5 land. Under current sea level and an extreme stillwater flood event (200-year return period / 0.5% annual exceedance probability), the Ambleside-Capilano West zone is exposed to minimal, shallow (<0.5 m deep) flooding limited to park areas and the high-density mixed-use area centred on Bellevue Avenue and 15th Street. Shallow flooding is unlikely to overtop the railway embankment but may seep through the embankment fill or through drainage pipes. Three DWV sanitary pump stations on the shoreline in line with 15th Street, 18th Street, and 19th Street are also exposed to flooding. The eastern portion of this zone is on the Capilano River alluvial fan, so it would be pertinent to integrate coastal and riverine flood protection.

Flood extents are generally maintained with sea level rise, but depths increase. Under 1 m of sea level rise and the same extreme event, flood depths are generally in the 0.5 m to 1 m range and shallow flooding impacts Marine Drive at 15th Street.

Under 2 m of sea level rise, flood depths are generally in the 1 m to 2 m range with likely overtopping of the rail embankment. Flooding also extends to the Village at Park Royal shopping area and further onto Marine Drive. At 2 m of sea level rise, extreme flooding would reach BC Hydro's John Lawson substation which is a key factor in the overall flood risk profile discussed in Section 6.

Onset of Flooding Probability

Table 7-5 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Ambleside – Capilano West area for different sea level rise scenarios.

Table 7-5: Ambleside – Capilano West Area Annual Probability for the Onset of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
John Lawson Substation (4.8 m CGVD28)	< 0.5% (>200)	< 0.5% (>200)	< 0.5% (>200)	14% (7)
Ambleside Beach at Ferry Building Gallery (3.5 m CGVD28)	< 0.5% (>200)	9% (11)	31% (3)	100%
Bellevue Avenue at 14th Street (3.8 m CGVD28)	< 0.5% (>200)	1% (100)	15% (7)	100%
Marine Drive at 15th Street (3.5 m CGVD28)	< 0.5% (>200)	9% (11)	31% (3)	100%
Forested lands between railway and The Village at Park Royal (2.6 m CGVD28)	23% (4)	100%	100%	100%
The Village at Park Royal (Whole Foods Market) (4.7 m CGVD28)	< 0.5% (>200)	< 0.5% (>200)	< 0.5% (>200)	18% (6)

Initial Adaptation Concepts

Adaptation planning in the Ambleside – Capilano West zone will involve collaboration between DWV and SN, and other stakeholders within the zone.

Structural flood protection measures may be appropriate, in addition to policy measures, for consideration in this zone because of the extent of flood exposure for dense, mixed-used development and the notable onset of flooding probabilities in the near term (0.5 m sea level rise scenario).

The CN railway corridor runs through the Ambleside – Capilano West zone and is a key consideration in developing adaptation concepts that include structural flood protection.

Challenges related to railway corridor for adaptation planning include:

- Lack of jurisdiction for local governments and First Nations to implement changes to railway corridors;
- Railway design requires relatively low grades and does not easily accommodate significant changes; and

- Flood gates for dikes and seawalls to cross railways present jurisdictional and operational issues, and also make the efficacy of the flood protection provided by the dike contingent on the operation of gates.

Raising the railway corridor to serve as a dike stands out as a potential concept. However, this may not be technically and/or economically feasible given the design grade challenges mentioned above. Additionally, the North Shore partners' role would be limited to coordination and advocacy, and would otherwise be reliant on others for implementation.

There are significant habitat enhancement opportunities in this zone, provided by the streams, wetlands and pond system located in Ambleside Park.

The Strategy suggests that a comprehensive adaptation plan be developed by DWV and SN for the Ambleside – Capilano West zone, which identifies and evaluates adaptation concepts involving a combination of structural and policy measures. Flood protection best management practice would be to avoid flood protection alignments that cross the railway and require flood gates.

An initial concept to serve as a starting point for the comprehensive adaptation plan is presented in Figure 7-2.

The concept involves a combination of the following measures:

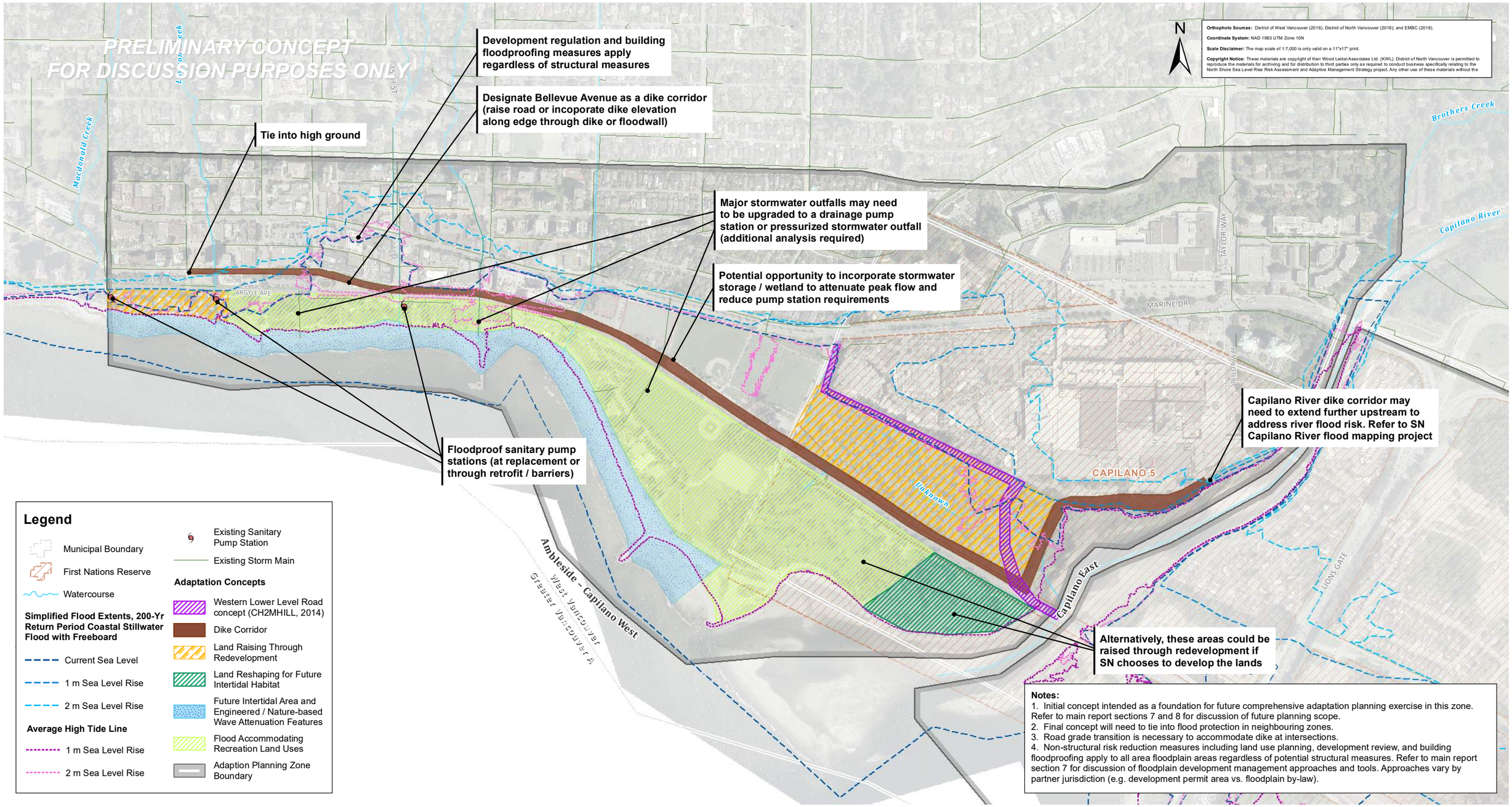
- A setback dike on the north side of the railway and incorporated into the road network starting at Bellevue Avenue near 18th Street, running through Ambleside Park and Capilano I.R. No. 5 forested lands. The portion of the dike incorporated into Bellevue Avenue would generally involve a raise of less than 1.3 m for adaptation to 1 m of sea level rise. The proposed Western Low-Level road extension (CH2MHILL, 2014) is also planned to route through I.R. No 5 forested lands, and should be a consideration for flood protection works in this zone.
- A Capilano River west bank dike to south of Bridge Street (but potentially needing to extend further north for Capilano River flood risk management);
- Land raising through redevelopment for waterfront lots between 19th Street and 18th Street;
- Land raising through redevelopment for SN's Capilano I.R. No. 5 lands south of The Village at Park Royal;
- Recreational land use and infrastructure that is flood resilient and consistent with accommodate/tolerate approaches in the park areas south of Bellevue Avenue (including the golf course on Capilano I.R. No. 5);
- Nature-based wave attenuation features (e.g., groynes, reefs, breakwaters) incorporated into the shoreline / intertidal area to reduce wave effects;
- Opportunity for land preservation and reshaping for future intertidal habitat on the Capilano I.R. No. 5 lands at the mouth of the Capilano River;
- Floodproofing of sanitary pump stations on the shoreline (replacement or floodwalls);
- Relocation (preferred) or floodproofing of BC Hydro's John Lawson substation;
- Pressurized stormwater outfalls or drainage pump stations for existing outfalls; and
- Potential creek bank dikes (at McDonald, Lawson and Vinson Creeks) for backwater effects (additional analysis required).

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District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

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Notes:
1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

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Initial Adaptation Concept for Ambleside - Capilano West Comprehensive Adaptation Planning Zone

Figure 7-2

This concept has the benefit of providing structural protection for most of the developed areas while not requiring a dike crossing of the railway. By designating Bellevue Avenue as a dike corridor, a dike could be incorporated through raising the entire road, raising strips of land along the road (e.g., parking areas or shoulders with retaining walls), partial raising in combination with a low floodwall, or adding a floodwall along the edge of a dike. The floodwall approach generally is not preferred as the dike would become reliant on flood gates at pedestrian/vehicle crossings. Road corridor diking would also help future redevelopment meet flood construction levels more easily. Utilities within the roadway would need to be carefully designed to not reduce the effectiveness of the dike. Wave effects may not need to be added to the crest elevation of this alignment given that it is set back from the shoreline and if nature-based wave attenuation works are also implemented.

Road corridor diking could be implemented gradually through regular roadworks asset management or a major capital works project.

Adaptation measures should also be incorporated into planned upgrades to Ambleside Park. DWV Council approved the Ambleside Waterfront Plan in September 2019, which will advance the waterfront and park upgrade project.

Capilano East

The Capilano East zone covers the area east of the Capilano River, which includes SN's Capilano I.R. No. 5, DWV land, and borders on the DNV's Norgate neighbourhood. Land use in this zone is generally residential, with pockets of industrial/commercial, and includes the Lions Gate Bridge in Provincial jurisdiction. As with the Ambleside – Capilano West zone, a portion of the Capilano East zone is on the Capilano River alluvial fan, so integrating coastal and riverine flood protection is an important consideration.

Under current sea level, 200-year return period (0.5% annual exceedance probability) stillwater flooding in the Capilano East zone is limited to only low-lying, undeveloped lands. Squamish Nation residential and commercial areas are not inundated.

Under 1 m of sea level rise and a 200-year return period stillwater flood, the majority of land south of the railway is flooded, including the DWV site of Metro Vancouver's existing, but soon to be relocated, Lions Gate Wastewater Treatment Plant. After the plant is decommissioned, the site lands will be returned to Squamish Nation in accordance with a Provincial/Federal cut-off lands agreement (Metro Vancouver, 2019). Some flooding is also shown north of the railway but is unlikely to overtop the railway embankment although ponding north of the railway could occur through seepage or drainage pipes.

A small portion of the Squamish Nation's band-owned housing adjacent to the Capilano River east bank is exposed to flooding in extreme flooding under 1 m of sea level rise, and the exposure grows significantly under 2 m of sea level rise to approximately the entire southern half of the residential area. Social facilities such as the Chief Joe Mathias Centre and Xwemelch'stn School are exposed to flooding under 2 m of sea level rise, and floodwaters would also block a portion of Welch Street (0.5 m to 1 m deep).

Onset of Flooding Probability

Table 7-6 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Capilano East area for different sea level rise scenarios.

Table 7-6: Capilano East Area Annual Probability for the Onset of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
Lions Gate Wastewater Treatment Plant (existing) (4.2 m CGVD28)	<0.5% (>200)	<0.5% (>200)	50% (2)	100%
Welch Street at Raindance Crescent (4.2 m CGVD28)	<0.5% (>200)	<0.5% (>200)	50% (2)	100%
Forested lands between Welch Street and Railway (1.8 m CGVD28)	100%[1]	100%	100%	100%

1. These lands are protected by the railway and do not flood at the current sea level, despite their low elevation.

Initial Adaptation Concepts

Adaptation planning in the Capilano East zone can be led by SN with collaboration with DNV as the eastern boundary of the zone borders with the Norgate – Mosquito planning zone. As with other zones, a CN railway corridor divides the zone into two halves and is an important consideration for incorporating any structural measures.

Given that the majority of lands in the zone that would be impacted by future flooding are currently undeveloped, land raising through redevelopment will provide a significant opportunity to implement adaptation and share costs with developers. Alternatively, the undeveloped lands also present an opportunity for land preservation and reshaping for future intertidal habitat to offset losses elsewhere with hardened shorelines.

Two initial adaptation concepts are provided as a starting point for a comprehensive adaptation plan in this zone:

- Land raising with setback dike – refer to Figure 7-3; and
- Shoreline dike – refer to Figure 7-4.

The land raising with setback dike concept involves:

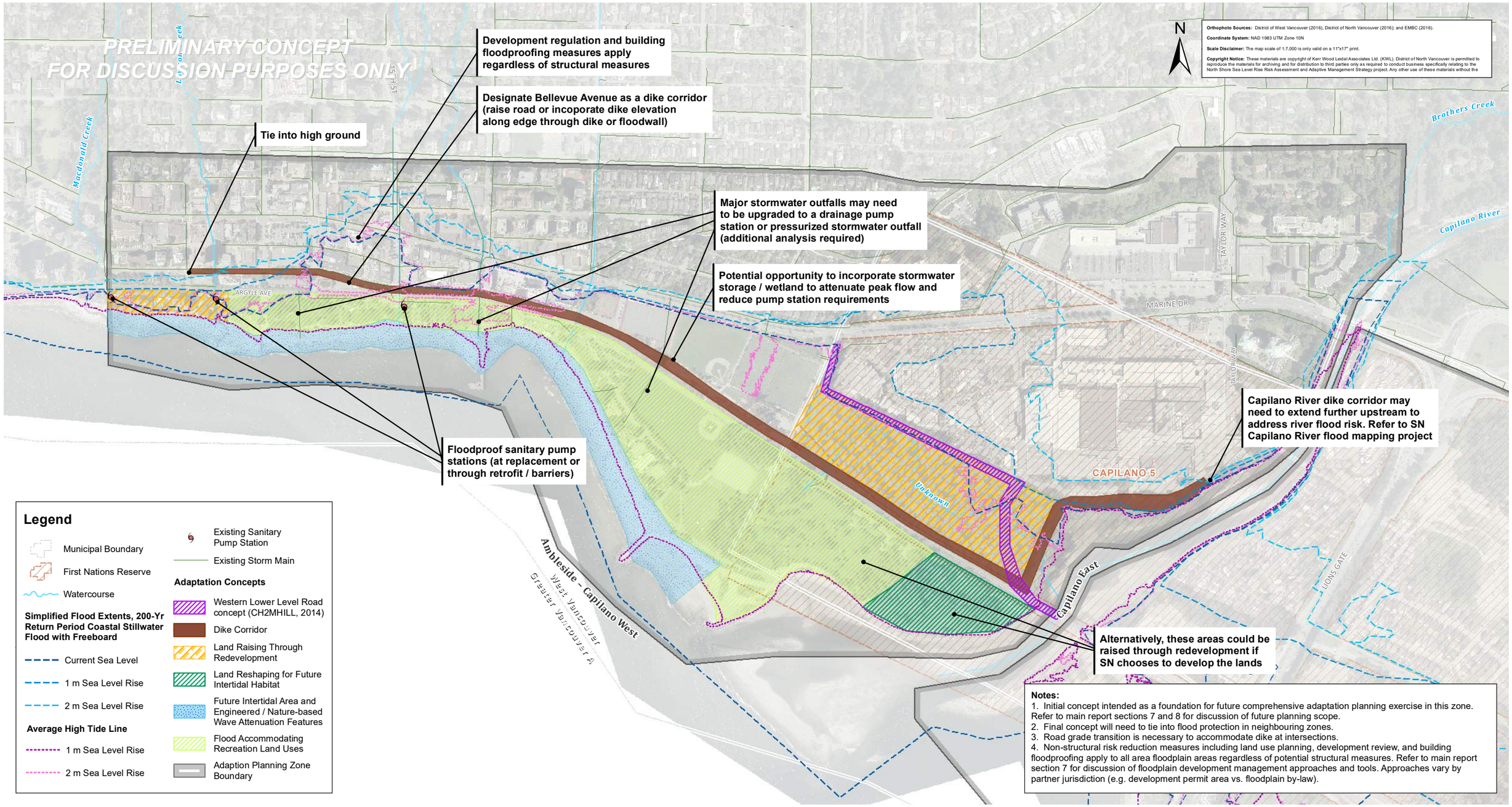
- Raising lands south of Welch Street through redevelopment;
- Designating Welch Street as a dike corridor with minimal raising required for adaptation to 1 m of sea level rise and generally less than 1 m raising for adaptation to 2 m of sea level rise;
- Capilano River east bank dike extending to the south of Bridge Street (but potentially needing to extend further north for Capilano River flood risk management); and
- Opportunity for land preservation and reshaping for future intertidal habitat along the undeveloped shoreline area.

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District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

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Notes:
1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

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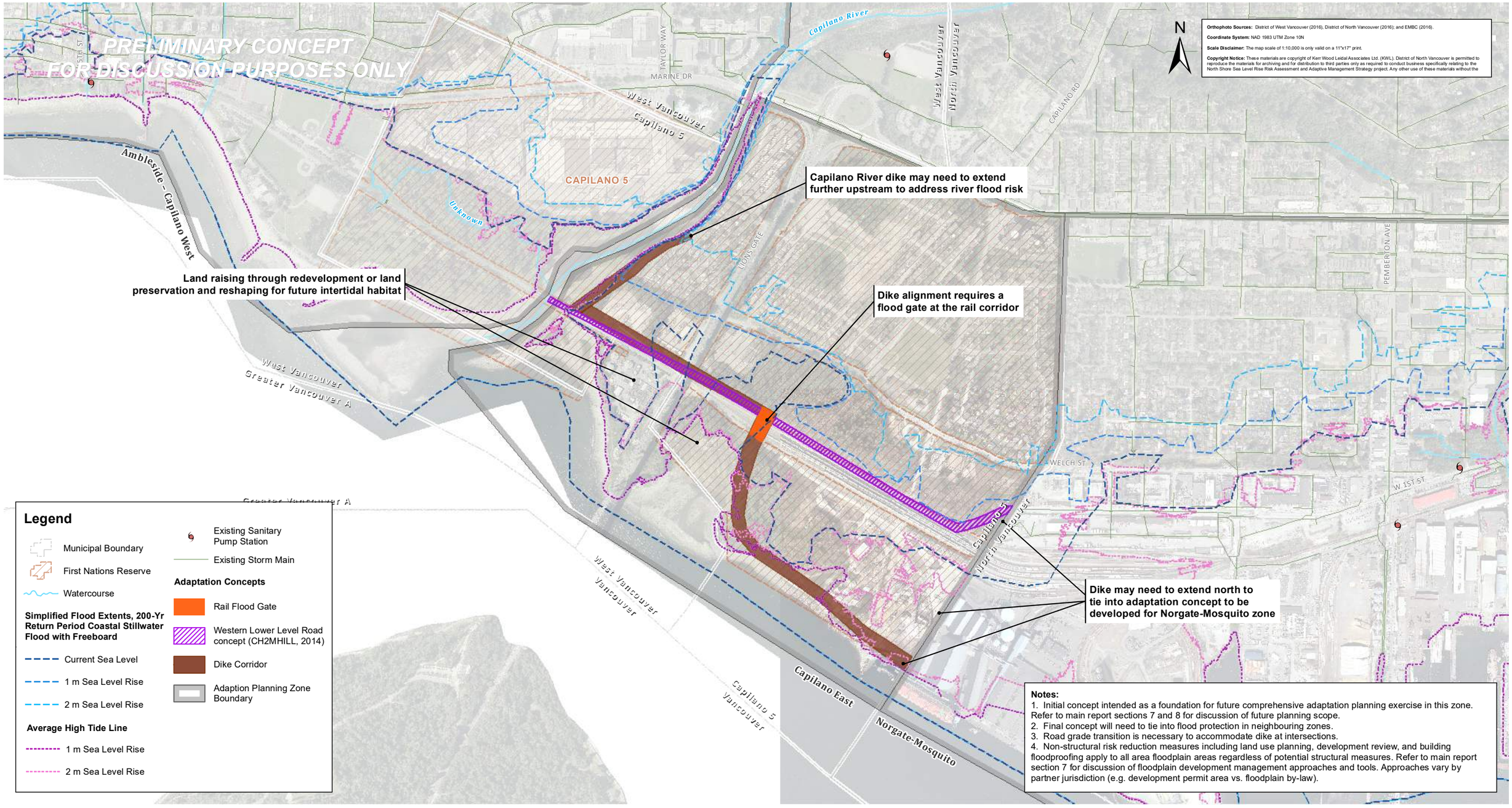
Initial Adaptation Concept for Ambleside - Capilano West Comprehensive Adaptation Planning Zone

Figure 7-2

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

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Notes:
1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

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Scale	1:10,000

Shoreline Dike Initial Adaptation Concept for Capilano East Comprehensive Adaptation Planning Zone

Figure 7-4

It is important to note that the setback dike designation for Welch Street would involve relatively minor (<1 m) raising because it is on the fringe of the flood extent. The designation would serve as a way to create a continuous line of flood protection for developed lands north of Welch Street. Incorporating a dike into the Welch Street corridor will also provide reliable flood protection while lands south of Welch Street develop and land raising is applied. There is significant potential to incorporate land raising in a way that reduces or eliminates the need for stormwater pump stations. This would be achieved through grading of the raised land to incorporate new overland drainage paths (e.g., through internal roads / paths).

The shoreline dike concept is an alternative to land raising. However, as shown in the associated figure, the concept would require a flood gate across the rail corridor. As previously noted, this is not preferred from a flood protection objective of a passive system that does not rely on the manual or mechanical operation. Another disadvantage of a shoreline dike is that it would be much taller than a setback dike and would introduce a dike breach hazard for areas north of it if they are not raised. An alternative dike alignment would be along the future Western Low-Level Road extension (CH2MHILL, 2014), which is proposed to run through Capilano I.R. No. 5, north of the CN rail line from Park Royal, across the Capilano River and to West 1st St.

Norgate – Mosquito

This zone extends from the eastern edge of the Capilano East zone to the west bank of Mosquito Creek and includes DNV, CNV, SN, and Port jurisdiction. The Norgate-Mosquito zone could experience overland coastal flooding directly from Burrard Inlet and also through coastal floodwaters rising water levels in Mackay and Mosquito creeks resulting in creek bank overtopping (in addition to the riverine flood hazard at the current sea level, as this zone is located on creek fans). The zone comprises a variety of land uses with Welch Street acting as the north-south division between residential (north) and commercial and waterfront industrial land uses (south) in DNV. Metro Vancouver's new North Shore Wastewater Treatment Plant in DNV is planned to accommodate 1 m of sea level rise with up to a 200-year return period coastal storm including wave effects using a conservatively-calculated flood construction level of 6.0 m CGVD28 (AECOM, 2014).

Land use is generally commercial and light industrial in CNV and SN Mission I.R. No. 1 lands. An approved development in the CNV's Harbourside Drive area (see graphic to the right) will introduce phased mixed-use (including residential) to the area. The SN reserve lands in the zone also include the SN community operations facilities.

Under current sea level, 200-year return period (0.5% annual exceedance probability) stillwater flood depths are relatively shallow (less than 0.5 m) with some pockets of potential deeper flooding within the Port lands and creek park/wetland areas.



Approved Harbourside Drive mixed use development (City of North Vancouver, 2020)

Under 1 m of sea level rise and the same extreme stillwater event, there is widespread flooding in the 0.5 m to 1 m depth range throughout the zone: nearly all of the Port lands in the zone, extending as far north as the residential area north of Welch Street in DNV, and the business district in the CNV and on SN's Mission I.R. No. 1. Major transportation corridors including 1st Street and the rail corridor are also flooded in this scenario. Flood extents are similar, but depths increase under 2 m of sea level rise (1 m to 2 m deep range). At 2 m of sea level rise, extreme flooding would reach the Norgate substation which is a key factor in the overall flood risk profile discussed in Section 6. Substation floodproofing or relocation is an important risk reduction strategy for this zone.

Onset of Flooding Probability

Table 7-7 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Norgate - Mosquito area for different sea level rise scenarios, chosen to represent a variety of land uses across the zone (e.g. transportation/electrical infrastructure, coastal parks, industrial etc.).

Table 7-7: Norgate – Mosquito Area Annual Probability for the Onset of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
Norgate Substation (4.1 m CGVD28)	<0.5% (>200)	<0.5% (>200)	10% (10)	100%
McKeen Avenue at Senator Road (2.8 m CGVD28)	15% (7)	100%	100%	100%
Pemberton Avenue at W 1st Street (2.7 m CGVD28)	18% (6)	100%	100%	100%
Kings Mill Walk Park (3.6 m CGVD28)	10% (10)	23% (4)	100%	100%
Harbourside Drive at Gostick Place (3.4 m CGVD28)	0.5% (200)	13% (8)	47% (2)	100%
W 1st Street at Fell Avenue (4.9 m CGVD28)	<0.5% (>200)	<0.5% (>200)	<0.5% (>200)	13% (8)

Initial Adaptation Concepts

The railway corridor and Port terminals are key features that will influence collaborative adaptation planning in the Norgate – Mosquito zone. While at first review, it may appear that raising of the rail corridor and/or Port terminals may provide a comprehensive adaptation concept, there are multiple challenges limiting that concept:

- Railway grade cannot easily be changed to act as dike;
- Port terminal land raising may occur at different timescale due to terminal operators' infrastructure lifespans, water access needs, and flood risk tolerance;

- Raising all waterfront industrial lands or raising the railway corridor would not address Mackay Creek and Mosquito Creek as coastal flood pathways without additional diking along creek banks. This approach would also create a new overland creek/stormwater flood bathtub effect hazard where floodwaters from overflowing creeks and the networks would become impounded behind the raised lands / railway.

Based on the above, two similar concepts based on a theme of setback diking and land raising through redevelopment have been developed to serve as a foundation for future collaborative adaptation planning.

The concepts are:

- Spirit Trail/Welch Street to West 1st Street setback dike and land raising – refer to Figure 7-5; and
- West 1st Street setback dike and land raising – refer to Figure 7-6.

In both concepts, a setback dike is incorporated into the road network and lands south of the dike are raised through redevelopment. Development regulation and building floodproofing would apply to all areas in the coastal floodplain, including lands north of the setback dike. The variation between the concepts is the alignment of the setback dike west of Mackay Creek. The setback dike component would ensure that properties north of the dike are protected regardless of the pace of redevelopment and land raising south of the dike. This would protect smaller parcels and residential areas north of the dike. The larger parcels south of the dike alignment are primarily industrial/commercial and generally have a higher flood risk tolerance and which gives them more flexibility if the pace of redevelopment doesn't implement land raising. These industrial properties can also more easily implement temporary or retrofit-style flood protection measures and can access a commercial flood insurance market that is more developed than the emerging residential insurance market.

In both concepts, diking incorporated into roads would require road raising of up to 2 m for adaptation to 1 m of sea level rise. The lowest ground elevation and area of highest raising is generally located at Pemberton Avenue.

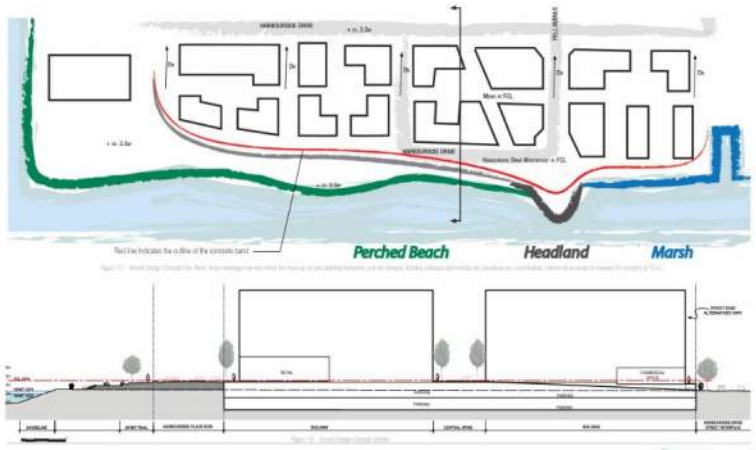
An important feature of both concepts is a combination of the following measures to reduce the size and need for drainage pump stations:

- Separation of the upper catchment (approximately above elevation 5 m CGVD28) through construction of a new pressurized stormwater outfall (e.g., on the Phillip Avenue alignment) to capture and convey stormwater directly to Burrard Inlet without flooding the lower catchment; and
- The incorporation of overland stormwater routes in between (e.g., existing roads) and within land raising parcels south of the setback dike corridor.

At this preliminary concept stage, it is too early to determine the right elevation of land raising and floodways for areas south of the dike corridor. Roads in this area may need to be lower than the parcels to act as stormwater overflow routes, but they should not be so low as to cut off access to the raised parcels. A starting point for planning on this topic may be to set the roads at the 10-year return period (10% annual exceedance probability) plus 1 m sea level rise coastal flood level which would be consistent with the existing level of service for stormwater infrastructure.

It should also be noted that several properties rely on railway access. It is assumed that the railway will eventually be raised, but the timing may be later than the start of implementation of land raising on other properties that don't rely on rail access. The land-raising concept enables individual properties to adapt in a way that fits their context at the time of redevelopment. As discussed in Section 8, the North Shore

partners will continue to engage and liaise with CN Rail and it is suggested that CN Rail be involved in the majority of future CAPZ projects.



In CNV, a sea level rise flood management plan (Golder, 2013) was prepared for the approved and forthcoming mixed-use Harbourside Drive development (see graphic to the right), which incorporates land raising for the development parcels and the portion of Harbourside Drive that is located along Burrard Inlet into the development proposal. The flood management plan does not suggest raising of other roads and grades the land raising down to existing grade for the portion of Harbourside Drive on the north side of the development area. This portion of the road is shown at an existing elevation of approximately 3 m CGVD28, which would have an annual probability of flooding in the future of ~30% under 0.5 m of sea level rise and ~100% under 1 m of sea level rise. This suggests that some additional road raising would be beneficial in this area and could be linked with the Harbourside Drive development. Road raising to an elevation of 4.1 m CGVD28 would achieve a 10% annual probability of flooding under 1 m of sea level rise (including freeboard).

There is also an opportunity for land preservation and reshaping (lowering) for future intertidal habitat in CNV along the shoreline of Kings Mill Walk Park. This can be linked with the CNV's current Kings Mill Walk Park master planning process, which is also linked to the Harbourside Drive development. The Harbourside Drive developer received approval from the Port Authority in April 2020 for shoreline and habitat enhancement work involving five rocky reef headlands, stormwater outfall upgrades, and shoreline erosion protection works (Port Authority, 2020).

In addition to the set back east-west dike corridors, effective flood protection of the area would require diking along the Mackay Creek and Mosquito Creek corridors, which would be needed without sea level rise. A diking concept was developed in 2015 for Mackay Creek and an initial phase of conveyance upgrades and creek enhancements was completed in early 2020 as a joint CNV-DNV project.

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers

PRELIMINARY CONCEPT
FOR DISCUSSION PURPOSES ONLY

N

Orthophoto Sources: District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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Development regulation and building floodproofing measures applies to floodplain areas north of dike corridor

Lower Mackay Creek corridor dike concept based on previous work by DNV and CNV

Mosquito Creek diking required to contain coastal flooding. Additional diking upstream may be required to address creek flood risk

Land raising to incorporate new overland drainage corridors to minimize the need and size of drainage pump stations

Dike corridor could be incorporated into Spirit Trail linear park upgrades

Tie in with Capilano East setback dike concept

Bridge upgrade

Potential opportunities along Mackay Creek for setting back land raising to provide habitat areas and natural shorelines

North to south road corridors maintained at a lower elevation to raised parcels to provide future overland drainage paths and reduce the need and size of drainage pump stations

CAPILANO 5

MISSION 1

Ambleside–Capilano East

Norgate-Mosquito

Mission-Lonsdale

West Vancouver

North Vancouver

Vancouver

Capilano 5

W 16TH ST

W 15TH ST

W 13TH ST

W 3RD ST

W ESPLANADE

E ESPLANADE

CAPILANO RD

FELL AVE

FORBES AVE

LONSDALE AVE

Mosquito Creek

Mackay Creek

Wagg Creek

Lower Mackay Creek

Legend

- Municipal Boundary
- First Nations Reserve
- Watercourse

Simplified Flood Extents, 200-Yr Return Period Coastal Stillwater Flood with Freeboard

- Current Sea Level
- 1 m Sea Level Rise
- 2 m Sea Level Rise

Average High Tide Line

- 1 m Sea Level Rise
- 2 m Sea Level Rise

- Existing Sanitary Pump Station
- Existing Storm Main

Adaptation Concepts

- Bridge Upgrade
- Western Lower Level Road concept (CH2MHILL, 2014)
- Dike Corridor
- Land Raising Through Redevelopment
- Future Intertidal Habitat
- Adaption Planning Zone Boundary

Notes:

1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

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Spirit Trail / Welch Street to West 1st Street Setback Dike Initial Adaptation Concept for Norgate - Mosquito Comprehensive Adaptation Planning Zone

Figure 7-5

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers

PRELIMINARY CONCEPT
FOR DISCUSSION PURPOSES ONLY

N

Orthophoto Sources: District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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Development regulation and building floodproofing measures applies to floodplain areas north of dike corridor

Lower Mackay Creek corridor dike concept based on previous work by DNV and CNV

Mosquito Creek diking required to contain coastal flooding. Additional diking upstream may be required to address creek flood risk

Land raising to incorporate new overland drainage corridors to minimize the need and size of drainage pump stations

Tie in with Capilano East setback dike concept

Flood gate required at railway crossing

Bridge upgrade

Note: dike concept requires that land raising is completed in this part of Squamish lands

Potential opportunities along Mackay Creek for setting back land raising to provide habitat areas and natural shorelines

North to south road corridors maintained at a lower elevation to raised parcels to provide future overland drainage paths and reduce the need and size of drainage pump stations

CAPILANO 5

MISSION 1

North Vancouver Mission 1

Norgate-Mosquito

Mission-Lonsdale

W 16TH ST

W 13TH ST

W 2ND ST

W 1ST ST

W 3RD ST

Mosquito Creek

Mackay Creek

Wagg Creek

Lower Lynn

Ambleside–Capilano 10 Yr St

Capilano 5

West Vancouver

Vancouver

North Vancouver

Capilano East

Legend

- Municipal Boundary
- First Nations Reserve
- Watercourse

Simplified Flood Extents, 200-Yr Return Period Coastal Stillwater Flood with Freeboard

- Current Sea Level
- 1 m Sea Level Rise
- 2 m Sea Level Rise

Average High Tide Line

- 1 m Sea Level Rise
- 2 m Sea Level Rise

- Existing Sanitary Pump Station
- Existing Storm Main

Adaptation Concepts

- Bridge Upgrade
- Rail Flood Gate
- Western Lower Level Road concept (CH2MHILL, 2014)
- Dike Corridor
- Land Raising Through Redevelopment
- Future Intertidal Habitat
- Adaption Planning Zone Boundary

Notes:

1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

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West 1st Street Setback Dike Initial Adaptation Concept for Norgate - Mosquito Comprehensive Adaptation Planning Zone

Figure 7-6

Mission – Lonsdale

The Mission-Lonsdale zone captures the eastern portion of SN's Mission I.R. No. 1 comprises a marina and related businesses, and the mixed-use urban waterfront Lonsdale Quay area of CNV. Mosquito Creek lies on the western edge of this zone, so creek fan hazards including riverine flooding should be considered when weighing adaptation options. Adaptation planning in this zone will require collaboration between CNV and SN with the Port being a major stakeholder given the adjacent grain terminals on the eastern boundary of the zone.

Under 1 m of sea level rise and a 200-year return period (0.5% annual exceedance probability) stillwater event, flooding is very limited with only some shallow inundation (<0.5 m) in waterfront areas. Under 2 m of sea level rise and the same event, shallow flooding covers most of the marina area, portions of Lonsdale Quay, and the port terminals. Shallow flooding also reaches the rail corridor and Esplanade Avenue. Under 2 m of sea level rise, flooding is generally in the 1 m to 2 m depth range and generally extends to south of Esplanade Avenue.

Onset of Flooding Probability

Table 7-8 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Lonsdale – Mission area for different sea level rise scenarios.

Table 7-8: Lonsdale – Mission Area Annual Probability for the Onsite of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
Mosquito Creek Marina (entrance at Esplanade W) (3.5 m CGVD28)	< 0.5% (>200)	9% (11)	31% (3)	100%
Spirit Trail at Waterfront Park (3.9 m CGVD28)	< 0.5% (>200)	0.5% (200)	13% (8)	100%
Lonsdale Quay Terminal Dropoff Area at Chadwick Court (3.3 m CGVD28)	15% (7)	100%	100%	100%
Lonsdale Avenue at Carrie Cates Court (4.1 m CGVD28)	<0.5% (>200)	<0.5% (>200)	10% (10)	100%

Initial Adaptation Concepts

A combination of diking and land raising through redevelopment appears to be required to provide flood protection for SN residential areas and the marina. As with other zones, the railway corridor divides the reserve into 2 segments: the marina to the south and the residential to the north.

The Lonsdale Quay area is unique and requires special consideration for adaptation planning because of the following factors:

- There is not enough open space for a conventional dike footprint to be incorporated; a conventional dike footprint would also significantly impact the urban character and aesthetics of the core waterfront area,

- The railway corridor goes through a tunnel from west of Chesterfield Place to east of St. George Avenue,
- The area has experienced significant recent redevelopment (Polygon Art Gallery, Shipyards, etc.). This means that building floodproofing to current CNV standards is already in place. The next round of redevelopment may be several decades into the future and not a reliable path for further adaptation, and
- A shipbuilding dry dock and associated infrastructure located in the eastern portion of the zone requires water access and it may difficult to incorporate a dike or seawall along the site. The dry dock may also have a higher level of flood risk tolerance than surrounding dense, urban land uses.

Two initial adaptation concepts have been developed to serve as a foundation for future adaptation planning in this zone:

- Esplanade dike and shoreline seawall – refer to Figure 7-7; and
- Esplanade dike and special flood risk tolerance zone (no permanent structural measures) – refer to Figure 7-8.

Both concepts involve constructing a dike on the north edge of the railway corridor in Mission I.R. No. 1 to provide flood protection to the residential area on Esplanade. A potential co-benefit of this dike alignment would be the reduction of rail noise in the adjacent residential area. Noise reduction can be incorporated as part of a retaining wall against the rail line or potentially an at-grade tunnel structure for the railway that is integrated with the dike. Potential options for incorporating the dike into the corridor may include road raising or a dike in between the railway and the road. Both concepts also involve land raising through eventual redevelopment for the marina. Given that the marina is a water-oriented site, the level of flood risk tolerance may be higher and land-raising elevation may be lower than other areas. However, the onset of flooding analysis suggests that some level of land raising would beneficial for 1 m and certainly for 2 m of sea level rise.

The concepts diverge in the treatment of the Lonsdale Quay area.

The shoreline seawall concepts would involve incorporating a seawall / standalone floodwall along the shoreline in developed areas. To incorporate a shoreline alignment, a flood gate would be required at the railway to connect the dike to the Esplanade dike. Incorporating a seawall along the shoreline will have several challenges including obtaining a sufficient right-of-way, aesthetics, and water access for the dry dock.

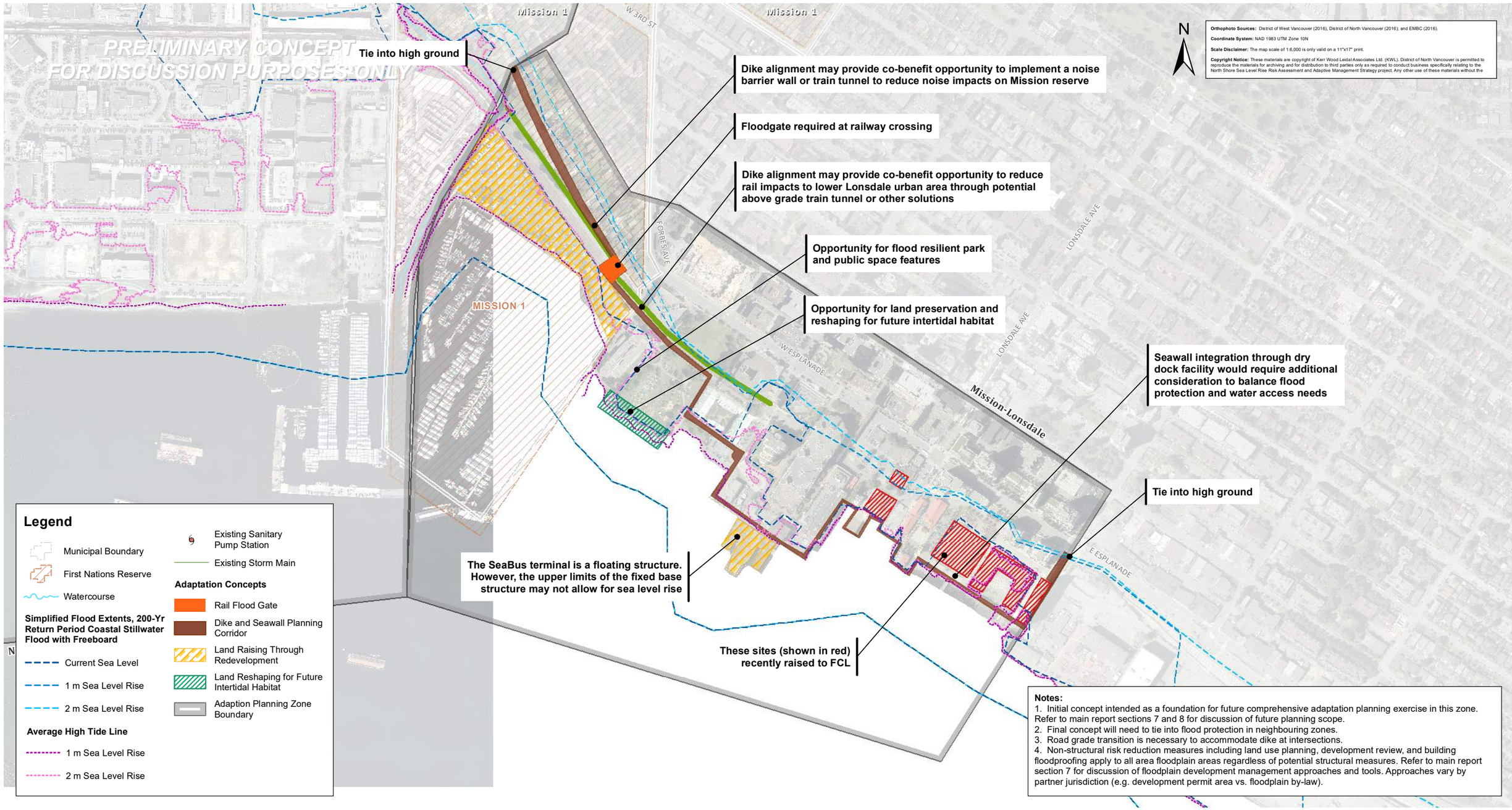
As an alternative to the shoreline seawall, the second concept would involve continuing the setback dike along Esplanade and designating the Lonsdale Quay area south of Esplanade as a special flood risk tolerance zone (subject to approval by CNV) and implementing only building floodproofing measures through retrofits (e.g., flood doors). The special flood risk tolerance zone would acknowledge that shallow coastal flooding of roads and at-grade properties would occur more frequently (e.g., 10% annual probability in Year 2100 for Lonsdale Avenue at Carrie Cates Court), but permanent structural measures would not be implemented. Instead, flood risk could be tolerated through education and business-level flood resilience measures (e.g., insurance, retrofits), in addition to the use of seasonal temporary flood barriers. Another option is to restrict the business types in the area to those that would be less likely to sustain flood damage. Additional analysis to better understand the existing flood resilience of the area, such as a review of existing building entrance elevations, and building materials/stored goods below the flood level, would help in the refinement of this concept.

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District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Orthophoto Sources: District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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Notes:
1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

Project No.	31-548
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Scale	1:6,000

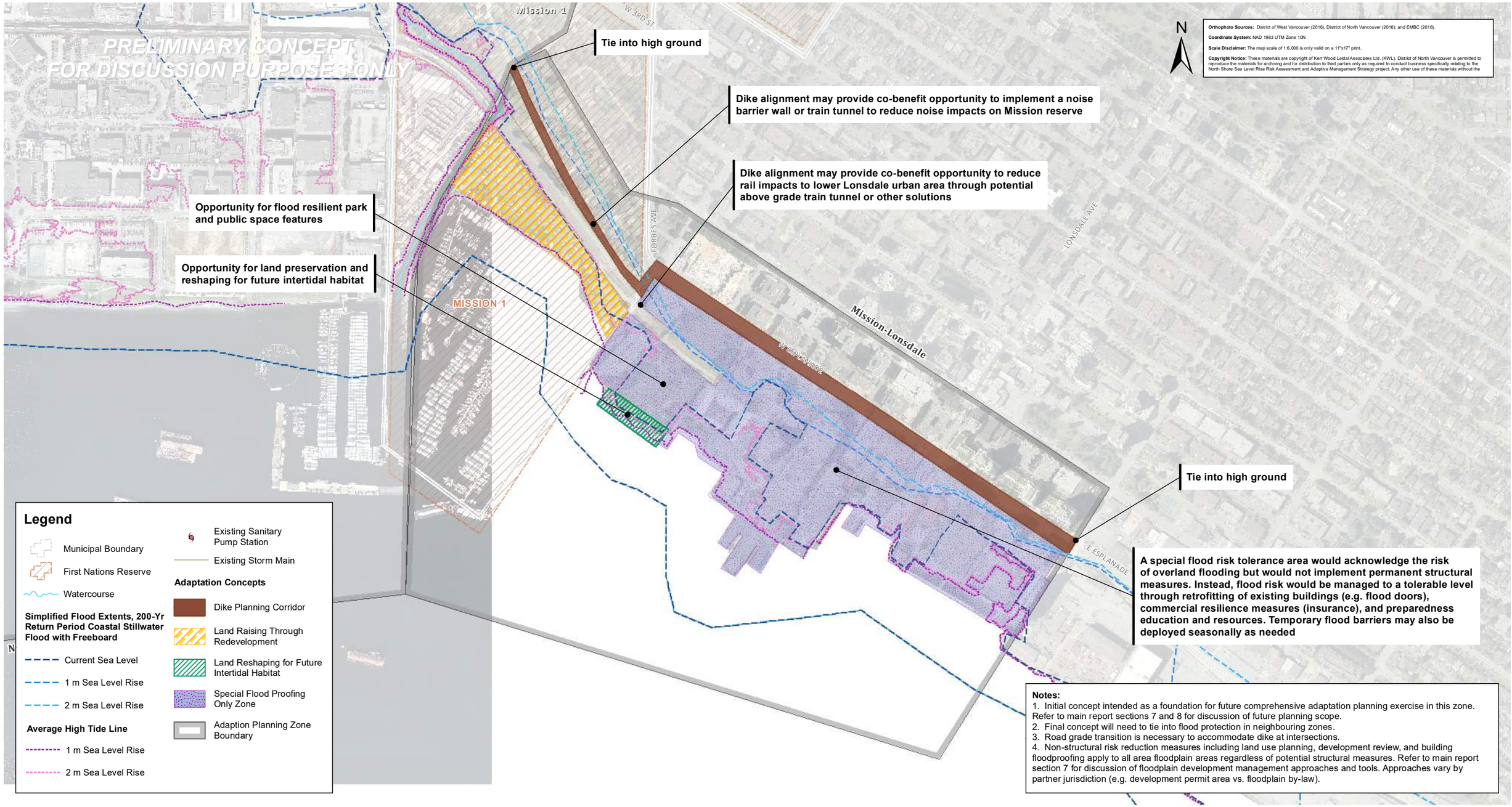
Esplanade Dike and Shoreline Seawall Initial Adaptation Concept for Lonsdale - Mission Comprehensive Adaptation Planning Zone

Figure 7-7

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Project No.	31-548
Date	July 2020
Scale	1:6,000

Esplanade Dike and Special Flood Risk Tolerance Zone (no permanent structural measures)
Initial Adaptation Concept for Lonsdale - Mission Comprehensive Adaptation Planning Zone

Figure 7-8

Lynn – Seymour

The Lynn-Seymour zone includes port terminals south of Low-Level Road in CNV and Main Street in DNV, the commercial Park and Tilford area in CNV, Phibbs Exchange transit, highway infrastructure area in the Province's jurisdiction and SN's Seymour I.R. #2 which includes band administration offices and businesses. Watercourses in this zone include Lynn Creek and Seymour River, which both have alluvial fans. Adaptation planning will involve DNV, CNV, SN, and the Port.

Under current sea level and a 200-year return period (0.5% annual exceedance probability) stillwater event, overland flooding is generally not expected in the zone. Under 1 m of sea level rise and the same extreme event, shallow flooding (<0.5 m) is predicted throughout the Port lands south of the rail corridor, deeper flooding of the underpass on Mountain Hwy., and some limited shallow flooding is evident in Phibbs Exchange and the Park and Tilford area. However some of the areas showing flooding are due to low-lying land and floodwater would only reach it via drainage through the railway corridor, which is not expected to be overtopped. Drainage paths through the railway corridor, including seepage paths, culverts, and buried stormwater pipes, were not assessed as part of the Strategy but should be considered in future CAPZ projects. Under 2 m of sea level rise, there is widespread flooding in the 0.5 m to 2 m depth range in the Port lands and generally 0.5 m to 1 m flooding in the Park and Tilford area and Phibbs Exchange. Shallow flooding of the southern portion of SN's Seymour I.R. #2, including the band administration office area, is also apparent. A low point in the rail corridor near Low-Level Road and 3rd Street E is shown as being overtopped.

Onset of Flooding Probability

Table 7-9 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Lynn – Seymour area for different sea level rise scenarios.

Table 7-9: Lynn-Seymour Area Annual Probability for the Onsite of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
Port Terminals (foot of Brooksbank) (3.3 m CGVD28)	1% (100)	15% (7)	100%	100%
Gladstone Avenue at Cotton Road (4.6 m CGVD28)	<0.5% (>200)	<0.5% (>200)	<0.5% (>200)	23% (4)
Front Street at Mountain Highway (3.5 m CGVD28)	< 0.5% (>200)	9% (11)	31% (3)	100%
Main Street below Iron Workers Memorial Bridge Approach (4.6 m CGVD28)	<0.5% (>200)	<0.5% (>200)	<0.5% (>200)	23% (4)

Initial Adaptation Concepts

Two initial adaptation concepts are proposed involving a setback dike incorporated into either the Cotton Road – Main Street transportation corridor (Figure 7-9) or the rail corridor (Figure 7-10). Under both concepts land raising through redevelopment is proposed for the area south of the dike corridor.

Both setback dikes would prevent coastal flooding from impacting the important Cotton Road – Main Street transportation corridor and the Phibbs Exchange / Highway 1 transportation hub.

The rail corridor alignment would have fewer impacts on the Cotton Road – Main Street corridor but would require coordination with CN Rail.

The Cotton Road – Main Street dike corridor would more easily tie in with potential diking and land raising along the Lynn Creek corridor to address creek flood risk. These concepts are being developed as part of the current Lynn Creek Flood Risk Assessment and Reduction Plan project, led by CNV in partnership with DNV. As with other dike-in-road concepts, planning and design would need to consider the potential impact of infrastructure within the road on the dike and vice versa, and develop design solutions to address potential impacts.

Lands south of the dike corridor would be raised through redevelopment. Port lands south of CNV may raise to a lower elevation due to a higher flood risk tolerance and a requirement for water access. As previously discussed, flood risk tolerance decisions currently reside with each North Shore partner organization.

High capital and operation and maintenance costs related to drainage pump stations may be avoided through a pressurized stormwater pipe system for the upper catchment and careful planning of the land raising through redevelopment to maintain overland stormwater routes. The road network-grade would need to be designed to below low enough to provide sufficient overland stormwater routes, but not so low that coastal flooding would regularly interrupt access and egress for parcels on raised land. Determining this elevation is a flood risk tolerance decision. It may be appropriate to set the road network elevation to the 10-year return period (10% annual exceedance probability) coastal flood level (3.6 m CGVD28 with 1 m of sea level rise and freeboard) because that would match the existing 10-year return period rainfall criteria used for the sub-surface stormwater network.

On the west bank of the Seymour River, the setback dike would tie into a diking corridor along and through SN reserve land has been incorporated into multiple flood planning studies, including the 2014 North Vancouver Floodplain Mapping project (KWL, 2014).

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers

PRELIMINARY CONCEPT
FOR DISCUSSION PURPOSES ONLY

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Tie into high ground

Land raising to incorporate new overland drainage corridors to minimize the need and size of drainage pump stations

Lynn Creek Dike

Coordinate and tie into potential diking and land raising for creek flood risk assessment - refer to joint CNV-DNV Lynn Creek flood risk assessment and reduction plan (2020)

Development regulation and building floodproofing applies to floodplain areas north of dike corridor

Bridge upgrade

Tie into high ground

Seymour River Dike

Mountain Highway underpass will be expanded and existing pump station upgraded as a project led by CN Rail

Floodproof pump station (retrofit or at time of replacement)

North to south road corridors maintained at a lower elevation to raised parcels to provide future overland drainage paths and reduce the need and size of drainage pump stations

Redevelopment is ongoing at the G3 Grain Terminal Site

E KEITH RD
HENDRY AVE
E 3RD ST
LOW LEVEL RD
North Vancouver
MT SEYMOUR PKWY
LILLOOET RD
MOUNTAIN HWY
MAIN ST
Seymour Creek 2
Maplewood Creek
RIVERSIDE DR
OLD DOLLARTON RD
Lynn Creek
SEYMOUR CREEK 2
Vancouver
Unknown

Legend

- Municipal Boundary
- First Nations Reserve
- Watercourse
- Existing Sanitary Pump Station
- Existing Storm Main

Simplified Flood Extents, 200-Yr Return Period Coastal Stillwater Flood with Freeboard

- Current Sea Level
- 1 m Sea Level Rise
- 2 m Sea Level Rise

Average High Tide Line

- 1 m Sea Level Rise
- 2 m Sea Level Rise

Adaptation Concepts

- Bridge Upgrade
- Dike Corridor
- Increased Creek Corridor
- Land Raising Through Redevelopment
- Adaption Planning Zone Boundary

Notes:

1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

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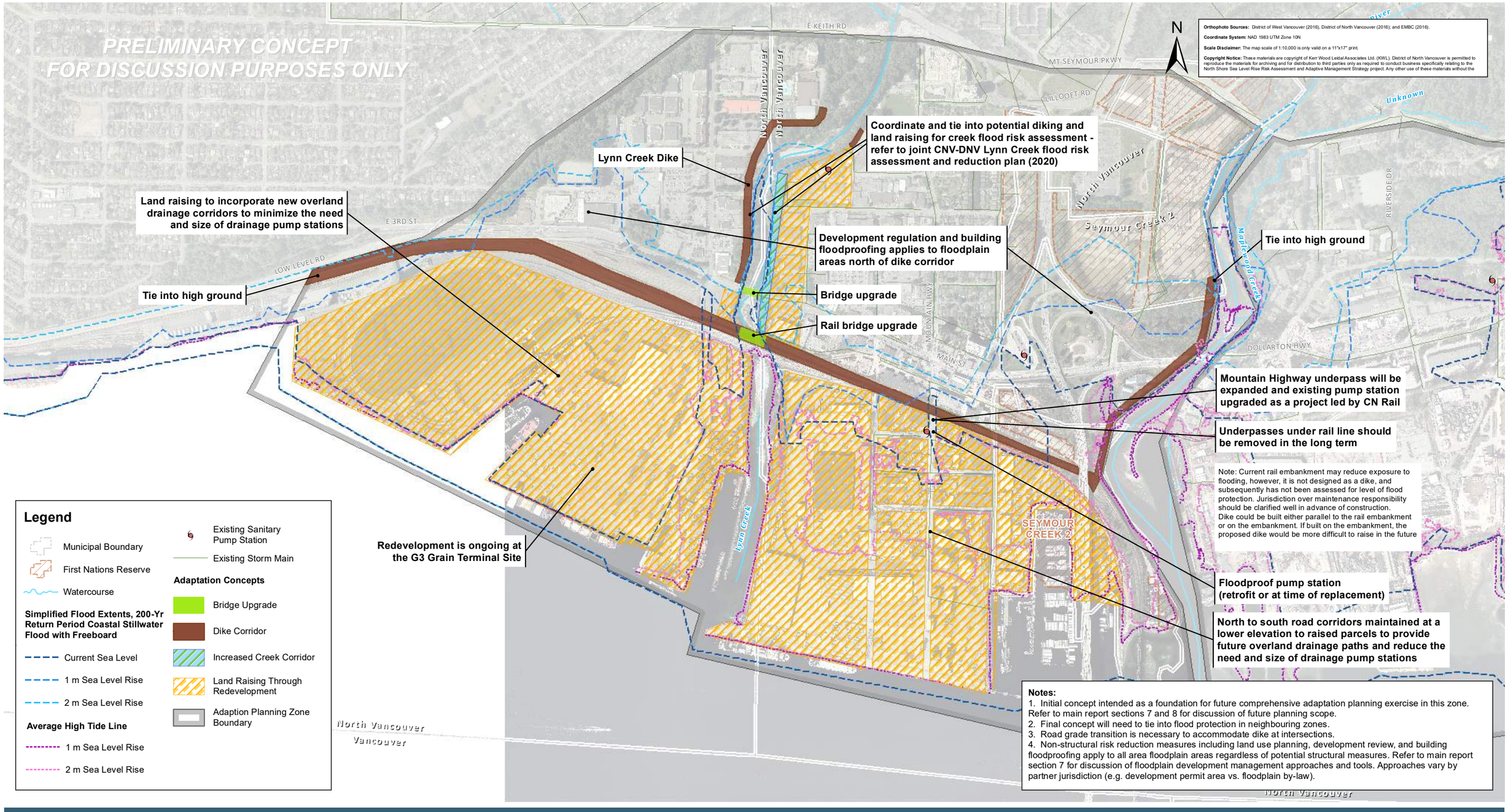
Cotton Road - Main Street Setback Dike and Land Raising Initial Adaptation Concept for Lynn - Seymour Comprehensive Adaptation Planning Zone

Figure 7-9

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Notes:
1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

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Scale	1:10,000

Rail Dike and Land Raising Initial Adaptation Concept for Lynn-Seymour Comprehensive Adaptation Planning Zone

Figure 7-10

Maplewood

The Maplewood zone covers the commercial/industrial areas east of the Seymour River to the boundary with the Tsleil-Waututh Nation's Burrard I.R. No. 3.

Under 1 m of sea level rise and a 200-year return period (0.5% annual exceedance probability) stillwater event, overland flooding is generally not expected in the zone. Under 1 m of sea level rise and the same extreme event, shallow flooding is evident in the industrial area south of Spicer Road and adjacent to the east bank of the Seymour River, and in the road network surrounding Dollarton Highway at Forester Street. Under 2 m of sea level rise, there is widespread flooding in the zone with flood depths up to 2 m. Flood extents reach north of Old Dollarton Road and all major transportation routes through the zone are also flooded.

Onset of Flooding Probability

Table 7-10 presents the annual probability (and return period) for the onset of stillwater flooding for a few distinct locations in the Maplewood area for different sea level rise scenarios.

Table 7-10: Maplewood Area Annual Probability for the Onsite of Stillwater Flooding

Location (Approx. Elevation)	Annual Probability of Stillwater Flooding (return period, years)			
	Current Sea Level	0.5 m Sea Level Rise (~Year 2050)	1.0 m Sea Level Rise (~Year 2100)	2.0 m Sea Level Rise (~Year 2200)
Industrial waterfront shoreline (3.2 m CGVD28)	2% (50)	18% (6)	100%	100%
Spicer Road at Amherst Avenue (4.2 m CGVD28)	<0.5% (>200)	<0.5% (>200)	50% (2)	100%
Dollarton Highway at 2420 Dollarton Highway (3.9 m CGVD28)	< 0.5% (>200)	0.5% (200)	13% (8)	100%
Forested lands north of Old Dollarton Road near Forester St. (3.4 m CGVD28)	0.5% (200)	13% (8)	47% (2)	100%
Maplewood Flats Conservation Area building (3.4 m CGVD28)	0.5% (200)	13% (8)	47% (2)	100%

Initial Adaptation Concepts

Adaptation planning in the Maplewood zone can be led by DNV with the Port and Tsleil-Waututh Nation participating as key partners given their land interests.

Two initial adaptation concepts are proposed involving a setback dike incorporated into the Dollarton Highway corridor or the Spicer Road / rail corridor. Both concepts involve land raising through redevelopment south of the dike corridor. These are presented in Figure 7-11 and Figure 7-12.

A Dollarton Highway setback dike is envisioned in the Maplewood Centre Implementation Plan and Design Guidelines (DNV, 2017). The plan highlights raising the eastern portion of Dollarton Highway to an elevation of 4.7 m CGVD28. The initial concept presented in the Strategy includes designating the full length of Dollarton Highway from Seymour River to Tsleil-Waututh Nation's Burrard I.R. No. 3 as a diking corridor. Dollarton Highway raising of up to 1 m would be required to designate it as a dike for adaptation to 1 m of sea level rise.

A Spicer Road setback dike was previously identified and discussed as part of a flood risk management strategy developed for the Maplewood Area (NHC, 2016). NHC reported that the dike height would be between 0.7 m and 1.7 m above surrounding grade and that there appears to be sufficient space north of the rail corridor to accommodate the dike alignment with some limited unoccupied / parking property acquisition.

As with other similar concepts in other zones, lands south of the dike corridor would be raised through redevelopment. An option to explore is that waterfront industrial lands may be raised to a lower elevation due to a higher flood risk tolerance and a requirement for water access.

High capital and operation and maintenance costs related to drainage pump stations may be avoided through a pressurized stormwater pipe system for the upper catchment and careful planning of the land raising through redevelopment to maintain overland stormwater routes. The road network-grade would need to be designed to below low enough to provide sufficient overland stormwater routes, but not so low that coastal flooding would regularly interrupt access and egress for parcels on raised land. Determining this elevation is a flood risk tolerance decision. It may be appropriate to set the road network elevation to the 10-year return period (10% annual exceedance probability) coastal flood level (3.6 m CGVD28 with 1 m of sea level rise and freeboard) because that would match the existing 10-year return period rainfall criteria used for the sub-surface stormwater network.

Three sanitary pump stations located south of the diking corridor are recommended to be floodproofed through either retrofitting or at the time of replacement. An additional sanitary pump station located north of the dike corridor would also benefit from floodproofing to add resilience against potential dike overtopping in the future.

On the east bank of the Seymour River, the setback dike would tie into diking and land raising corridor concept was developed in support of the Maplewood Plan (KWL, 2017).

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers

PRELIMINARY CONCEPT
FOR DISCUSSION PURPOSES ONLY

Land raising flood protection concept for Seymour River flood risk - refer to Maplewood Village flood mitigation plan (KWL, 2017)

Development regulation and building floodproofing applies to floodplain areas north of dike corridor

This area (like all floodplain areas) is subject to FCL and floodplain regulation

Tie into high ground

Opportunity for habitat enhancement including preservation of land for future reshaping for future intertidal habitat

North to south road corridors maintained at a lower elevation to raised parcels to provide future overland drainage paths and reduce the need and size of drainage pump stations

Current Port-led habitat restoration and enhancement project

Potential opportunities along Seymour River for setting back land raising to provide habitat areas and natural shorelines

Land raising to incorporate new overland drainage corridors to minimize the need and size of drainage pump stations

Orthophoto Sources: District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:12,000 is only valid on a 11"x17" print.

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Legend

- Municipal Boundary
- First Nations Reserve
- Watercourse

Simplified Flood Extents, 200-Yr Return Period Coastal Stillwater Flood with Freeboard

- Current Sea Level
- 1 m Sea Level Rise
- 2 m Sea Level Rise

Average High Tide Line

- 1 m Sea Level Rise
- 2 m Sea Level Rise

- Existing Sanitary Pump Station
- Existing Storm Main

Adaptation Concepts

- Seymour River Flood Protection Land Raising
- Land Raising Through Redevelopment
- Land Reshaping for Future Intertidal Habitat
- Adaption Planning Zone Boundary

Notes:
1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

Project No.	31-548
Date	July 2020
Scale	1:12,000

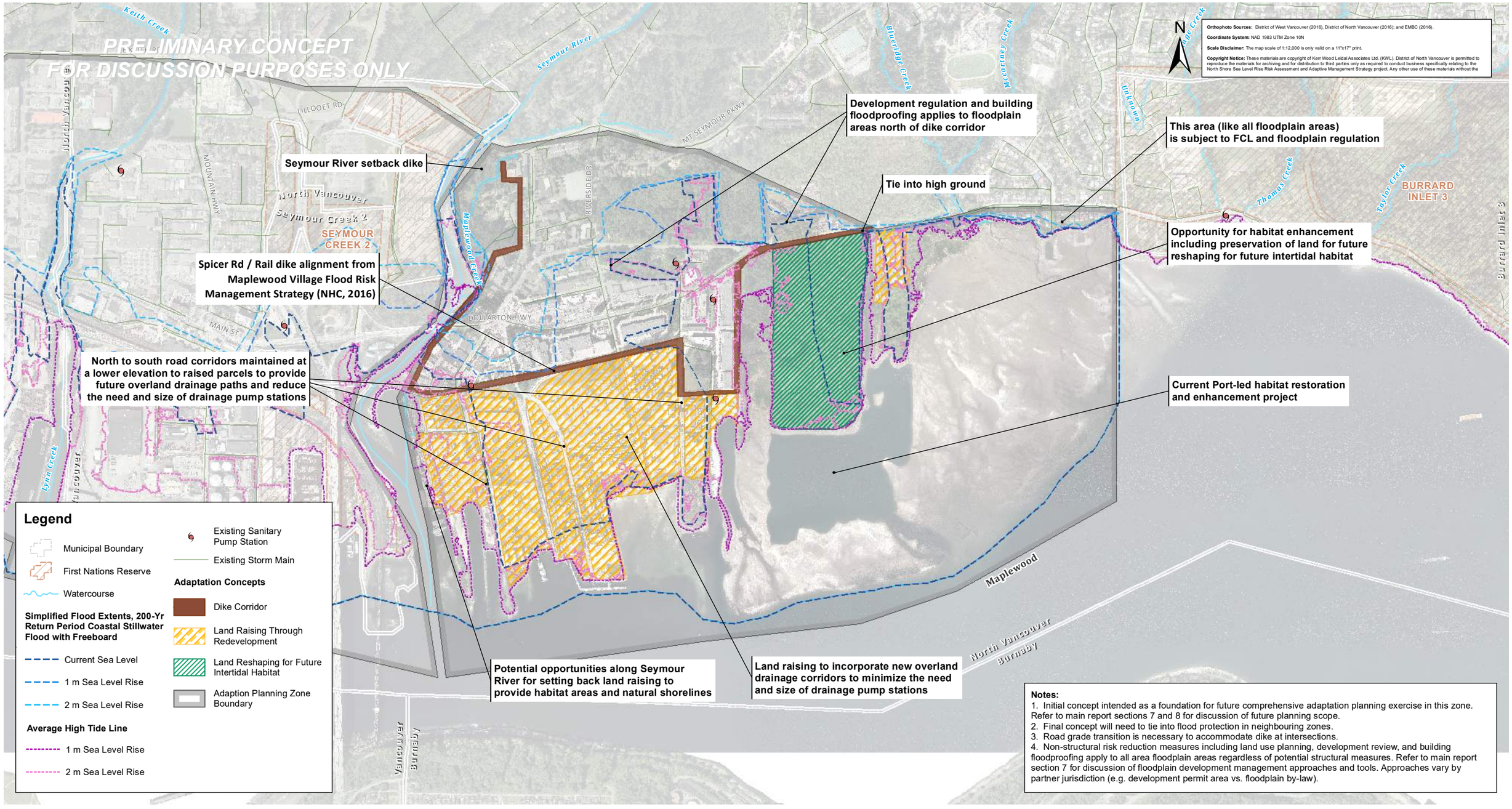
Dollarton Highway Setback Dike and Land Raising Initial Adaptation Concept for Maplewood Comprehensive Adaptation Planning Zone

Figure 7-11

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Notes:
1. Initial concept intended as a foundation for future comprehensive adaptation planning exercise in this zone. Refer to main report sections 7 and 8 for discussion of future planning scope.
2. Final concept will need to tie into flood protection in neighbouring zones.
3. Road grade transition is necessary to accommodate dike at intersections.
4. Non-structural risk reduction measures including land use planning, development review, and building floodproofing apply to all area floodplain areas regardless of potential structural measures. Refer to main report section 7 for discussion of floodplain development management approaches and tools. Approaches vary by partner jurisdiction (e.g. development permit area vs. floodplain by-law).

Project No.	31-548
Date	July 2020
Scale	1:12,000

Spicer Road /Rail Dike and Land Raising Initial Adaptation Concept for Maplewood Comprehensive Adaptation Planning Zone

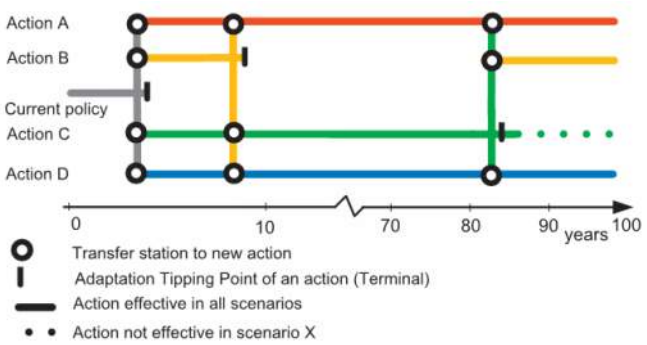
Figure 7-12

7.5 Adaptation Concept Refinement and Evaluation Considerations

This sub-section provides suggestions on criteria and considerations for refining and evaluating adaptation concepts, such as the preliminary concepts in the previous sub-section as well as alternatives. These suggestions are intended to assist with preparing comprehensive adaptation plans.

Adaptation Pathways Approach

An 'adaptation pathways' approach (Haasnoot et al, 2012) is recommended for developing comprehensive adaptation plans for each planning zone. The adaptation pathways approach can be used to summarize various alternative adaptation concepts and sequences of variations into a visual decision guidance map (see graphic to the right).



The horizontal axis on the decision map represents time, which can also be translated to the magnitude of sea level rise to help keep the decision guidance map relevant as projections change in the future.

The adaptation pathways approach also identifies adaptation concept tipping points and transfer stations between alternative concepts. A tipping point is a time at which a concept is no longer able to perform its intended purpose or is no longer viable. For example, shoreline dikes may not be technically or economically feasible if the design flood height increases beyond several metres. A transfer station is an opportunity to change adaptation concepts.

This approach promotes understanding and preserving different adaptation concept alternatives. Preserving alternatives into the future will allow adaptation plans to be more flexible to future change. A relevant example for the North Shore is using the approach to preserve potential shoreline diking corridors and setback dike corridors while monitoring the uptake and effectiveness of land raising through redevelopment and also engaging with CN Rail to determine if and when they may raise rail corridor. Preserving options will increase the likelihood that the most effective path is selected at the right time.

Implementation Triggers and Risk Tolerance

Another key component of developing comprehensive adaptation plans for planning zones will be the definition of triggers for implementing adaptation concepts. Implementing concepts too early can have long-term consequences if they commit a community to a particular concept that may not be appropriate under a future condition that was not foreseen earlier. Implementing concepts too late may lead to increased implementation costs and reactive planning.

Determining the appropriate timing trigger for an adaptation concept can be defined as follows:

Implementation trigger date = **Required in-service date** *minus* **the implementation lead time**

The required in-service date for an adaptation concept is the approximate date at which flood risk becomes no longer tolerable.

Various jurisdictions around the world use flood risk tolerance criteria to guide flood management planning. For example, the Netherlands defines flood risk tolerance in terms of the maximum loss-of-life probability for an individual (0.001% or 10^{-5}/year) and as the maximum annualized economic damages ($/ha/year, $ value varies by location) (Van Alphen, 2016).

Canada and British Columbia do not have explicit flood risk tolerance criteria at this time. The Government of Canada, through Natural Resources Canada (NRCAN) is developing various guidelines related to flood management, which may lead towards definitions of flood risk tolerance.

While not related to coastal hazards, there are risk tolerance criteria on the North Shore: the DNV's natural hazards risk tolerance criteria which are applied through the creek hazard development permit area. Following a 2005 landslide that resulted in a fatality, the DNV developed risk to loss of life tolerance criteria, which are used in determining the need for risk reduction measures for developments exposed to various geohazards.

The current regional and provincial approach to flood hazard management in British Columbia is based on hazard likelihood instead of a risk-based approach. Historically, flood protection policies and infrastructure in the province were linked to the 200-year return period (0.5% annual exceedance probability) flood event; this was applied regardless of the consequences, and therefore risk, associated with the hazard. This is referred to as a hazard-based approach. Use of the 200-year return period flood was linked to the previously-estimated return period of the 1894 flood of record on the Fraser River.

There is a gradual trend towards a more risk-based approach, led by the regional work of the Fraser Basin Council through the Lower Mainland Flood Management Strategy (the North Shore partners are participants). It is not known at this time whether the Lower Mainland Strategy will define flood risk tolerance for the region. If flood risk tolerance emerges for the region, the North Shore partners could consider using the regional flood risk tolerance for an expanded quantitative risk assessment.

In the absence of formal risk-based flood risk tolerance criteria from senior or regional bodies, it is reasonable for the North Shore partners to continue to use either a 200-year or 500-year return period hazard level for risk tolerance in line with the Province's guidelines (for stillwater levels the difference between the 200-year and 500-year return period events is small).

Risk tolerance could be further refined by linking it to a maximum tolerable flood depth at the 200-year or 500-year return period event. This would acknowledge that shallow flooding (< 0.5 m) may be tolerable in some areas and land uses. For example, the flood risk tolerance for roads could be linked to the maximum tolerable flood depth for emergency vehicle access.

If risk tolerance is defined, flooding probability analysis can be used to identify the amount of sea level rise that will result in flood risk exceeding the tolerance level for different planning zones. For example, if 0.5 m flood depth at the 200-year return period event is the tolerance threshold, a spatial analysis could develop a map showing how much sea level rise will exceed the tolerance. The information could also be presented in terms of dates (years) based on current sea level rise projections. This approach can be tested through future CAPZ projects to determine its suitability and if suitable could be expanded in scale.

Evaluation Criteria

The Strategy suggests the following criteria for future evaluation of alternative adaptation concepts and measures. They reflect the Strategy principles, which were informed by the initial public engagement process.

1. **Risk Reduction Effectiveness**: What magnitude of risk reduction is achieved through implementing this concept? Does this concept increase risk elsewhere or for particular sectors?
2. **Uncertainty Tolerance:** Does this concept continue to effectively reduce risk with changing sea level rise projections? If projections increase greatly, is the approach still effective? Are there fail-safe measures if this concept fails?
3. **Environmental Impact/Benefit**: Does this concept have a positive or negative impact on the surrounding aquatic and terrestrial environment? Are there opportunities for environmental co-benefits such as carbon sequestration or habitat creation?
4. **Social Impact/Benefit:** What are the social impacts of this concept? Are there groups of people that are disproportionately burdened by, or benefit from, this concept?
5. **Economic Impact/Benefit**: What are the economic implications of this concept? How does it impact the local jurisdiction (e.g. tax base), neighbouring jurisdictions, the local business community, and the regional or national economy?
6. **Cost**: How much does the concept cost (capital and maintenance) compared to other concepts? Do the benefits outweigh the costs? What funding streams can the partners draw upon to fund this concept?
7. **Phasing**: Can the concept be implemented gradually over time or does it need to be constructed altogether? What is the impact or risk if the concept is only partially completed by the targeted service date? What control does the local jurisdiction have over ensuring completion of the concept by the service date?

8. Implementation Plan

The Strategy provides a toolkit of adaptation measures (Appendix G) and policy basis and concepts for coastal adaptation (Section 7) to support North Shore partners in developing adaptation strategies tailored to their local contexts. The Strategy provides a platform of shared understanding about sea level rise risks and consequences and the various options available. These measures are outlined at a high level and many require additional study, feasibility, and design before they can be implemented.

Furthermore, while this shared understanding provides an important starting point, ongoing coordination between North Shore partners and other actors will make it possible to develop adaptation measures that are compatible along the shoreline and jurisdictional boundaries. Coordination can also create opportunities for cost-sharing and efficiencies, and support consistent messaging around risks and action across the region.

This Implementation Plan outlines next steps to implement the Strategy and recommendations for measuring adaptation progress over time.

8.1 Priority Next Steps (2020 - 2030)

Six priority next steps have been identified by the Project Team to help North Shore partners work together to implement the findings and approaches in this Strategy over the next 10 years. These next steps are described in the section below, along with specific actions that partners can take to move forward. It is assumed that these next steps, and associated actions, are to be applied across the North Shore, either completed by partners individually or in collaboration where appropriate.

1. Formalize a North Shore Sea Level Rise Adaptation Working Group

It is recommended that the project Steering Committee be formalized into an ongoing working group of North Shore partners that continue to meet at regular intervals, such as on a semi-annual basis. The group would provide an important forum for leading region-wide studies and sharing adaptation progress, lessons learned, and opportunities for funding or partnership. It could also provide a framework for establishing sub-committees for developing comprehensive adaptation plans for planning zones that involve multiple partners. Membership in the Working Group would include existing Steering Committee members and could be expanded to include other actors such as Tsleil-Waututh Nation, Metro Vancouver, and CN Rail.

The partners should consider what ongoing administration of the working group would look like, including who will be responsible for coordinating meetings, membership, and managing a North Shore Sea level Rise webpage. One option is to have NSEM act as a formal office for coordination: this would be in line with recent resiliency planning efforts.

Specific actions associated with this next step include:

- Select an organization to lead the group administration, including arranging meetings, facilitating dialogue, and facilitating information sharing between partners.
- Identify any additional groups on the North Shore that should be included in the formalized Working Group.
- Create refined Terms of Reference for the group, including group members, objectives, and protocols.

2. Continue to Build Knowledge about the Impacts of Sea Level Rise

Developing this Strategy involved a detailed analysis of coastal flooding and intertidal area change under future sea level rise scenarios. While this information provides a foundation for identifying potential adaptation approaches, partners may choose to pursue additional studies to support this work and site-level adaptation planning.

The following list outlines additional monitoring, studies, and analysis that partners may want to consider to support future coastal planning. They could be carried out in various ways (such as a study, monitoring, additional analysis, or required through regulatory tools). This could be carried out by an individual partner, a group of partners and stakeholders for an area or partners across the North Shore coordinated through the Working Group.

- Wave modelling to address knowledge gaps (underway by DWV);
- Local sea level rise and wave monitoring;
- Shoreline erosion screening assessment to identify areas with highest vulnerability to sea level rise and vessel traffic;
- Detailed analysis of intertidal area change (based on more complete bathymetric survey information);
- Study on impacts of sea level rise on creek and groundwater quality (e.g., cross-contamination, salt wedge);
- Coastal sediment source and transport study (to support nature-based coastal concepts);
- Analysis of combined sea level rise and river flood hazards and risks (for smaller creeks not covered by recent studies).
- Analysis of stormwater system upgrade options (e.g., pressurized outfall systems to reduce the size and need for drainage pump stations).
- Research on policy and implementation options and limitations of flood insurance, particularly for First Nation reserves (Squamish Nation) - consider coordinating with Tsleil-Waututh Nation;
- Impact of contaminated and hazardous waste generating/storage site vulnerable to sea level rise (e.g. site contaminants, site sensitivity, and sensitivity of neighbouring land uses to cross-contamination); and
- Update mapping and databases to support assessment of archaeological and cultural site vulnerability to sea level rise.

3. Establish Comprehensive Adaptation Plans in Collaboration with Partners

North Shore partners are encouraged to work together to create Comprehensive Adaptation Plans (CAPs) for each inter-jurisdictional comprehensive adaptation planning zone (CAPZ), drawing on the findings, measures, and concepts in this Strategy. Each plan should be created collaboratively, under the leadership of a sub-committee or working group of relevant North Shore partners and with ongoing input from other actors such as BC Hydro, Fortis BC, CN Rail, Metro Vancouver, Province of BC (MOTI, IOD), and BC Ferries. It is also recommended that CAPs consider integration with land use, transportation, creek flood, and drainage master planning.

Each planning process should consider using an adaptation pathways framework (described in Section 7.5) to design approaches that consider future uncertainty and are adaptive to changing

conditions over time. After evaluating concepts and selecting a preferred option, the comprehensive adaptation plans should outline an approach for managing sea level rise in the planning area, including site-specific projects, timelines, and high-level costing information. The plans would provide direction for feasibility assessments, detailed design, and strategic financial planning. Additional zone-specific risk assessments may also be warranted to guide the evaluation of options; this would involve calculating the risk reduction and residual risk for a number of shortlisted options.

Some of the planning areas are within one local jurisdiction (e.g. Horseshoe Bay, Stearman Beach, and Dundarave in DWV). Comprehensive adaptation planning in these three areas may not require a specialized area plan and instead may be incorporated into existing planning processes being led by the local government, such as parks or master planning.

Specific actions associated with this next step include:

- Define priorities and a phased timeline for completing CAPs, prioritized based on Board/Council direction.
- Establish sub-committees or working groups at the onset of each CAPs, including a Terms of Reference defining shared objectives, roles and responsibilities, and protocols to guide the collaborative process.
- Complete adaptation plans for the identified CAPZ in priority sequence, drawing on concepts outlined in Section 7.4 of this Strategy. Refer to Section 7.4 for key considerations for each CAPZ:
  - Horseshoe Bay;
  - Stearman Beach;
  - Dundarave;
  - Ambleside-Capilano West;
  - Capilano East;
  - Norgate-Mosquito;
  - Mission Lonsdale;
  - Lynn-Seymour; and
  - Maplewood.
- Report on CAPs progress to the broader North Shore SLR Working Group on an annual basis.

4. Integrate Findings from this Strategy into Community-wide Flood Management Initiatives

Adaptation to sea level rise will involve a broad suite of integrated measures, including structural measures within the CAPZ and broader-reaching planning and policy tools to be implemented at the local government level (e.g. beyond CAPZ boundaries). It is recommended that North Shore partners draw on the analysis and findings in this Strategy to inform other plans, policies, and initiatives that can support coastal flood management more broadly.

Partners are encouraged to consider how these, and other initiatives within their jurisdiction, may inform or be adjusted to support the CAPs development process and outcomes.

Specific actions associated with the next step include:

- Incorporate updated coastal flood construction levels (FCLs) and setbacks for future development into floodplain regulation tools such as floodplain bylaws or development permit areas (DPAs);
- Consider incorporating long-term avoid and retreat approaches into land-use planning as part of official community plan and local area plan updates;

- Incorporate adaptation toolkit measures into coastal management plans (DWV) and other master plans (e.g. parks);
- Incorporate findings and adaptation measures into asset management (water, wastewater, drainage) and/or natural asset management plans;
- Update climate change adaptation strategies to reflect the new Strategy; and
- Incorporate coastal flood mapping (current sea level) into emergency management and response plans.
- Present this Strategy to Boards/Councils to seek direction to continue adaptation planning and implementation.

5. Continue to Build Public Awareness about Coastal Flooding and Sea Level Rise

It is recommended that partners continue to engage the public and key community groups within their jurisdictions about sea level rise risks and adaptation planning. Ongoing engagement should aim to build community understanding of sea level rise impacts and refine an understanding of the key values and priorities that inform the development of tailored adaptation approaches within each community.

Ongoing engagement could include developing a central webpage for the North Shore SLR Working Group (refer to Next Step #1) or for individual partners to maintain webpages with information tailored to their communities. Some partners may wish to establish community member advisory committees to support coastal adaptation planning in each jurisdiction.

Specific actions associated with this next step include:

- Share key outcomes from the Strategy on the project webpage, currently hosted by the District of North Vancouver.
- Consider opportunities for ongoing communication of Strategy progress, either through the current DNV-hosted project webpage, a new central Working Group webpage, or individual partner webpages.
- Consider options to develop a North Shore SLR adaptation brand to support consistent and coordinated messaging around the sea level rise and coastal flood resilience.
- Continue to engage the public and community groups as each CAPs is developed.

6. Coordinate with Other Levels of Government

While local governments are responsible for flood management in BC, higher levels of government play an important role in setting standards and legislation that influence flood management at the local level. It is recommended that North Shore partners continue to engage with relevant provincial government departments and agencies throughout the CAPs planning and implementation process.

Provincial and federal government departments are leading a number of initiatives to provide guidance and support to local governments for coastal flood management. Some of these initiatives include:

- Province of BC Flood Management Strategy (administered by the Fraser Basin Council),
- Lower Mainland Flood Management Strategy (administered by the Fraser Basin Council),

- Fraser Basin Council Joint Program Committee (administered by the Fraser Basin Council), and
- NRCAN Flood Risk Assessment and other guidelines.

Furthermore, provincial and federal regulations have significant bearing on the design and implementation of flood management measures. In particular, the Province of BC IOD is responsible for approving dikes and should be engaged early in the design process for non-standard dikes. Early and ongoing engagement with provincial and federal agencies will encourage senior-level support and process efficiencies throughout flood planning and implementation.

Specific actions associated with this include:

- Work with the Province and/or Fraser Basin Council to inform flood risk tolerances and/or consistent criteria for flood management measures (e.g., 500-year return period).
- Seek out opportunities to participate in province-wide flood management working groups or to provide input into province-wide flood management initiatives.

8.2 Sustainable Funding Approaches

Building resilience to sea level rise will require a combination of approaches implemented over different scales and timeframes. While some of the planning and governance measures may be integrated into existing programs and initiatives at relatively low cost, other options have significant costs such as structural measures to protect shorelines from flooding or purchasing land in high flood-risk.

Results from community engagement suggest that there is no consensus about who should pay for flood protection and coastal adaptation. Feedback on the community survey shows that perceptions about who should pay depending on whether the respondent lives in a potential coastal flooding area. Of the 27 respondents who live outside of the planning area, 17 people (63%) ranked property owners in the potential flooding areas as responsible for the highest portion of adaptation costs. In contrast, of the 38 respondents living in the planning area, 24 people (63%) ranked senior levels of government and municipal taxpayers as responsible for the highest portion of costs.

Successful implementation of the Sea Level Rise Adaptive Management Strategy will require creative financing approaches that leverage cost efficiencies wherever possible. Potential sources of funding for coastal adaptation measures include:

- **Federal and provincial government grants** e.g., Disaster and Mitigation Fund, Investing in Canada Infrastructure Program, Smart Cities Challenge, UBCM Community Emergency Preparedness Fund and Gas Tax Fund, FCM Green Municipal Fund, BC Housing Grants.
- **Other non-governmental grant programs** e.g., Real Estate Foundation of BC, New Relationship Trust Capacity Building Fund;
- **Municipal finance tools on an area-specific or community-wide basis** e.g., development cost charges, special levies, property taxes, user fees, utility funding;
- **Drawing on loans or reserves** for capital spending or ongoing maintenance of flood protection structures;

- **Cost-sharing agreements** with neighbouring communities that benefit from a measure, industry and property owners, academic organizations, non-profits, or other special interest groups;
- **Developer or property-owner funding** e.g., building or development permit requirements, flood construction levels, wet or dry floodproofing;

North Shore partners should consider a combination of funding approaches and look for opportunities for project partnerships and efficiencies. Strategies for making costs more affordable may include:

- **Adjusting project scope or phasing** to address highest priorities and fit grant program priorities.
- **Taking a risk-based approach** to focus investment in areas posing the highest consequence;
- **Leading cost-benefit analyses** for the evaluation and selection of flood management options;
- **Developing a funding strategy** for each comprehensive adaptation plan that lays out a roadmap for funding opportunities and approaches.
- **Drawing on asset management planning** to incorporate adaptation measures into renewal schedules for existing assets reaching the end of their useful life. Adding new adaptation structures or lands into asset management programs will support proactive maintenance and identify reliable funding sources for asset lifecycle costs;
- **Working together** through formal cost-sharing agreements, project planning to avoid redundancy and potential cost savings, and sharing insights on funding opportunities;
- **Participating in regional flood management and climate adaptation planning groups** (e.g., the Lower Mainland Flood Management Strategy Group led by the Fraser Basin Council) to draw on best practices, lessons learned, and strategies for cost efficiencies.

8.3 Progress Monitoring and Evaluation

Potential indicators for tracking the progress of implementing this Strategy and outcomes of sea level rise adaptation are outlined below.

It is recommended that partners consider these indicators when developing CAPs and monitor and report on them within their organization and to the Working Group on an annual basis. Partners may choose to report some or all of the results to the public through the project webpage or other local reporting pathways. Over time, indicators may be reviewed depending on data availability, or the Working Group may suggest other indicators to track progress.

Progress indicators have been categorized into two groups:

- **Process Indicators** that monitor the progress of implementing the Strategy in alignment with the strategic vision and principles (Section 4); and
- **Outcome Indicators** that evaluate whether progress towards adaptation is being achieved. Since sea level rise adaptation is a long-term process, it is not anticipated that the whole North Shore will achieve full adaptation within the next 10 years (the timeframe of this Strategy).

Potential indicators in each category are shown in Table 8-1. Targets are suggested to the year 2030, the planning horizon for this Strategy.

Table 8-1: Potential Indicators for Evaluating Adaptation Progress

Potential Indicator		Data Source
Process Indicators	**PROACTIVE** - Percentage of Strategy "specific actions" that have been initiated or completed (suggested target: 100% by 2030)	Individual Partners or Working Group Meeting minutes
	PROACTIVE - Percentage of CAPZ with initiated or completed CAPs (suggested target: 100% by 2030)	Individual Partners or Working Group Meeting minutes
	ADAPTIVE/RISK-BASED - Percentage of completed CAPs developed using risk-based and adaptive approaches (suggested target: 100% by 2030)	CAPs project documentation
	COORDINATED – Number of North Shore SLR Working Group meetings each year (suggested target: minimum 1 each year to 2030)	Working Group Meeting minutes
	ALL OF SOCIETY - Percentage of initiated or completed CAPs actions that consider multiple values wherever possible (e.g., environment, social, economy, culture, recreation, residents). (suggested target: 100% by 2030)	CAPs or project documentation
	INFORMED DECISION-MAKING – Percentage of initiated or completed CAPs that include public and/or stakeholder engagement (suggested target: 100% by 2030)	Working Group Meeting Minutes
Outcome Indicators	Percent of number of projects in potential inundation areas using sea level rise information to inform risk reduction (e.g. developments, parks, utility, and environmental/habitat projects)	Development and Project Records
	Percent of new developments in the floodplain using floodproofing measures (e.g. land raising, FCLs)	Development Permit Process/Records
	Percent of building stock with adequate FCLs for existing and future conditions	A 5-year survey of records, supplement by LiDAR
	Number of complaints (e.g. online work requests) submitted to each partner organization citing coastal flood damage to public or private properties.	Recorded complaints, comments, work requests etc.

8.4 Updates and Amendments

Adaptive management approaches are designed to be flexible in the face of uncertain future conditions. Implementing this approach requires periodic review to ensure the Strategy reflects the most up-to-date projections of future conditions as new information becomes available.

It is recommended that the North Shore Sea Level Rise Adaptative Management Strategy is reviewed by the Working Group in 10 years (2030), or within 10 years if major changes occur that would trigger a review.

Major changes to current conditions or projections may trigger updates to the Strategy and plan to continue building resilience across the region. The Working Group should consider whether significant changes have occurred in the following areas:

1. **Changes to sea level rise projections**
    - Updated sea level rise projections (a new IPCC report is issued every 5 years, with the next report scheduled for 2023, which will provide updated climate data and projections);
    - Policy direction from higher-levels of government (e.g. Province of BC sea level rise planning policy);
    - Storm surge intensity or frequency; and
    - Coastal flood assessment methodologies under climate conditions.
2. **Changing local context**
    - Significant new or unexpected risks; and
    - Significant change in priorities (e.g. community values and priorities, or local or regional political priorities).
3. **Shifting adaptation approaches**
    - New framework or approach for long-range adaptation planning; and
    - Adaptation best practices or flood management approaches.
4. **Changing Working Group direction**
    - Significant changes to Working Group participation or direction; and
    - Overperformance of Strategy monitoring results.

Keeping the North Shore Sea Level Rise Adaptive Management Strategy up to date will support ongoing and interconnected resilience across the region.

9. Report Submission

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Potential Sea-level Rise Impacts to Intertidal Areas and Marine Riparian Areas

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This document represents KWL's best 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.

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Revision History

Revision #	Date	Status	Revision	Author
0	2021-02-28	FINAL	Revised based on additional feedback from DNV.	ATAL/RNH
H	2020-07-15	DRAFT	Revised based on consolidated comments received on June 11, 2020.	ATAL/DCS/RNH
G	2020-05-11	DRAFT	Added new sections (community engagement, strategic vision and principles, adaptation measures, and implementation).	ATAL/RNH
F	2020-03-25	PARTIAL DRAFT	All sections updated based on comments provided between December 2019 and January 2020.	ATAL
E	2019-08-19	PARTIAL DRAFT	Updated partial draft (risk section added). Hazard section updated based on commented provided on May 3, 2019.	ATAL/RNH
D	2019-02-28	PARTIAL DRAFT	Updated partial draft (hazard analysis section added).	ATAL
C	2018-12-14	PARTIAL DRAFT	Updated partial draft based on additional comments provided on December 13, 2018.	ATAL
B	2018-11-30	PARTIAL DRAFT	Updated partial draft based on consolidated comments provided on November 27, 2018.	ATAL
A	2018-10-22	PARTIAL DRAFT	Partial draft (introduction and context).	ATAL

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Appendix A

Engagement Summaries

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Appendix A-1
Initial Public Engagement Survey Summary (Winter 2020)

North Shore Sea Level Rise Adaptation Strategy
Initial Public Engagement Survey Summary (Winter 2020)

As part of the development of the North Shore Sea Level Rise Adaptation Strategy, the project partners (District of North Vancouver, City of North Vancouver, District of West Vancouver, Squamish Nation, Vancouver Fraser Port Authority, and North Shore Emergency Management) conducted a public survey, part of the initial public engagement.

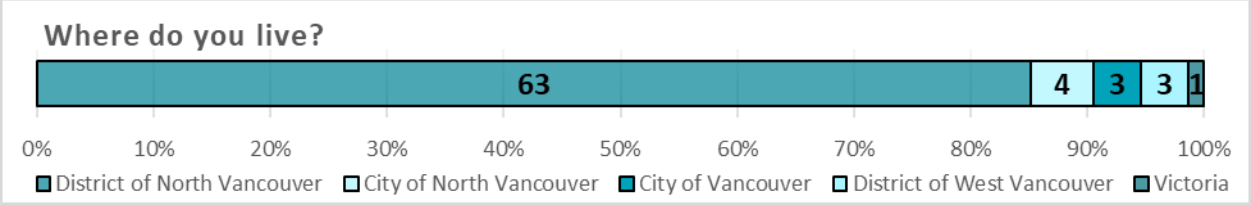
The survey was open from January 21, 2020 to March 9, 2020 on the District of North Vancouver's website at DNV.org/SeaLevelRise. Each partner determined how to communicate the survey to their respective communities.

Total number of respondents: 77

The number of responses for each question may vary, as not all respondents answered every question.

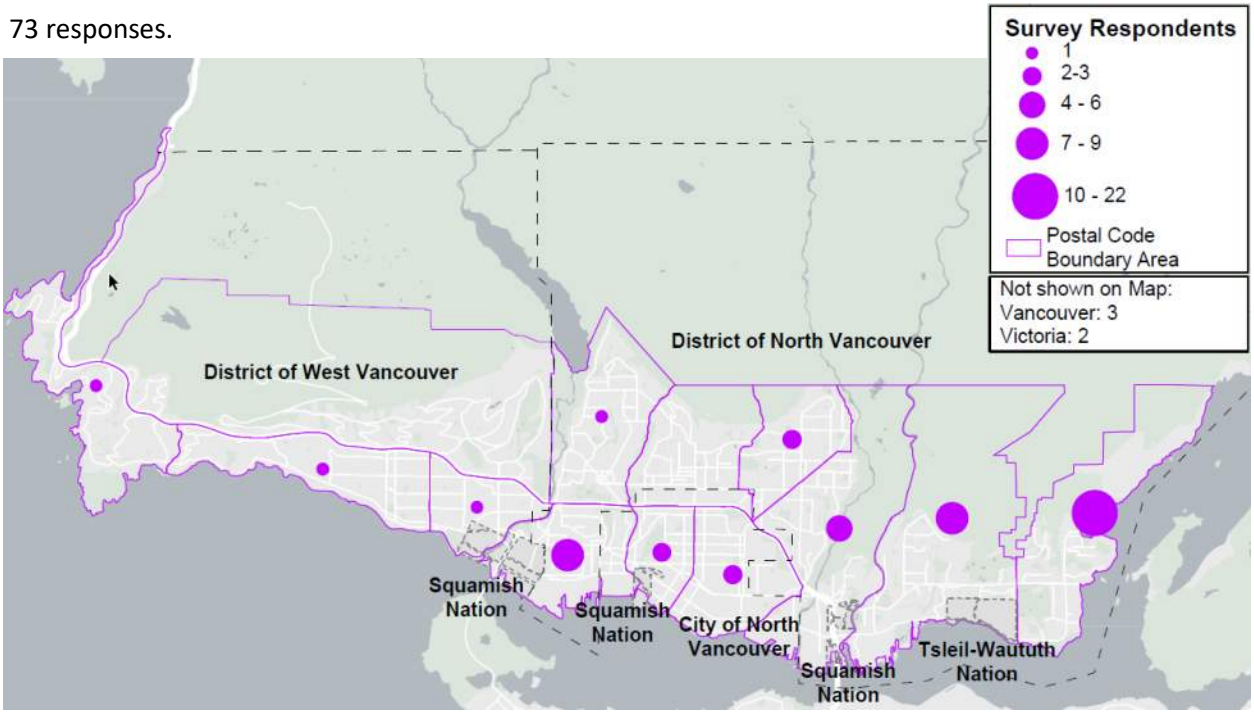
1. Where do you live?

The majority of respondents said they live in the District of North Vancouver (63 of 74, 85%).



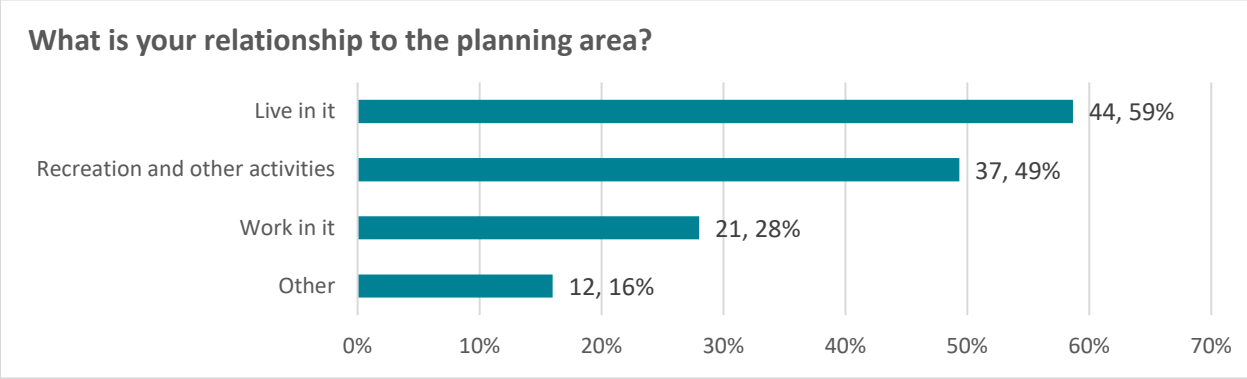
2. What are the first three letters of your postal code?

73 responses.



3. What is your relationship to the planning area? Choose all that apply.

Over half of the respondents live in the planning area (44 of 75, 59%), and almost half of the respondents recreate or participate in similar activities in the planning area (37 of 75, 49%).



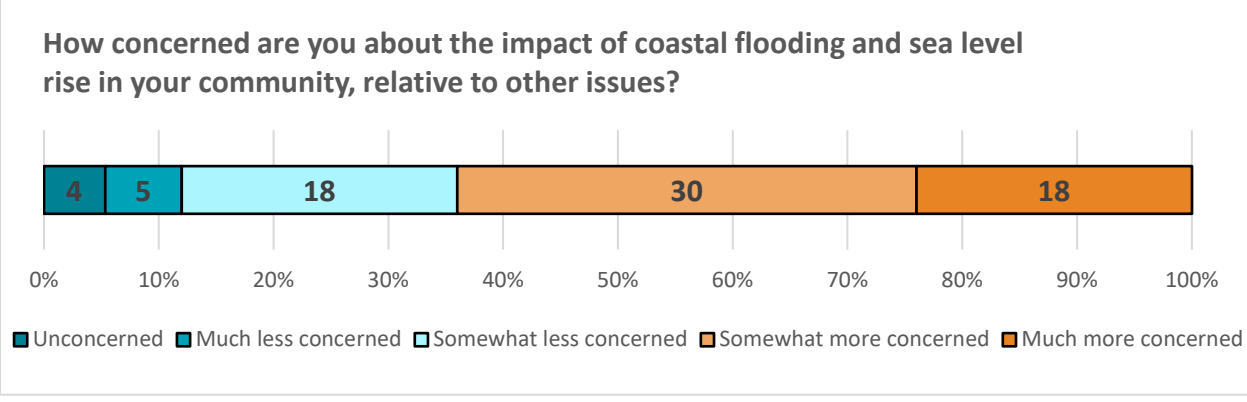
(Since respondents could choose more than one option, the percentage represents the portion of respondents who selected an option of the total respondents.)

Of the 12 respondents who selected "Other", the responses had the following themes:

- Live near or want to live in the planning area (3 responses)
- Own property in the planning area (3 responses)
- Use transportation routes through the planning area (3 responses)
- Use businesses in the planning area (1 response)
- Concerned about environmental impact (1 response)
- Interested in topic (1 response)

4. How concerned are you about the impact of coastal flooding and sea level rise in your community, relative to other issues?

Most respondents indicated they are somewhat more or much more concerned about sea level rise than other community issues (48 of 75, 64%).



5. Do you have comments about these guiding principles?

The guiding principles presented were:

1. **Sea level is rising and we have to be willing to accept change**
   Areas at risk of flooding due to sea level rise will be affected unless we take proactive steps to minimize the impact.
2. **Adaptation is flexible in the face of uncertainty**
   New scientific and technical information informs our decisions. Adaptation should prepare us for a range of scenarios in the future, including changes in the pace and height of sea level rise over time.
3. **Decisions are risk-based and consider impacts to different sectors**
   Hazard and risk information drives our discussions, and impacts to environment, economic, and social sectors are considered.
4. **Everyone has a role in adaptation**
   We need to work together to create more resilient communities by working collaboratively across levels of government and with our communities on our actions.
5. **Planning includes education and awareness opportunities**
   Openly communicating flood risks facing different areas on the North Shore, and being transparent about adaptation planning as it evolves, helps ensure our communities have a shared awareness.

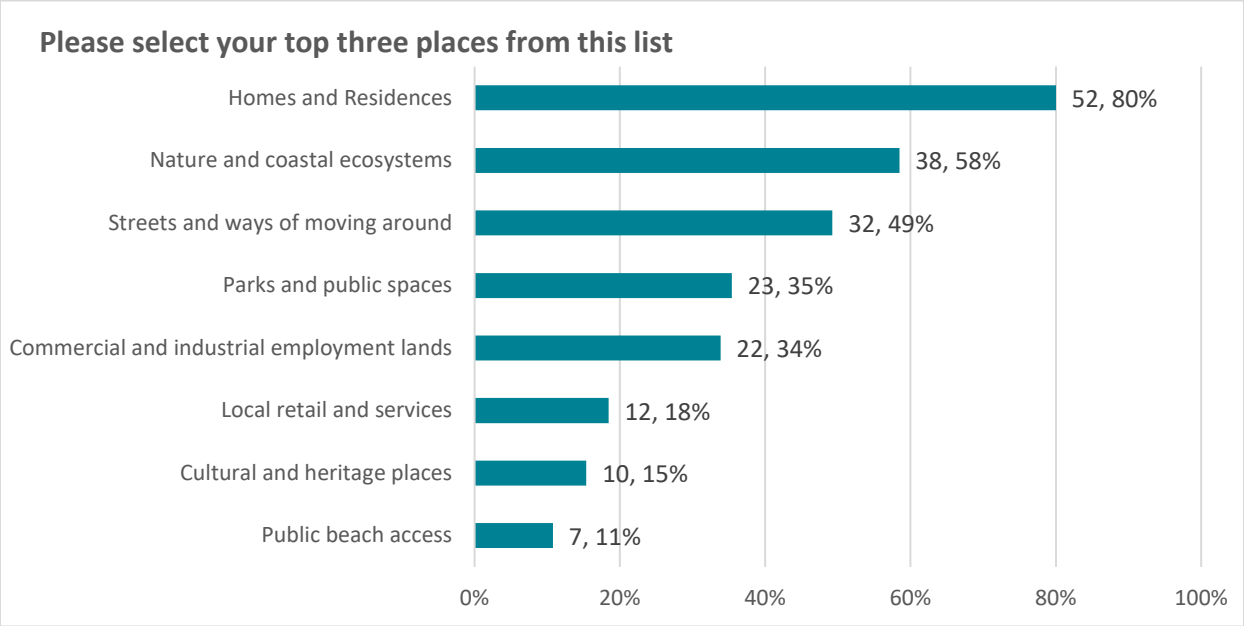
Of the 30 respondents who provided comments, most agreed with the guiding principles as presented (15 of 30, 50%). The responses had the following themes (some comments had more than one theme):

- Agree with the principles (15 responses)
- Climate change mitigation is important, too (5 responses)
- Importance of protecting habitats and the environment (3 responses)
- Concern about funds spent on sea level rise planning (2 responses)
- Concern about new development in sea level rise planning area (1 response)
- Impact on local First Nations (1 response)
- Importance of human safety and transportation (1 response)
- Sea level rise is less important than other issues (1 response)
- Need to be able to respond to changing scenarios (1 response)
- Support for adaptation planning (1 response)
- Suggestion to partner with communities outside the region (1 response)

6. Please select your top three places from this list.

Respondents were asked to select their top three places that matter most to them from a list of options.

The top three places selected by respondents were: homes and residences (52 of 65, 80%), nature and coastal ecosystems (38 of 65, 58%), and streets and ways of moving around (32 of 65, 49%).



(Since respondents could choose more than one option, the percentage represents the portion of respondents who selected an option of the total respondents.)

7. Are there other kinds of places that matter to you?

Of the 18 respondents who provided comments, one third expressed that they felt they couldn't choose or rank them because all or most of these places are important (6 of 18, 33%). The responses had the following themes:

- All or nearly all of these places are important (6 responses)
- Concern about vulnerable populations living or accessing services in or near areas at risk of flooding (2 responses)
- Critical infrastructure (2 responses)
- Schools (2 responses)
- Concern about impacts to First Nations' land (1 response)
- Transportation hubs (1 response)
- Ecosystems (1 response)
- Watersheds (1 response)
- Parks and streets and ways of moving around (1 response)
- Commercial and industrial employment lands (1 response)

8. Do you have thoughts about the consequences of sea level rise?

Of the 37 respondents who provided comments, nearly a quarter expressed the need to prepare for sea level rise now to reduce the consequences (9 of 37, 24%). The responses had the following themes:

- We need to prepare for sea level rise now (9 responses)
- Prevent new development in high-risk areas (6 responses)
- Build new buildings with sea level rise in mind (4 responses)
- We have time to adapt (3 responses)
- To reduce consequences, we need to mitigate climate change as well as adapt (2 responses)
- Preserve and restore coastal ecosystems (2 responses)
- Concern about the consequences of sea level rise (2 responses)
- Continue to educate residents about sea level rise (2 responses)
- There are more pressing issues than sea level rise (2 responses)
- Work with other levels of government and with other North Shore municipalities (1 response)
- Balance risks and costs (1 response)
- Use parkland as a natural barrier to sea level rise (1 response)
- Concerned about the costs of adaptation (1 response)
- Concerned about displacement of residents and businesses (1 response)

9. Do you have comments, ideas, or concerns about these adaptation approaches?

The four approaches presented were:

- **Resist:** Build structures to reduce the likelihood of flooding
- **Accommodate:** Acknowledge flood risk, define how much we are willing to tolerate, and raise livable spaces vulnerable to flooding
- **Avoid:** Avoid building or adding more to areas vulnerable to flooding, or gradually relocate buildings and infrastructure away from areas at risk of flooding
- **Advance**: Could include reclaiming (filling in) land to create space for a dike, for example

There were 34 respondents who provided comments. Of the 30 respondents who commented on a specific adaptation approach, almost half supported the Avoid approach (14 of 30, 47%). The responses had the following themes (some respondents' comments had more than one theme):

Comments supporting individual adaptation approaches:

- Support for Avoid (14 responses)
- Support for Accommodate (7 responses)
- Support for Resist (7 responses)
- Support for Advance (2 responses)

Other comments:

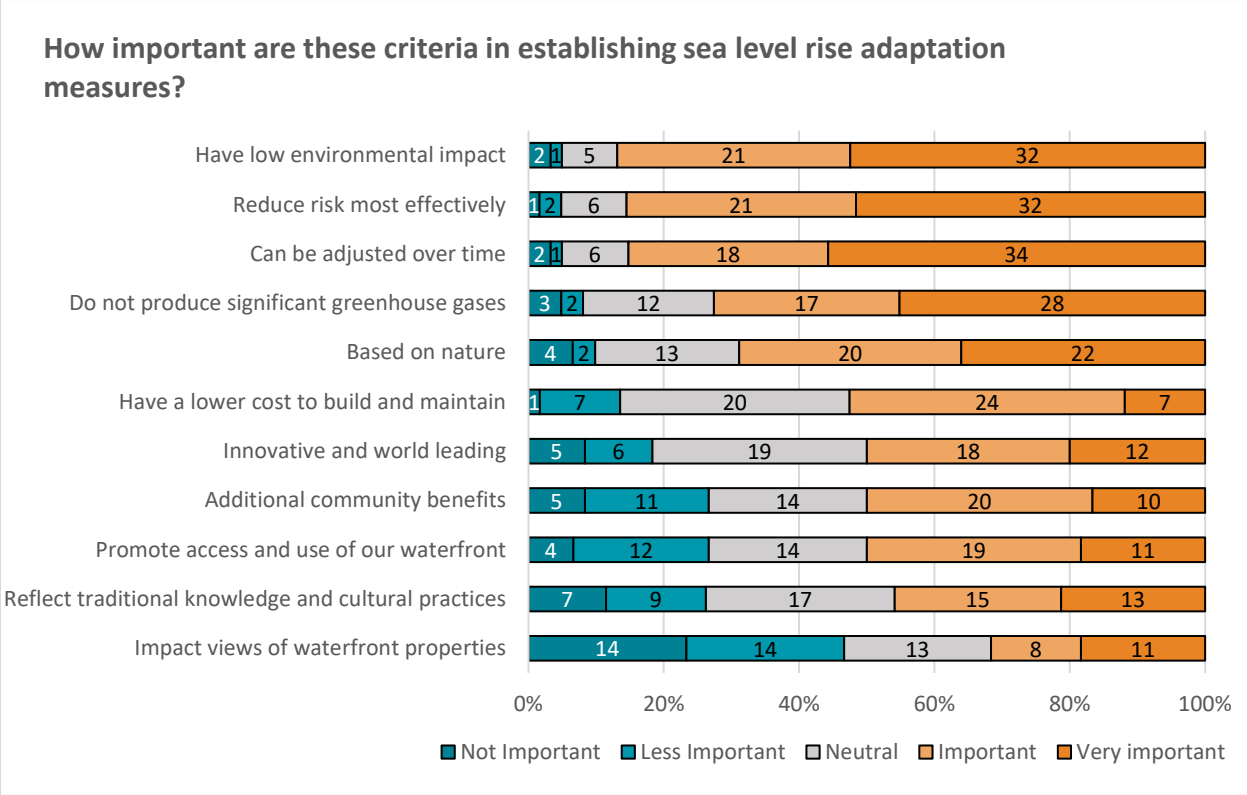
- General support for adaptation approaches (5 responses)

- Support nature-based solutions (3 responses)
- Do not shift impact onto another property (2 responses)
- Limit impact on environment (2 responses)
- Continue raising awareness about adaptation approaches and the risks of sea level rise (2 responses)
- Consider life cycle costs of these approaches, including future upgrades or maintenance (2 responses)
- Incentivize moving away from flood prone areas (1 response)
- Mitigation needed as well as adaptation (1 response)
- Support beach nourishment (1 response)
- Property owners should be compensated for loss of value (1 response)
- Incorporate sea level rise uncertainties (1 response)

10. How important are these criteria in establishing sea level rise adaptation measures?

Respondents were asked to rank the importance of criteria from a list of options.

The top ranking criteria that respondents indicated were important or very important to consider in establishing sea level rise adaptation measures were: have a low environmental impact (53 of 61, 87%), reduce risk most effectively (53 of 62, 85%), and be able to adjust over time (52 of 61, 85%).



(Total number of responses varies for each criterion.)

11. Please indicate the level of funding you think each group should provide.

Respondents were asked to rank the order of how much funding the following groups should provide for adaptation measures:

- Public and private owners of land that is on today's waterfront,
- Public and private owners of land that could be flooded from sea level rise if we do not adapt (on today's waterfront as well as inland),
- Taxpayers across the respondent's community, and
- Taxpayers outside of the respondent's community, including senior levels of government (Provincial, Federal).

There were 65 total responses. Responses were categorized by respondents who identified as living in the sea level rise planning area, and those who are not living in the planning area or did not specify (survey question 3).

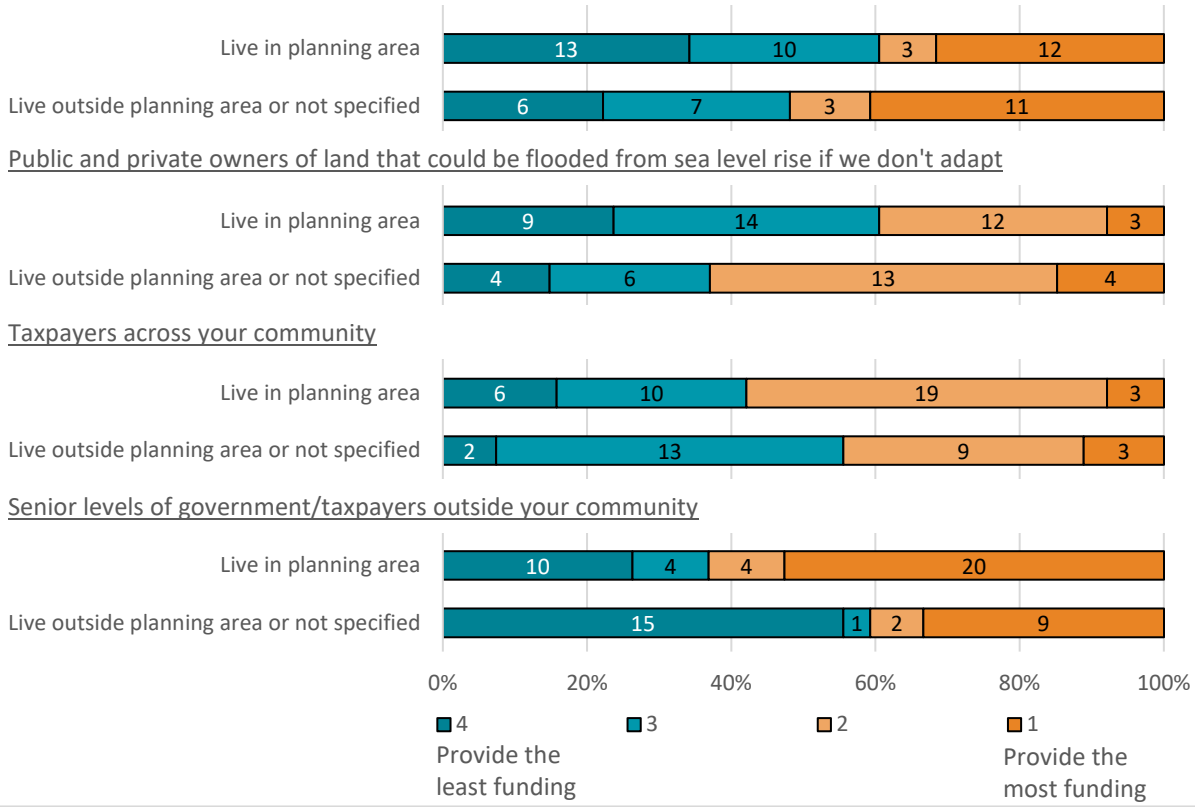
Of the 38 respondents who live within the planning area, they generally ranked the order of who should pay the most (ranked 1st or 2nd) as follows:

Most	Senior levels of government/taxpayers outside community (24 of 38, 63%)
↓	Taxpayers across their community (22 of 38, 58%)
↓	(Tied) Public and private owners of land that is on today's waterfront (15 of 38, 39%)
Least	(Tied) Public and private owners of land that could be flooded from sea level rise if we do not adapt (15 of 38, 39%)

Of the 27 respondents who live outside the planning area or did not specify where they live, they generally ranked the order of who should pay the most (ranked 1st or 2nd) as follows:

Most	Public and private owners of land that could be flooded from sea level rise if we do not adapt (17 of 27, 63%)
↓	Public and private owners of land that is on today's waterfront (14 of 27, 52%)
↓	Taxpayers across their community (12 of 27, 44%)
Least	Senior levels of government/taxpayers outside community (11 of 27, 41%)

Please indicate the level of funding you think each group should provide.



Other input received

One letter was received from the Medical Health Officer, Vancouver Coastal Health – North Shore was received in response to the initial public engagement (attached).

Vancouver Coastal Health
Promoting wellness. Ensuring care.

Office of the Medical Health Officer
Vancouver Coastal Health – North Shore
5th Floor, 132 West Esplanade Ave.
North Vancouver, BC V7M 1A2
Telephone: 604-983-6701
Facsimile: 604-983-6839

February 21, 2020

Stephen Bridger, PEng, MASc
Section Manager - Engineering Planning & Design
District of North Vancouver
355 West Queens Road
North Vancouver, BC V7N 4N5

via email: bridgers@dnv.org

Dear Mr. Bridger,

RE: North Shore Sea Level Rise Strategy

Thank you for giving Vancouver Coastal Health (VCH) the opportunity to participate and comment on the early phase of the North Shore Sea Level Rise Strategy. VCH supports engagement with community members and overall strategic planning to mitigate impacts of sea level rise near the North Shore shorelines due to climate change.

Climate change will impact human health in BC through various pathways including air and water quality deterioration, wildfires, flooding, extreme heat, change in food sources, and range extension of pathogens and disease vectors. These impacts may exacerbate current health and social disparities. Health impacts will be dependent on a person's exposure to the risk (e.g. location and quality of housing, occupation), sensitivity to that exposure (e.g. age, health status or health care needs) and adaptive capacity (e.g. economic resources, social capital, access to technology and information and skills). These health impacts will likely place increased stress on the health care system. The 2018 Lancet Countdown on Health and Climate Change states that "climate change threatens to undermine the past 50 years of gains in public health, and conversely, that a comprehensive response to climate change could be "the greatest global health opportunity of the 21st century."[1]

With this great opportunity, we offer the following recommendations for consideration:

1. Climate change and sea level rise will impact the physical, psychological, and social well-being of the population on the North Shore. We recommend reviewing information on the BC Centre for Disease Control (BCCDC) Community Health Profiles[2] about the demographics in each municipality, and various factors that could affect the health of the residents, especially the vulnerable populations. You may visit our VCH community care facilities website[3] for information about the locations of childcare and residential care facilities where vulnerable populations are in care. Furthermore, we encourage the committee to understand the demographic forecasts for the North Shore by utilizing the functions on the My Health My Community Health Atlas[4] when strategizing any adaptation approaches in specific areas.

[1] Watts N, Amann M, Ayeb-Karlsson S, Belesova K, Bouley T, Boykoff M, Byass P, Cai W, et al. (2018). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. *The Lancet* 391: 581-630. doi:10.1016/S0140- 6736(17)32464-9.
[2] BCCDC Community Health Profiles - http://communityhealth.phsa.ca/GetTheData
[3] VCH Childcare and Residential Care Facility - https://inspections.vcha.ca/ChildCare/Table
[4] My Health My Community Health atlas - https://myhealthmycommunity.org/explore-results/results-by-community/dashboard/

2. Climate change is a health equity issue that has the potential to exacerbate existing social and health vulnerabilities. Those with the least resources will likely be impacted the most. For example, BCCDC states that "neighbourhood-level investments to mitigate climate change may instigate neighbourhood gentrification and lead to further marginalization of low-income residents who can no longer afford to live in the very neighbourhoods designed to support them."[5] Communities can therefore be strengthened by articulating the potential health co-benefits and/or implications to vulnerable populations.
3. We encourage all participating municipalities to review and strengthen bylaws, policies, and strategies with standards that are equivalent to or higher than the Metro Vancouver Board's recently-approved Climate 2050 Strategic Framework[6] for the purpose of building resilience in the communities.
4. We strongly recommend ongoing public education and engagement in communities throughout all phases of this project to raise their understanding of how their neighbourhood may be directly affected by the rising sea level now and in the future. The collaborative approach offers a great opportunity to generate support and to ensure transparency in an authentic, cross-cultural community engagement and the decision-making process.
5. Given the topography of the area, we recommend planners consider the population and infrastructure impacts associated with a trifecta of potentially simultaneously occurring issues, including: (1) sea level rise, (2) king tides and (3) run off from increased precipitation on the slopes and potential associated water quality contamination/turbidity and infrastructure damage /loss of power from flooding.

VCH looks forward to working with the strategic team throughout all phases in this project. If there are any further questions regarding the comments above, please contact me at mark.lysyshyn@vch.ca or 604-983-6701.

Sincerely,



Mark Lysyshyn, MD, MPH, FRCPC
Medical Health Officer
Vancouver Coastal Health, North Shore

[5] BC Centre for Disease Control. (2017). Fact sheet: Supporting health equity through the built environment. Retrieved from http://www.bccdc.ca/resource-gallery/Documents/Educational%20Materials/EH/BCCDC_equity-fact-sheet_web.pdf
[6] Climate 2050 Strategic Framework - http://www.metrovancouver.org/services/air-quality/AirQualityPublications/AQ_C2050-StrategicFramework.pdf

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Appendix A-2
District of North Vancouver
Community Workshops
(February 2020)

North Shore Sea Level Rise Strategy
District of North Vancouver Community Workshops – February 2020
Summary

Three community workshops were held by the District of North Vancouver as part of the initial public engagement for the North Shore Sea Level Rise Strategy. The North Shore Sea Level Rise Strategy is a proactive, multi-partner project aimed at understanding vulnerabilities to coastal flooding due to sea level rise on the North Shore and developing options, with public input, to manage the potential risks. The project partners are the District of North Vancouver, City of North Vancouver, District of West Vancouver, Squamish Nation, Vancouver Fraser Port Authority, and North Shore Emergency Management.

The District of North Vancouver community workshops provided face-to-face engagement opportunities for those who could be potentially impacted by sea level rise if no adaptation is undertaken. The objectives of the workshops were to:

- Build awareness and understanding of sea level rise, and the potential risks of coastal flooding on the North Shore if no adaptation is undertaken;
- Educate about possible adaptation approaches;
- Start a community conversation about the potential trade-offs and co-benefits of managing coastal flood risk; and
- Listen to participants' views and issues about adapting to sea level rise.

Through structured group activities and a presentation, participants were able to learn more about sea level rise, ask questions, identify what matters to them, and share thoughts on a range of adaptation approach concepts. The workshops were held in Norgate, Maplewood, and Deep Cove with a total of 48 participants.

- February 11, 6:00 – 8:00 pm, Norgate Elementary School (20 participants)
- February 12, 9:00 – 11:00 am, Wild Bird Trust Corrigan Nature House (14 participants)
- February 13, 6:00 – 8:00 pm, Cove Cliff Elementary School (14 participants)


Norgate


Maplewood


Deep Cove

Communication

To invite participants to the workshops, letters were mailed to property owners within the sea level rise planning area in the District, and email notifications were sent to local community organizations; other government organizations, agencies and infrastructure asset owners; Tsleil-Waututh Nation[1]; District committees; and long-term leaseholders on District property in the planning area. Interested participants were invited to register in advance on the project webpage.

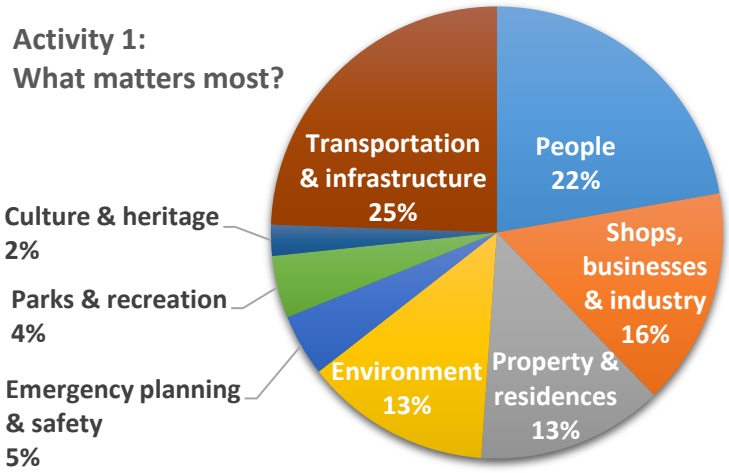


What we heard

As participants learned more over the course of the workshop, there was a general understanding of the challenges at hand, and the need for on-going, long-term planning.

During the presentation, participants shared comments and asked questions; in general these included: asking about the cost of adaptation, asking clarifying questions about sea level rise, recognition that we need to plan for adaptation, and identifying the need to update bylaws to allow buildings to adapt.

Key themes heard during the workshop activities are summarized below.



Activity 1: What matters most?

Participants were asked to share what matters most to them when thinking about sea level rise and coastal flooding. After discussion in table groups, each group was asked to note their top three themes discussed at their table, then verbally report out to the whole group. Overall, the top three themes reported by the most groups were transportation and infrastructure; people; and shops, businesses and industry. Close behind were properties and residences, and environment.

[1] Squamish Nation, the other First Nation with reserves on the North Shore, is a partner on the North Shore Sea Level Rise Strategy.

During the whole group discussion, key comments included:

- Update bylaws to allow buildings to adapt (height, siting);
- Environmental concerns (erosion, impact on animals and people, potential contamination);
- Importance of maintaining transportation routes and infrastructure;
- Concern about businesses (access, jobs, long-term impacts);
- Recognition that all themes matter;
- At the Norgate workshop, suggestion to focus adaptation in the industrial area between Norgate residential and the ocean to protect the residential area;
- Continue to engage with potentially impacted communities; and
- Concern about potential impact to homes.

Activity 2: Explore adaptation approaches

Participants learned about the adaptation approaches (resist, accommodate, avoid, and advance) and the benefits and disadvantages of each approach. They were asked to share their thoughts on the approaches and their benefits and disadvantages. Participants were encouraged to discuss these high-level concepts, and reminded that the group was not deciding or designing adaptation measures in these workshops. After discussion in table groups, each group was asked to verbally report out a summary of their discussion to the whole group. Key themes from the whole group discussion were as follows.

Resist – *Focus on structural measures such as building dikes to reduce the likelihood of flooding.*

- Support for the resist approach, particularly for waterfront industrial areas.
- Concern about impacts of the resist approach (land required, false sense of security in event of structural failure, questions of cost and implementation, bylaw changes needed).
- Co-benefits such as recreation trails with dikes or noise buffering with walls.
- A few suggested specific measures such as a sea dam or flood gates for creeks.

Accommodate – *Focus on non-structural adaptation measures, including consciously acknowledging flood risk, defining how much risk we are willing to tolerate, and raising livable spaces in areas vulnerable to flooding.*

- Interest in wet flood-proofing (floodable basements), and living with water.
- Concern about how to adapt existing structures.
- Leverage new development to implement the accommodate approach.
- Need to continue working with land owners and regulatory agencies (e.g. Port, Province).
- Concerns with this approach include: bylaw changes needed to facilitate the accommodate approach, how this approach addresses areas outside of buildings (e.g. roads), how to use accommodate with limited property space, and how it works with other natural hazards.

Avoid – *Focus on land use planning to avoid building or adding more uses in areas that are vulnerable to flooding, or gradually relocating buildings and infrastructure away from areas at risk of flooding.*

- Avoid adding more development in flood hazard areas.
- Question of costs to implement the avoid approach.
- General support for the avoid approach.
- Concerns with this approach included: equity issues of who should move or where could move to, loss of property value, need to update bylaws to allow for flexibility, and privacy on property if surrounding uses change.

Advance – *Reclaim land to make space for structures such as dikes, which can reduce the likelihood of flooding in coastal areas.*

- Concern about the environmental impacts from the advance approach (e.g. Maplewood mudflats).
- Some expressed support for the advance approach in waterfront industrial areas or where filling has already occurred, noting the advance approach has historically been used in some places on the North Shore.
- Questions about implementing the advance approach: cost, limiting regulation, how to implement it.

During Activity 2, there were comments during the large group discussion about adaptation in general. Key themes included:

- Concern about the environmental impacts from sea level rise and adaptation approaches;
- Concern about being able to achieve political consensus for action, recognizing that sea level rise is a difficult topic, and concern about failure of measures;
- Appreciate sea level rise planning is happening on the North Shore to build resiliency;
- Question of how much adaptation measures will cost versus taking no action;
- Update bylaws to be flexible and responsive to different areas; and
- Some voiced support for different combinations of adaptation approaches or all four approaches, and the need to tailor adaptation by area.

<u>Activity 3: Reflection on workshop</u>

To conclude the workshop, participants shared their final thoughts. Key themes during the group discussion included:

- Appreciate planning for sea level rise and opportunity for engagement;
- Recognize that climate mitigation (i.e. decreasing greenhouse gases) is important, too;

- Identify the need for coordination across many different groups to address the challenges presented by sea level rise;
- Concerns about impacts to human health, transportation routes, other natural hazards; and
- Recognize that the present state today is inherited from past decisions.

Next steps

Input received from the initial engagement will be considered alongside technical analysis as the draft Sea Level Rise Strategy is developed. Initial engagement for the Sea Level Rise Strategy included the District's community workshops, and an online survey jointly hosted by the project partners (input received via the online survey is summarized separately). Input from initial engagement will help inform the Strategy for Council's consideration.

KERR WOOD LEIDAL
consulting engineers

Appendix A-3
Squamish Nation Scope Engagement Summary (May 2020)

KERR WOOD LEIDAL
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T 604 294 2088
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Squamish Nation Engagement Summary

DATE: May 12, 2020

TO: Bob Sokol, Director of Planning and Capital Projects

FROM: Robin Hawker, Environmental Planner & Engagement Specialist

RE: **NORTH SHORE SEA LEVEL RISE ADAPTIVE MANAGEMENT STRATEGY**
Squamish Nation Scope – Engagement Summary
Our File 115.252

Squamish Nation retained Kerr Wood Leidal (KWL) to lead a community engagement program to build awareness and gather input from Squamish Nation members on the North Shore Sea Level Rise (SLR) Risk Assessment and Adaptive Management Strategy (North Shore SLR Strategy).

The North Shore SLR project involves the assessment of sea level rise risk and development of adaptation strategies for communities across the region, including on Squamish Nation reserve lands. The North Shore SLR Strategy was developed under the direction of a Steering Committee with representatives across the North Shore, including Squamish Nation, the District of North Vancouver, District of West Vancouver, City of North Vancouver, Vancouver Fraser Port Authority, and North Shore Emergency Management.

Community engagement for the project was led through a coordinated approach, with a combination of region-wide (shared) initiatives and individual initiatives led by each jurisdiction for their own community members.

This summary provides an overview of the individual engagement initiatives that Squamish Nation led to gather input from residents and businesses on reserve. Details on the regional engagement initiatives led by the District of North Vancouver on behalf of project partners are not included in this summary.

1. Overview

Squamish-led engagement for the North Shore SLR Strategy was designed to build community member awareness about the project and coastal flood risk and gather input on community concerns and priorities for coastal flood management strategies.

Engagement initiatives were carried out between December 2018 and March 2020 as planned under the project Community Engagement Plan. The Community Engagement Plan was drafted in April 2019 and refined in October 2019 to align with the coordinated plan for region-wide engagement initiatives.

1.1 Engagement Objectives

The Squamish Nation Community Engagement Plan defined five primary objectives for engagement as part of this project:

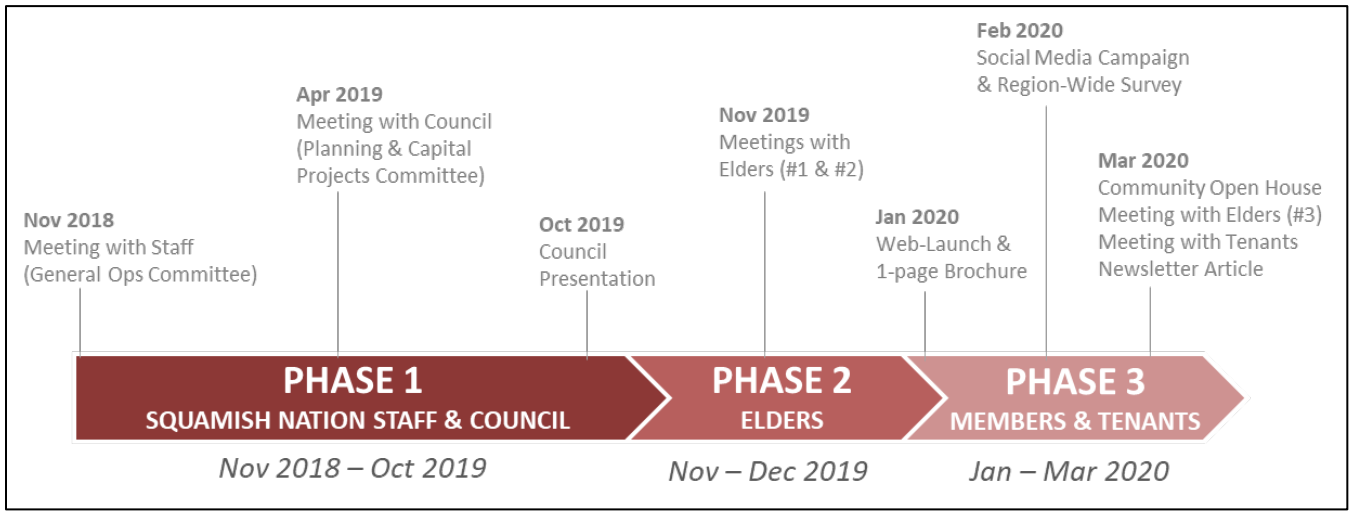
- **Build awareness** among staff, Council, and members about the project and different ways to get involved;
- **Increase understanding** about SLR: what it is, why it's happening, how it might affect Squamish Lands, and what can be done to mitigate and adapt to its impacts;
- **Encourage diverse participation** from Squamish Nation members and family groups;

- **Gather input from members** about traditional local knowledge, concerns, and priorities for adaptation; and
- **Encourage community support** for recommendations in the ultimate Adaptive Management Strategy.

The Plan also outlined key messages and community groups to be the focus of engagement initiatives. The final Community Engagement Plan is included in **Appendix A**.

1.2 Initiatives & Timeline

Squamish Nation engagement initiatives carried out over the course of the North Shore SLR Strategy project are shown in Figure 1.



Further details on the objectives and outcomes from each initiative are described further in this summary report.

2. Initiatives and Feedback

2.1 Meetings with Staff & Council

Early in the project timeline, the project team delivered three one-hour closed-door presentations to Squamish Nation staff and Council introducing project objectives and scope. These early presentations provided an introduction to the project, core concepts on coastal flooding and sea level rise, and preliminary flood inundation maps for Squamish Nation reserve lands. The presentations also gathered input on the draft Community Engagement Plan and recommendations for effective ways to engage Squamish Nation membership.

The following three presentations were delivered:

- Meeting with the General Operations Committee (GOC) on November 5, 2018
- Meeting with the Planning and Capital Projects Committee (PCPC) on April 1, 2019
- Presentation to Council on October 8, 2019

The General Operations Committee is made up of the EOO of Service Delivery, Directors, Managers and a technical advisory consultant who meet on a monthly basis to discuss issues related to infrastructure servicing, flood and erosion issues, housing challenges, etc. on the Nation's reserve lands.

The Planning and Capital Projects Committee is a subcommittee of Squamish Nation Council, which convenes to discuss topics around land use decision-making on Squamish Nation reserve lands.

Feedback received from all three groups was generally favorable, with Councillors noting that the project represents an important proactive approach to managing coastal flooding and sea level rise due to climate change.

2.2 Meetings with Elders

Squamish Nation Elders play an important role in guiding community decision-making and resilience. They hold extensive knowledge about past flooding, regional relationships, and practices to support community resilience.

Three two-hour meetings were held with Squamish Nation Elders. The first two meetings involved introducing project objectives, sharing preliminary flood hazard maps and consequences from flooding on Squamish Nation lands, and group discussion to gather input on concerns and priorities for adaptation. The third meeting involved sharing information about possible approaches for flood management and gathering feedback on preferred approaches on Squamish Nation lands.

The three meetings were as follows:

- Community Development Meeting at Totem Hall (Squamish Valley) on November 2, 2019;
- Squamish Nation Elders Lunch at the Elder's Centre (North Shore) on November 13, 2019; and
- Squamish Nation Elders Lunch at the Elder's Centre (North Shore) on March 4, 2020.

These three meetings were held to enable Elders across Squamish Nation lands the opportunity to provide input, including those living in the Squamish Valley and on the North Shore. A copy of the presentations from the November 12th and 13th meeting (combined) and March 4th meeting are included in Appendix B.

Comments received during each meeting are summarized below:

Squamish Valley Community Development Committee

- It's important that Squamish Nation Members are involved in this project.
- Concerned about how sea level rise could affect creek water quality (e.g. salt wedge) and risk of cross-contamination if flood waters reach the wastewater treatment plant and contaminated lands (e.g. Ambleside Park?).
- Adaptation should be proactive e.g. new wetlands, yield grass, habitat enhancement for smelts, herring and other habitat lost.
- Climate change education to members would be useful.
- Consider raising or floating houses.

North Shore Elders Lunch #1

- This project is important and demonstrates how the Nation is being proactive to understand and adapt to sea level rise.
- It would be helpful to show elevations, in relation to places/locations that people are familiar with, for example if 2 meters above sea level, then show a building that is located 2 meters above sea level.
- Our people need to be protected; this is our highest priority for adaptation action. We need to protect our families across all communities.
- Young people will have to live with the consequences, their interests will need to be looked at.
- Population growth and densification is expected on Squamish Nation North Shore lands. Take sea level into account when designing new development.
- It is important to think about our structures, people will be out of power, we need someplace safe to go to.
- District of Squamish showed us maps that left out the reserves. Glad the North Shore municipalities are participating. There cannot be any gaps.
- It is important that "best effort" be defined clearly and agreed upon by all North Shore partners to ensure a balanced commitment for adaptation from all.
- Interested in adaptation strategies that enhance natural habitat (e.g. wetlands) educate members about sea level rise.
- Concerned about the cost/lack of land to move out of flood area.
- CN Rail will be key to what will happen, maybe the tracks could be raised to protect against sea level rise and future flooding.
- Who is going to pay for this and how much will it cost? E.g. senior levels of government, developers, Port of Vancouver.

North Shore Elders Lunch #2

- Important to consider how future flooding could affect the Squamish Nation cemetery and St. Paul's Church.
- Also concerned about impacts of cross-contamination from flooding of the Wastewater Treatment Plant and/or contaminated lands.
- There are so many hazards we face in our world today: we need to act quickly and efficiently in areas where we can act (e.g. coastal flood management). The sooner we respond to this future risk, the better.
- The Nation needs to start now to prepare for sea level rise and flooding in the future.
- Adaptation approaches suggested include raising the seawall and working with CP Rail to raise the railway as a dike (transfer liability to Federal Government/ CP Rail).
- Squamish Nation Elder Wendy Charbonneau is sharing messages on climate change through the Cambridge Music Conference (Xwmelch'stn – Where the Salmon Tumble, 2018) http://www.cambridgemusicconference.org/migration/wendy-charbonneau.html.

2.3 Print & Social Media

Print and social media was important for sharing information on project progress. The release of information about the project to the Squamish Nation membership was timed in coordination with the launch of the project website on January 21st, 2020.

Information about the project was distributed to Squamish Nation members through the following:

- Announcement on the Squamish Nation website (January 21, 2020);
- 1-page brochure "About the SLR Project" (January 27, 2020);
- Social media campaign, with weekly posts (February 18th – March 2nd, 2020); and
- Article in the Community Newsletter – North Vancouver (March 9, 2020).

Details on these initiatives are described below:

Web-Launch & 1-Page Brochure

Squamish Nation posted information about the project on the Nation's webpage on January 21, 2020 and distributed a 1-page brochure about the project through the Squamish Nation Community Newsletter, sent to homes across the Nation's North Shore and Squamish Valley reserve lands. The brochure included information about project objectives and the importance of coastal flood management for building the Nation's resilience to climate change. A copy of the brochure is included in Appendix C.

Social Media Campaign

Information about the project was also posted to the Squamish Nation Facebook page, which is a closed group for Squamish Nation members. The social media campaign involved sharing four short scenarios, one per week, of how a major coastal flood event could affect homes and properties on the reserve. The purpose of the campaign was to share results from the SLR project in a way that would be relatable and engaging, while also linking members with the project website to learn more about the project and provide feedback through the region-wide survey.



Figure 1 Social Media Campaign - Facebook Post #3

Posts were made on the following dates and topics:

- Post #1 – February 18th (Homes & Residents): 11 reactions, 6 shares
- Post #2 – February 24th (Cultural Sites): 0 reactions, 1 share
- Post #3 – February 28th (Social Services): 7 reactions, 3 shares
- Post #4 – March 2nd (Squamish Buildings): 2 reactions

Two comments on the posts were received, including:

1. Post #3: “Off reserve. But for emergency preparedness why not build a "sea wall"? The cost of a wall vs. The potential loss n damages to homes, infrastructure? Have an emergency shelter/ICC up in Squamish to place displaced families. Stocked with supplies? Partner with PEP?”
2. Post #4: “Easier to park your canoe!”

Newsletter Article

A newsletter article on the project and potential consequences from coastal flooding on Squamish Nation lands was distributed to homes on March 9, 2020. The article was distributed after the community open house, providing an opportunity to share some of the content presented at the open house with community members unable to attend. A copy of the draft article is included in Appendix D.

2.4 Community Open House

Community members were invited to attend a community open house event to learn about the project, ask questions, and share input on concerns and priorities for adaptation. The event was held at the Elder’s Centre (100 Mathias Road) on March 4th from 5pm to 7pm.

The event was advertised through the Squamish Nation Newsletter and Facebook page on February 24, 2020.

Six Squamish Nation members attended the event, primarily residents living on Squamish Nation North Shore reserves. Though a small group, this provided an opportunity for in depth dialogue to address questions and concerns and build an understanding of the relationship between coastal flooding and sea level rise.

Information was shared through a 20-minute presentation and six posters with information on project objectives, sea level rise and coastal flooding, possible consequences of future flooding on Squamish Nation lands, and potential adaptation approaches that could be considered.

The 1-page brochure was provided as a handout for attendees to take home to share with friends and family. Attendees were encouraged to ask questions of members of the project team.

The meeting included several interactive components to get input from members about their concerns about coastal flooding in their community and preferred approaches for adaptation.



Community Open House – March 4, 2020

Activities included:

- An interactive wave tank to show how waves can be managed using different approaches;
- A hardcopy survey adapted from the online region-wide survey;
- Questions/sticky notes asking members to share their concerns with sea level rise;
- Questions/sticky notes asking members to comment on preferred adaptation approaches.

A copy of the presentation slides and posters are included in Appendix E.

Comments and feedback shared during the open house included:

- "Squamish Nation members hold important knowledge about Squamish lands, environment, and climate impacts."
- "Get started on implementation – how much more planning? Let's get started!"
- "Likes the idea of "resist" adaptation approaches that make use of trails, spirit trails, and create greenspace."
- "Get industry to pay."



Community Open House - Wave Tank

2.5 Meeting with Tenants

Third-party (non-member) tenants that lease property on Squamish Nation North Shore lands were invited to attend a one-hour meeting on March 4, 2020 to learn about the North Shore SLR project. Representatives were invited from the following tenants: Park Royal Mall, the International Plaza, Mosquito Creek and Lynnwood Marina, Metro Vancouver (Lions Gate Treatment Plant), and the Department of Environment and Climate Change Canada. Park Royal was the only invited group who attended the meeting and discussion centered around flood risk to the Park Royal South site and potential adaptation approaches that may be considered.

2.6 Region-Wide Survey

A region-wide survey was developed by the District of North Vancouver with input from all project partners and hosted on the project website to gather input from community members across the North Shore. Squamish Nation provided input on the survey questions to ensure the questions would be relevant for Squamish Nation members.

The Nation also took a number of different approaches to advertise the survey to increase response rates from Squamish Nation members. Measures to advertise the survey included:

- Providing a link to the survey in each Facebook post as part of the Social Media (Facebook) Campaign
- Having hardcopy surveys available at the community open house for community members to complete or take home; and
- Door-to-door survey delivery on March 11, 2020.

Despite this, only one completed survey was received and no Squamish Nation members identified themselves in the online survey. A copy of the completed survey is included in Appendix F.

Unfortunately, the door-to-door delivery coincided with the onset of pandemic-related stay-at-home measures to ensure health and safety of Squamish Nation members. It is expected that these critical safety measures may have served as a barrier for members to complete and return the survey to Squamish Nation offices in a safe way.

3. Informing the Adaptation Strategy

Feedback provided by community members throughout engagement initiatives for this project will be used to inform the development of measures and strategies for managing coastal flooding on Squamish Nation North Shore lands and across the North Shore.

A key message coming out of engagement is the importance of ongoing collaboration between Squamish Nation and neighbouring jurisdictions to ensure that coastal flood management approaches are coordinated and compatible across boundaries. Ensuring that Squamish Nation concerns and priorities are reflected in flood protection planning will be important to the success of adaptation measures moving forward.

Opportunities to incorporate Squamish Nation community input into the Sea Level Rise Adaptive Management Strategy are as follows:

- Identify structural and land use planning measures to protect Squamish Nation members and property from coastal flood damage;
- Recommend coastal flood management measures that also enhance natural habitats, create greenspace and trails, and include educational components (e.g. signs) to support broader community benefits;
- Consider options to work with CN to raise the railway to provide coastal flood protection;
- Propose flood management measures that may be suitable for protecting cultural areas of importance;
- Consider measures to floodproof homes and other buildings within the flood inundation area;
- Identify land use planning approaches to consider flood inundation risk when planning new development;
- Explore options for risk management and transfer (e.g. insurance) and cost-sharing for structural works;
- Present the Draft Strategy to the General Ops committee and Planning, Capital Projects Committee, and Council for feedback;
- Continue to participate in a regional Steering Committee for ongoing collaboration on coastal flood management initiatives across the North Shore;
- Establish a community climate change advisory committee comprised of members, including Youth and Elders, to provide ongoing input on implementation of the Strategy; and
- Continue to update the community on project progress and sea level rise adaptation through the Squamish Nation website, newsletter, social media page, and announcements at community and Elders meetings.

Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

Robin Hawker, M.Sc., MCIP, RPP
Environmental Planner

Reviewed by:

Erica Ellis, M.Sc., P.Geo.
Project Manager

Jeff Derer, AScT., PMP
Technical Reviewer

Statement of Limitations

This document has been prepared by Kerr Wood Leidal Associates Ltd. (KWL) for the exclusive use and benefit of Squamish Nation for the North Shore Sea Level Rise Adaptive Management Strategy – Community Engagement. No other party is entitled to rely on any of the conclusions, data, opinions, or any other information contained in this document.

This document represents KWL's best 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.

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Revision History

Revision #	Date	Status	Revision	Author
0	2020-05-12	FINAL	Final Summary	RNH

KERR WOOD LEIDAL
consulting engineers

Appendix A-4
District of North Vancouver
Summary of Public Engagement on Draft Strategy

North Shore Sea Level Rise Strategy:
Summary of Public Engagement on Draft Strategy

September 2020

Overview

An online survey was hosted on the District's webpage from September 1-22, 2020 (three weeks) to seek public input on the draft North Shore Sea Level Rise Strategy. The online survey was accompanied by summary information highlighting key aspects of the draft strategy, and a copy of the complete document. The initial public engagement on developing the Sea Level Rise Strategy was held in January-March 2020, and the September 2020 public engagement was a focused follow-up engagement.

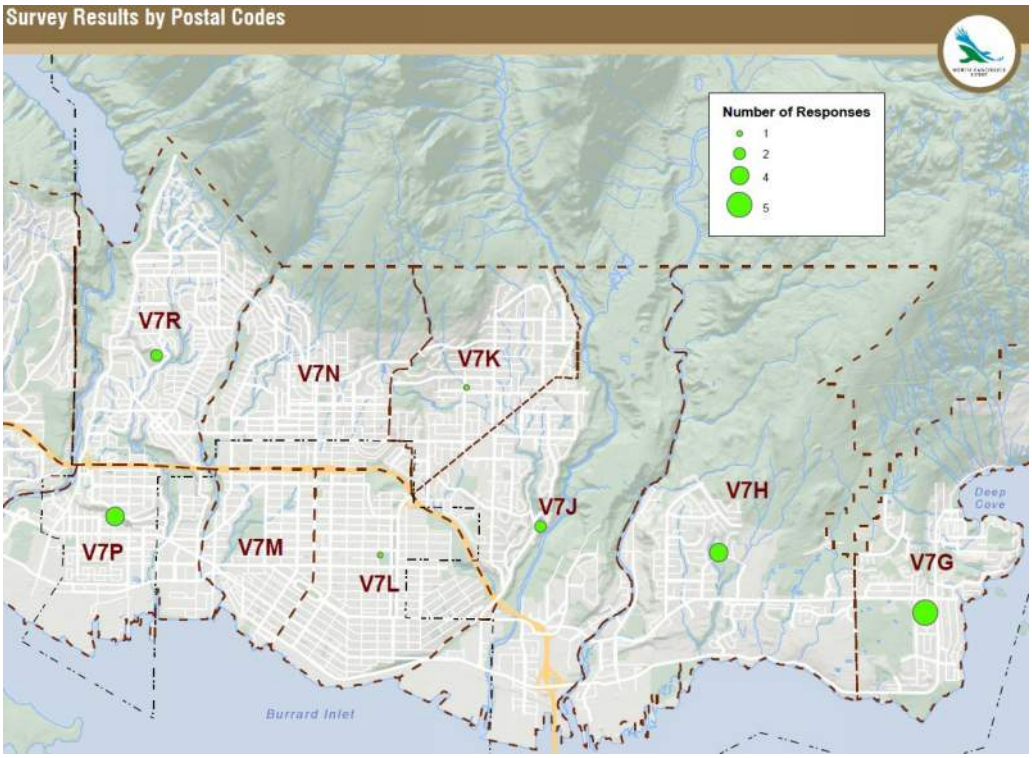
Communication

The District sent email notifications about the survey to participants from the community workshops held in February 2020, those who signed up for email notification and identified as District residents (each project partner is responsible for communicating with their respective communities), and key community partners and stakeholders (e.g. Metro Vancouver, infrastructure asset owners, Tsleil-Waututh Nation). The survey was also available online for any interested members of the public.

Survey questions and responses

1. **Where do you live?**
   District of North Vancouver (19 of 19 respondents, 100%)

2. **What are the first three letters of your postal code?** Total respondents: 19.



3. **Do you have comments about the key actions outlined in the draft strategy?**

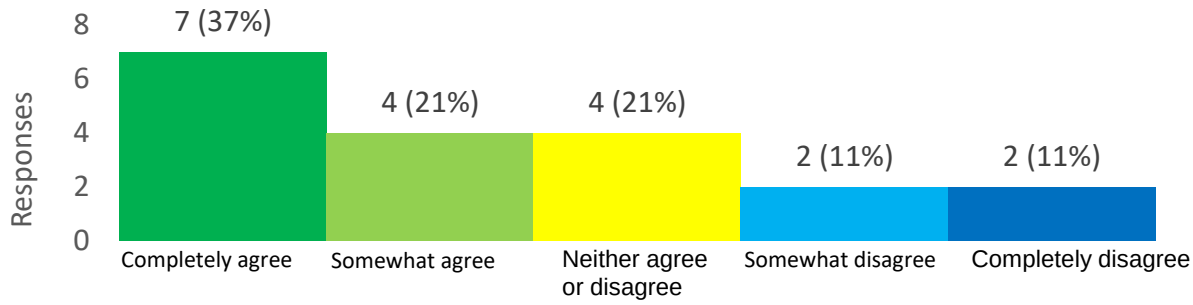
   Total respondents: 14.

   Response themes (open-ended question format; note that some respondents mentioned more than one theme):

   - Support for the actions and continuing sea level rise adaption planning (3)
   - Support for specific measures or actions:
     - nature-based adaptation measures (1)
     - avoid or accommodate approaches (1)
     - assess the feasibility of adaptation measures (1)
     - dikes in Maplewood (1)
     - tax large vehicle owners (1)
     - consider impacts of a large earthquake that will have larger consequences than sea level rise (1)
   - Do not think much sea level rise will happen (2)
   - Concern that lack of political will impede implementation (1)
   - Concern about climate change and human impacts on the environment (1)
   - Concern that long-term sea level rise projections are too far into future for planning today (1)
   - Desire to be involved in future sea level rise planning (1)
   - Concern some properties on Indian Arm currently experience flooding during storms (1)

4. **Please respond to this statement: The draft strategy points us in the right direction to continue our work towards preparing our communities for sea level rise.**

   Total respondents: 19.



5. Do you have other comments about sea level rise adaptation or the draft strategy?

Total respondents: 13.

Response themes (open-ended question format; note that some respondents mentioned more than one theme):

- Support for sea level rise regulations for new and existing development (3)
- Support for more education and awareness about sea level rise (2)
- Comments on specific measures or actions:
    - Support for avoid or accommodate approaches (1)
    - Support for dikes in Maplewood (1)
    - Do not support dikes or building close to waterways (1)
- Do not think much sea level rise will happen, so do not think a strategy is needed (2)
- Suggestion to prioritize protection of natural environment as the most cost-effective long-term solution (1)
- Suggestion that impacts of a large earthquake that will have larger consequences than sea level rise (1)
- Suggestion to add a carbon cost on all projects (1)
- Ensure flexibility in adaptation measures (1)
- Concern about the long-term horizon of the sea level rise projections (1)
- Concern that larger changes are needed to prevent sea level rise from happening (1)
- Desire to be involved in future sea level rise planning (1)

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consulting engineers

Appendix B

Stillwater Flood Map Package (Compiled Separately)

APPENDIX A: FLOOD MAPPING ASSURANCE STATEMENT

To: The Client Date: February 28, 2021

Stephen Bridger, M.A.Sc., P.Eng., Section Manager Engineering Planning and Design
Name (print)

District of North Vancouver (on behalf of North Shore sea level rise strategy partners)

355 West Queens Road, North Vancouver, BC, V7N 4N5
Address (print)

Flood Mapping Project:

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

The undersigned hereby gives assurance that he/she is an APEGBC registered professional and the Qualified Professional for the project identified above.

I have signed, sealed and dated the attached report in accordance with the *APEGBC Professional Practice Guidelines – Flood Mapping in BC*. The report supports and accurately reflects the assurances made in this Assurance Statement.

I have completed the following activities:

(Check the applicable items)

	Activity
X	Reviewed the relevant provincial legislation and local government regulations, policies, and floodplain bylaws
X	Reviewed available and relevant background information, documentation and data
X	Visited the site and reviewed the conditions in the field that may be relevant
X	Considered the need for, and scale of, investigations that address future land use changes and climate change
X	Developed and executed the flood mapping in accordance with the criteria established by the client
X	Addressed any significant comments arising from internal or peer reviews
X	Prepared a flood mapping report along with the accompanying digital information

**Note: flood mapping was conducted in support of a regional risk assessment and a regional strategy. Refer to limitations noted on flood maps and discussed in the final report.*

I hereby give assurance that the attached flood mapping report and supporting digital documentation have been produced in accordance with the *APEGBC Professional Practice Guidelines – Flood Mapping in BC*.

Amir Taleghani, M.Eng., P.Eng.
Name (print)

Signature

February 28, 2021
Date

Kerr Wood Leidal Associates Ltd.
Address (print)
200-4185A Still Creek Drive
Burnaby, BC V5C 6G9

2021-02-28

(Affix Professional Seal here)

604-294-2088
Telephone
ataleghani@kwl.ca
(email)

If the APEGBC Qualified Professional is a member of a firm, complete the following:

I am a member of the firm Kerr Wood Leidal Associates Ltd.,
and I sign this letter on behalf of the firm.
(Print name of firm)

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North Shore Sea Level Rise Risk Assessment & Adaptive Management Strategy

Stillwater Flood Map Package

Final
February 2021
KWL Project No. 031.548-300/AppB

Prepared for:

DISTRICT OF NORTH VANCOUVER

city of north vancouver

west vancouver

NSEM

Skwxwú7mesh Úxwumixw
Squamish Nation

PORT of vancouver

KERR WOOD LEIDAL
consulting engineers

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Scenario A:

Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016), and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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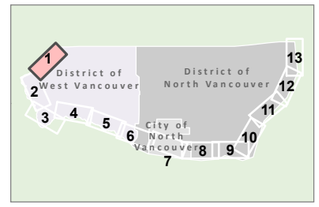
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Average High Tide (no sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-1

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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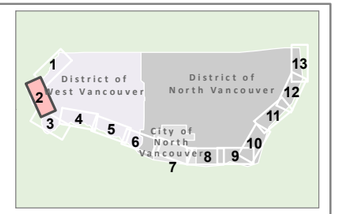
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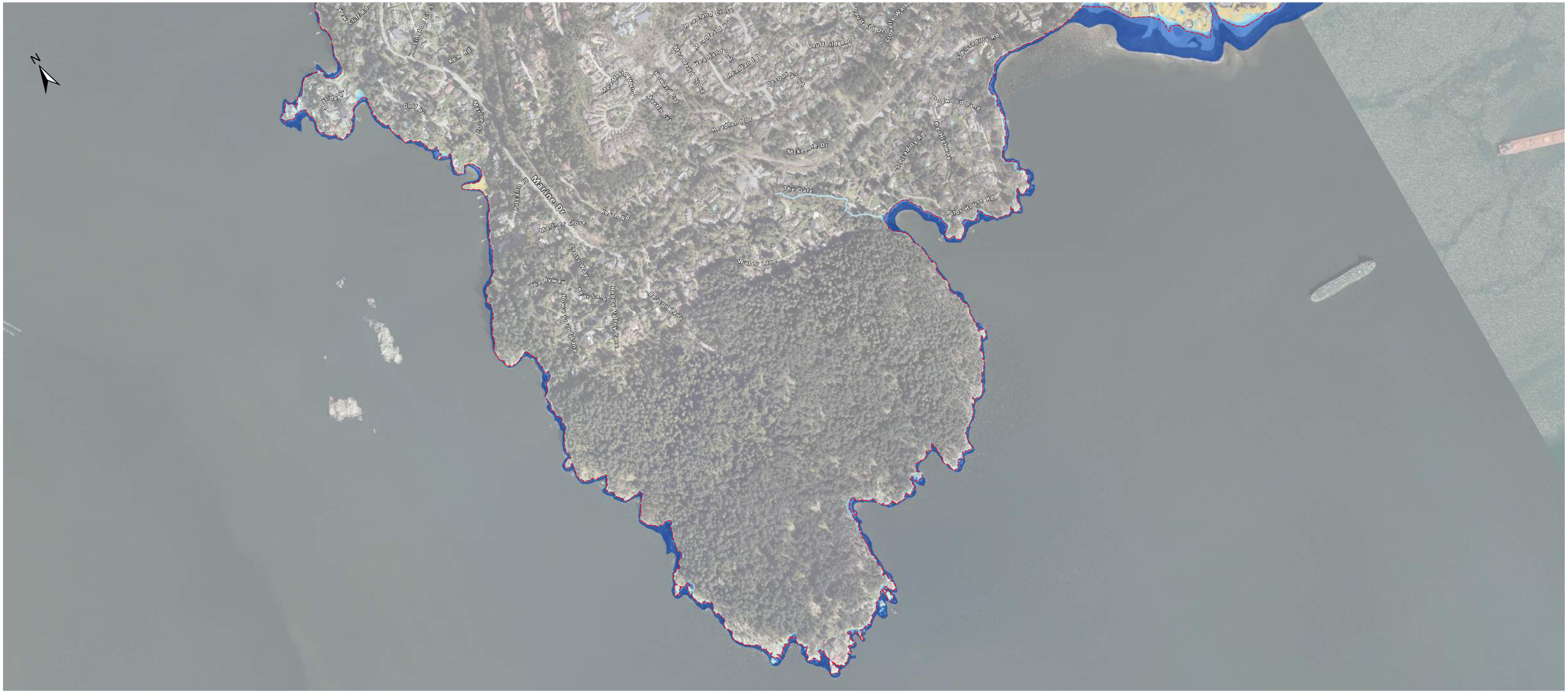
Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-2

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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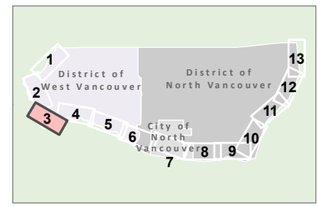
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Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-3

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

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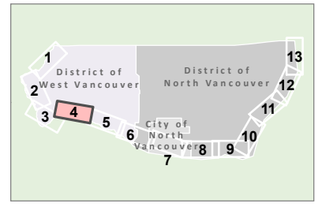
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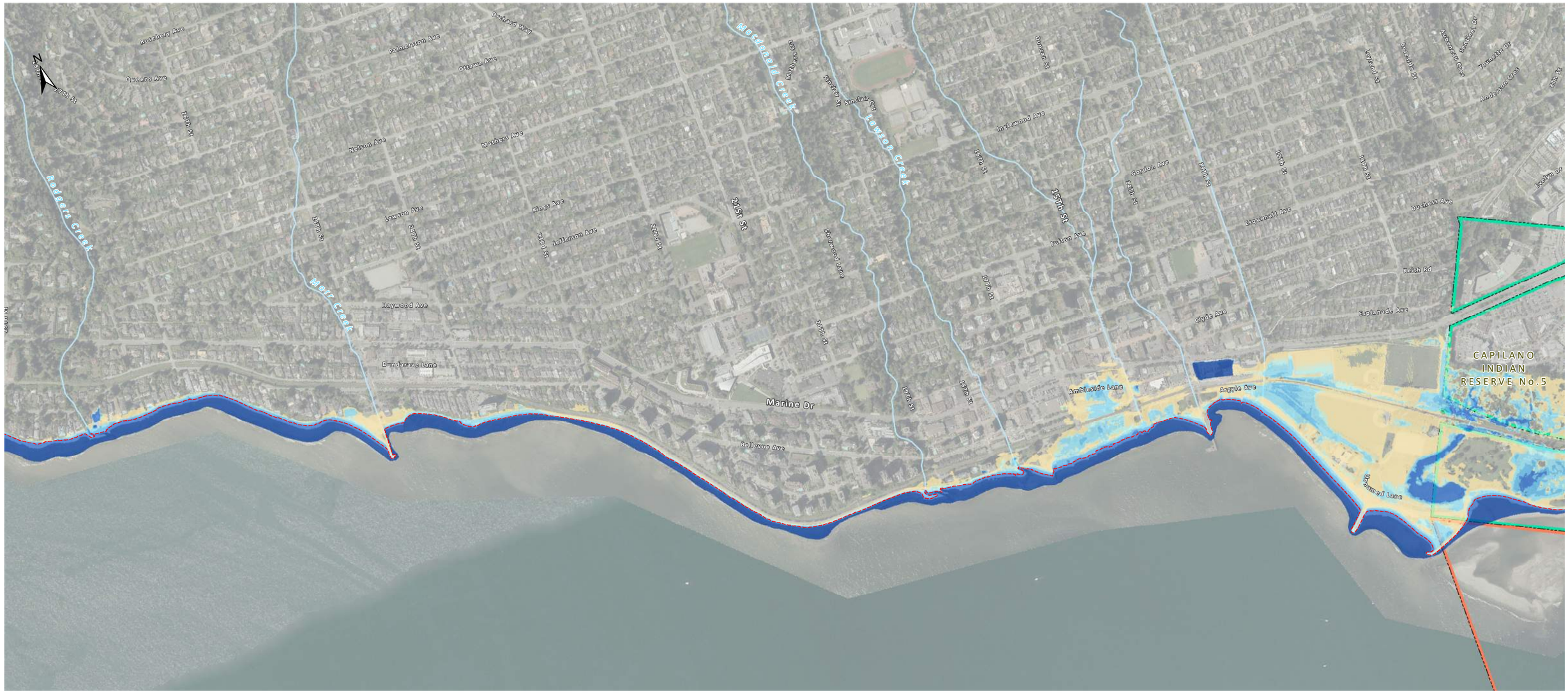
Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-4

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

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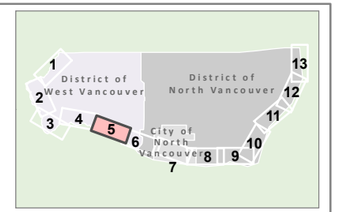
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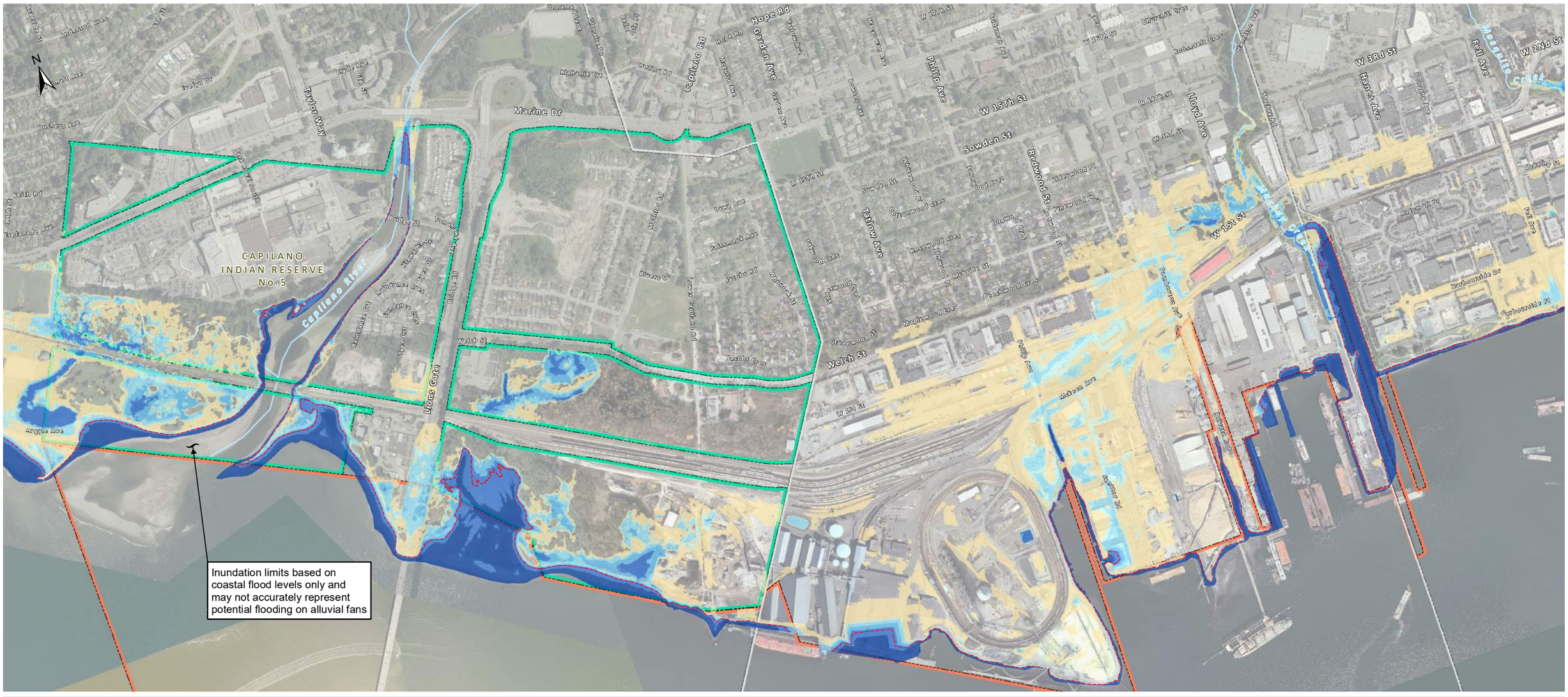
Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-5

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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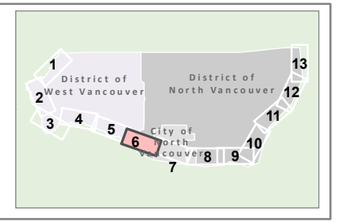
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Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-6

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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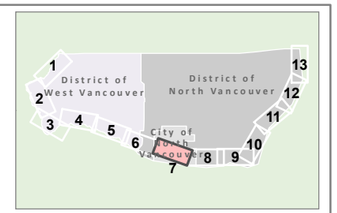
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Sea Level Rise Flood Inundation Map
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Figure A-7

District of North Vancouver

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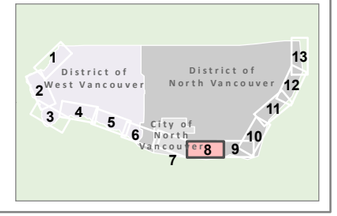
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Sea Level Rise Flood Inundation Map
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Figure A-8

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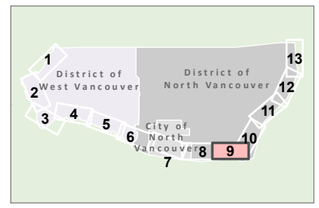
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Average High Tide (no sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-9

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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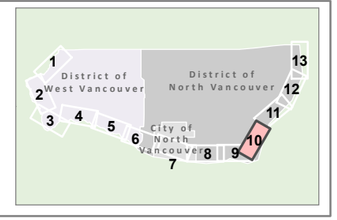
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Average High Tide (no sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

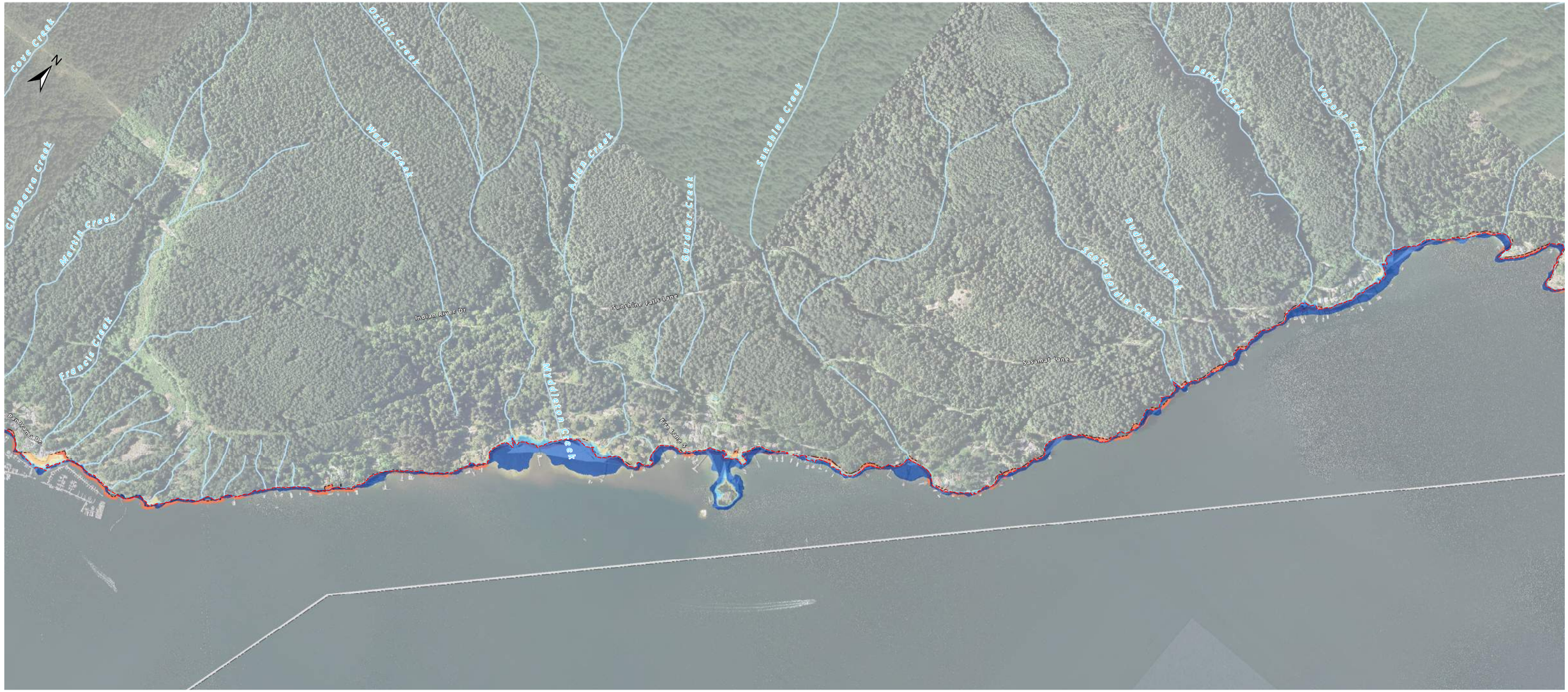
Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-10

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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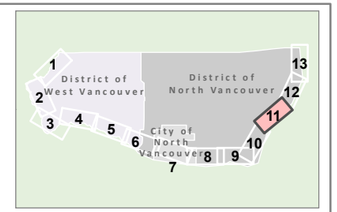
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Average High Tide (no sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

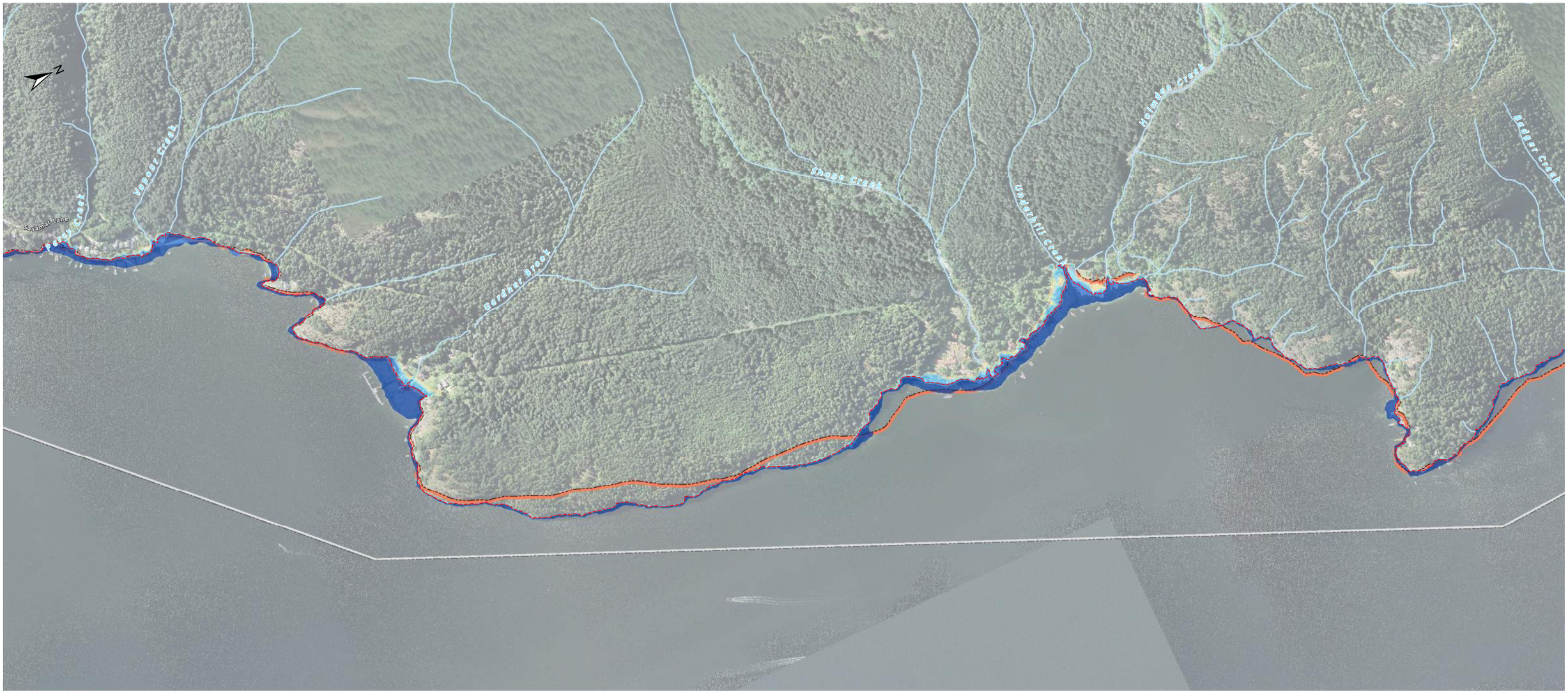
Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-11

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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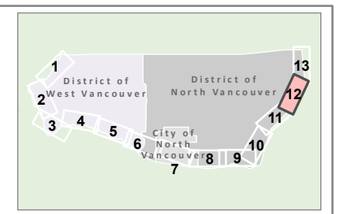
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Average High Tide (no sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

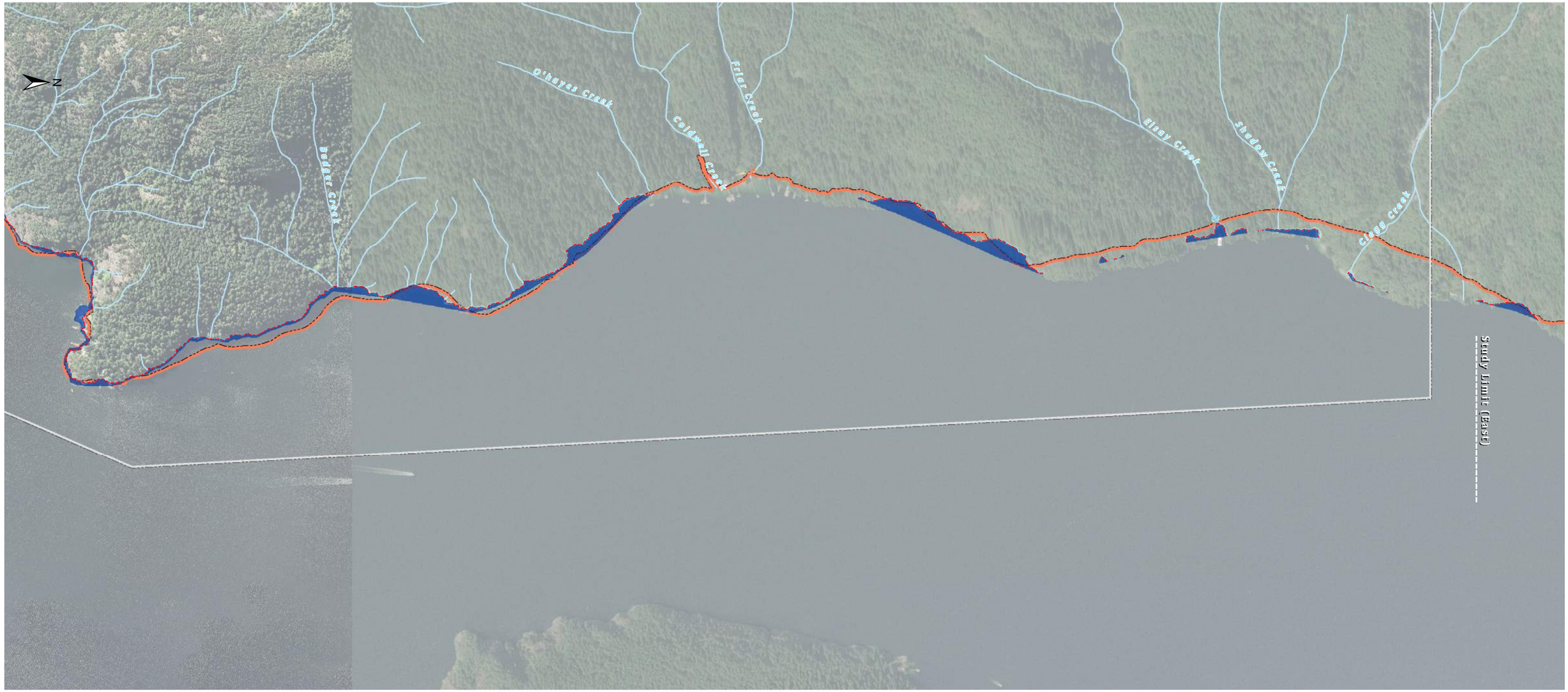
Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-12

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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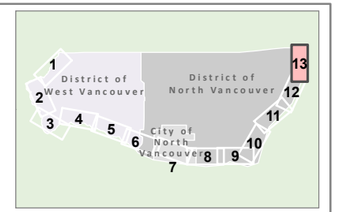
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Average High Tide (no sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario A: Current Sea Level plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure A-13

KERR WOOD LEIDAL
consulting engineers

Scenario B:

0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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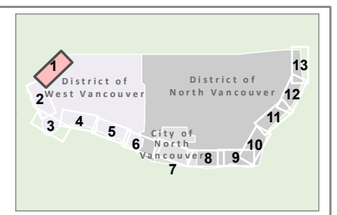
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-1

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016), and EMBC (2016).

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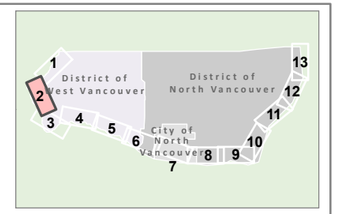
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

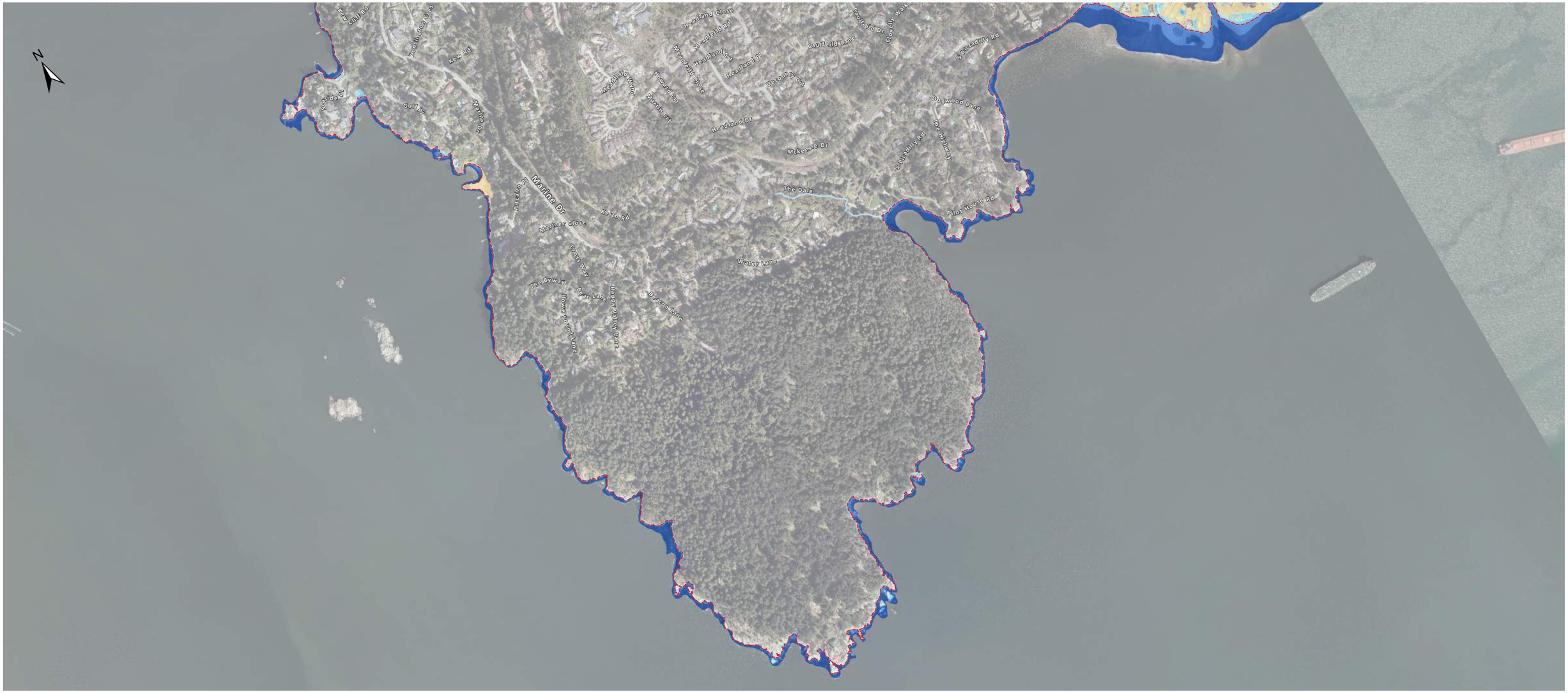
Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-2

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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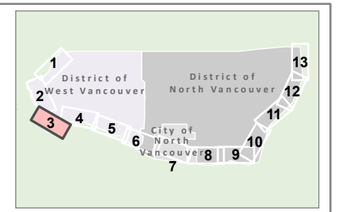
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-3

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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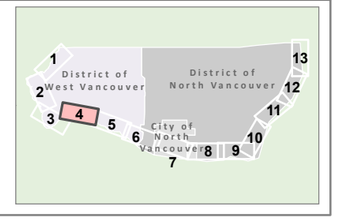
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-4

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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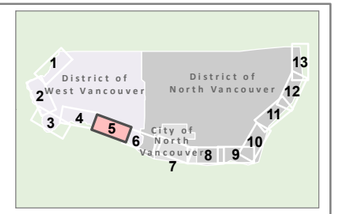
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-5

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:10,000 is only valid on a 11"x17" print.

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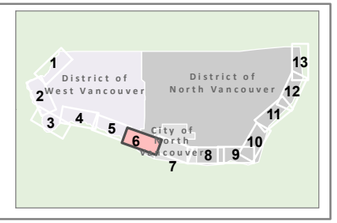
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-6

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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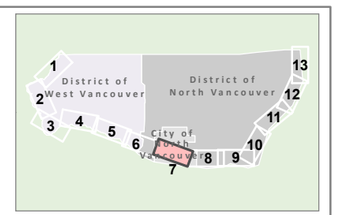
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

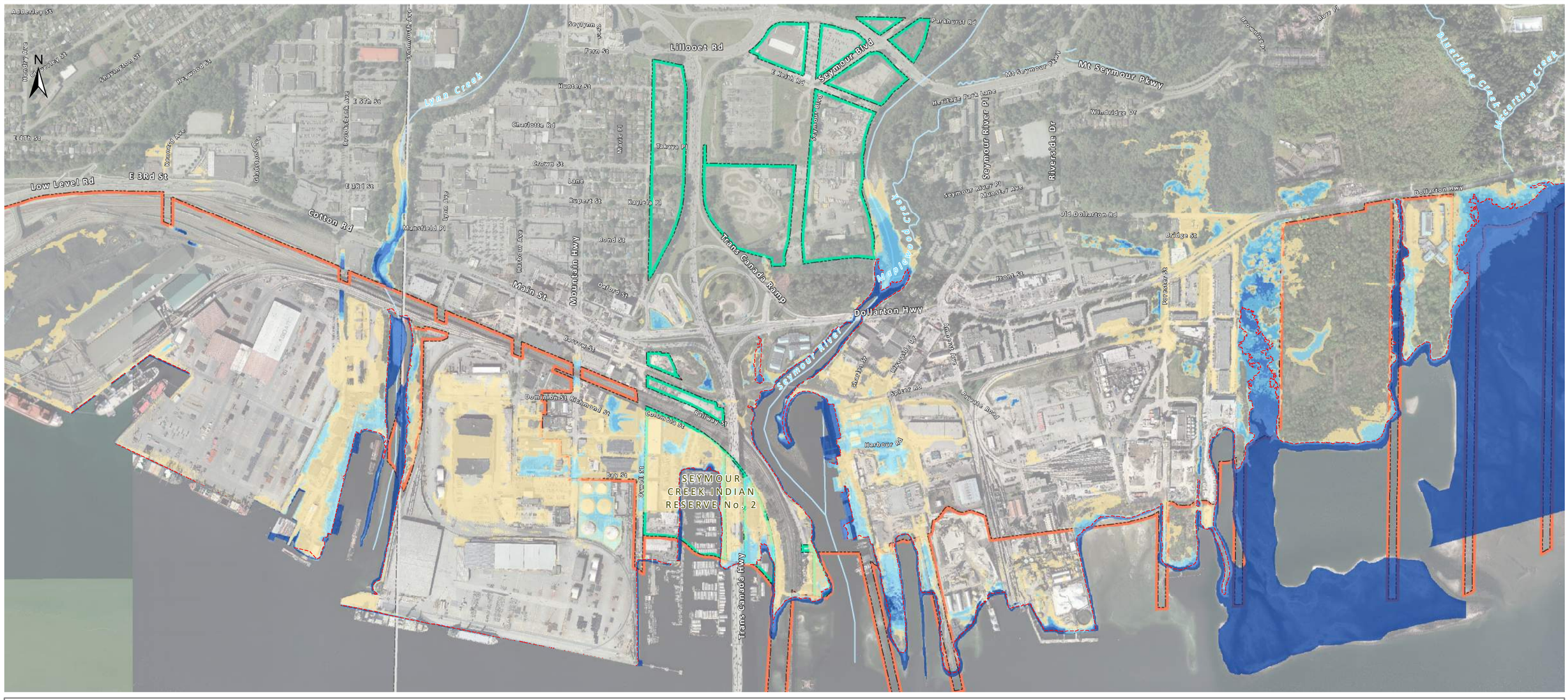
Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-7

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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Coordinate System: NAD 1983 UTM Zone 10N

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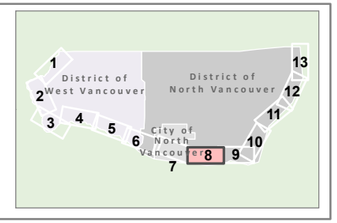
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-8

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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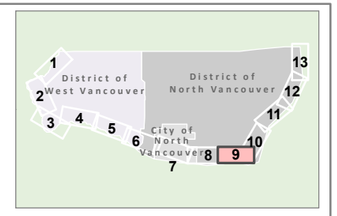
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-9

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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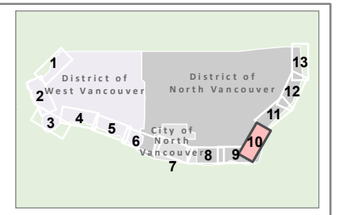
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

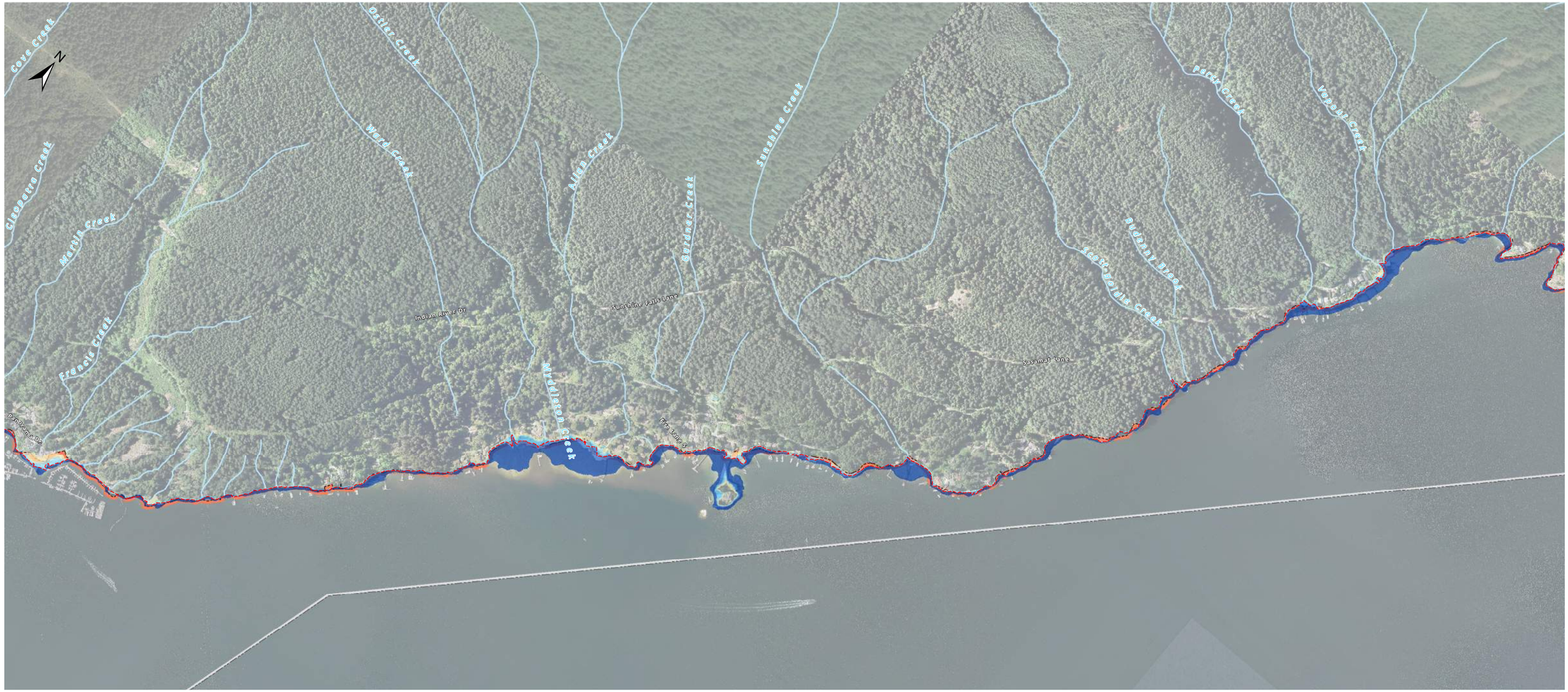
Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-10

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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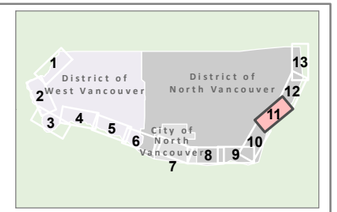
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

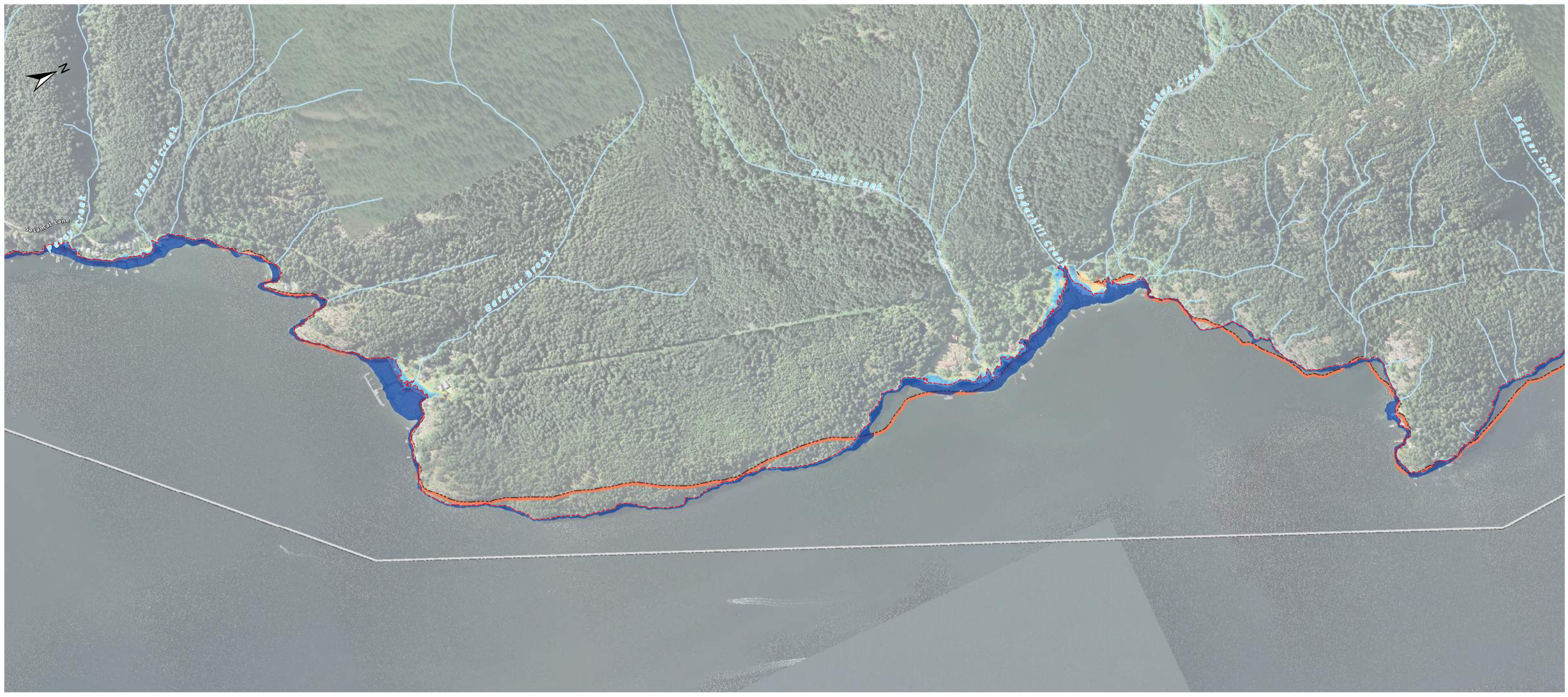
Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-11

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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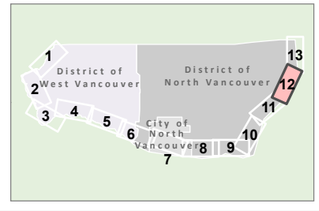
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

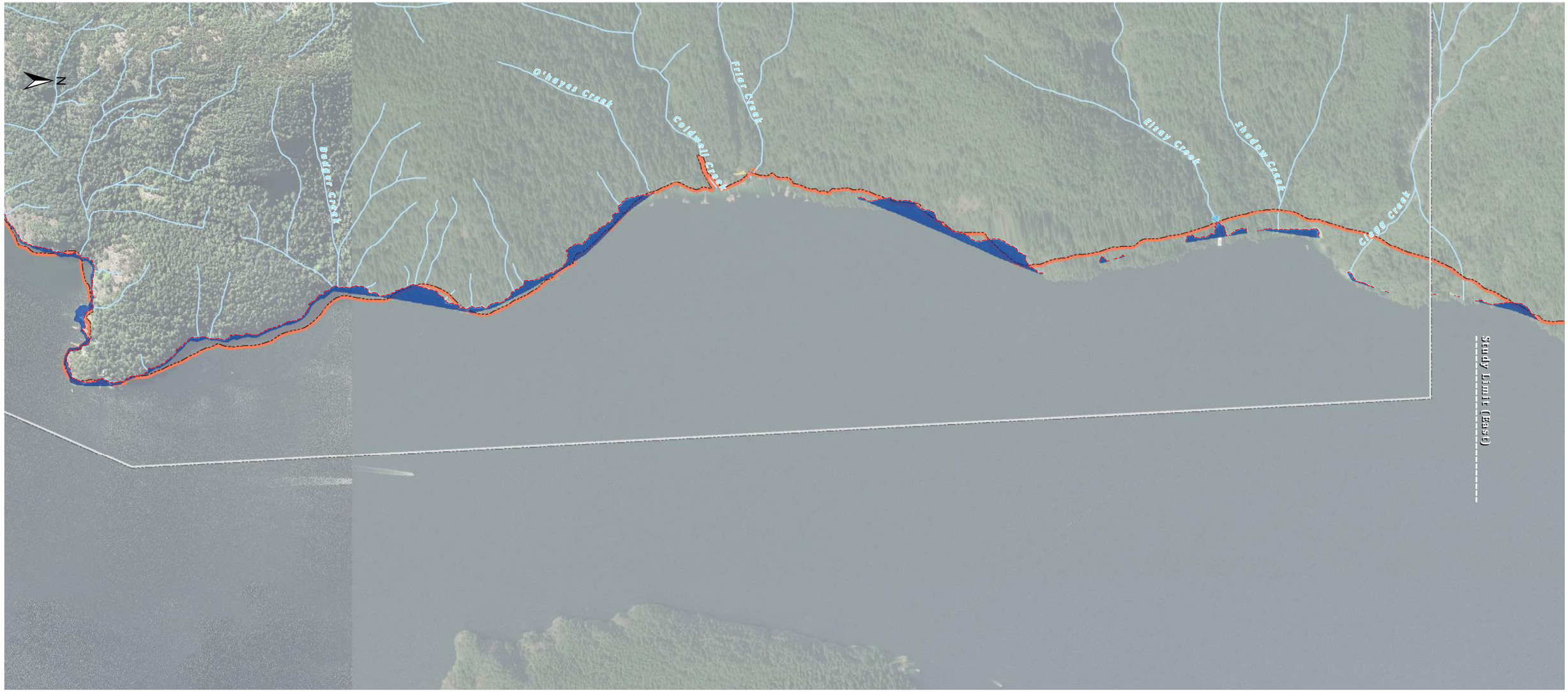
Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-12

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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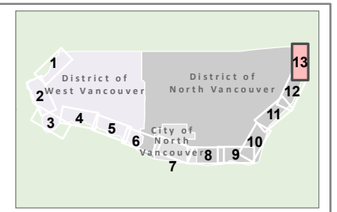
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (0.5 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario B: 0.5 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure B-13

KERR WOOD LEIDAL
consulting engineers

Scenario C:

1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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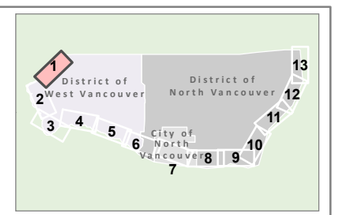
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-1

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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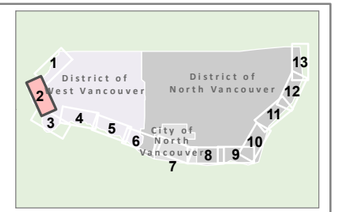
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m)

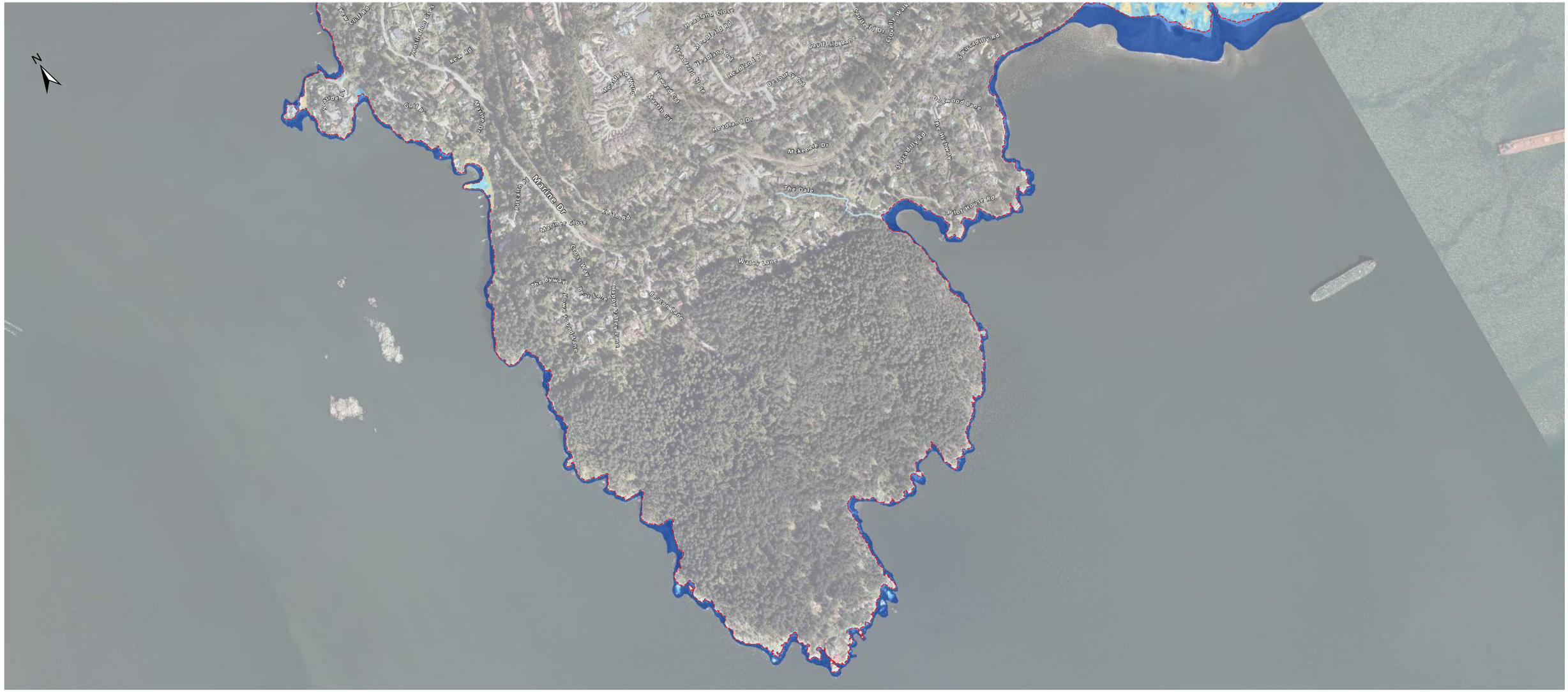
Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-2

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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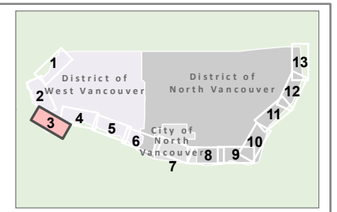
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-3

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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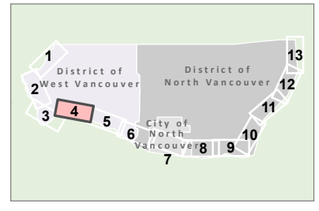
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-4

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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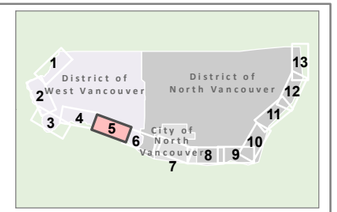
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

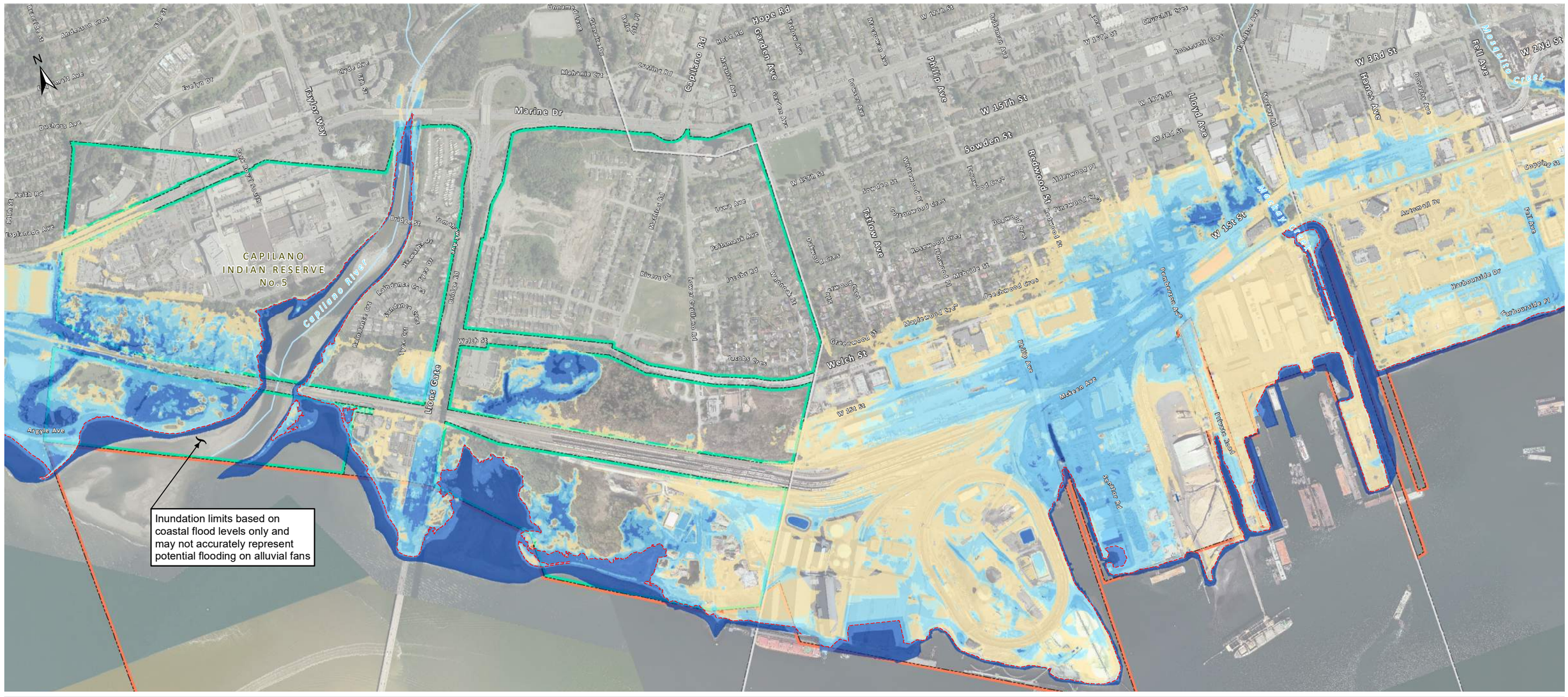
Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-5

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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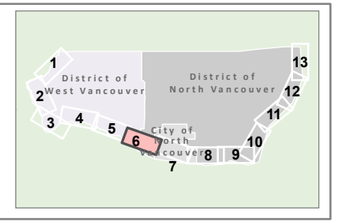
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-6

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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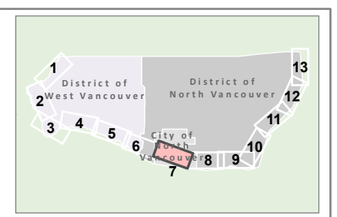
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Legend

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- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
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Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 m)

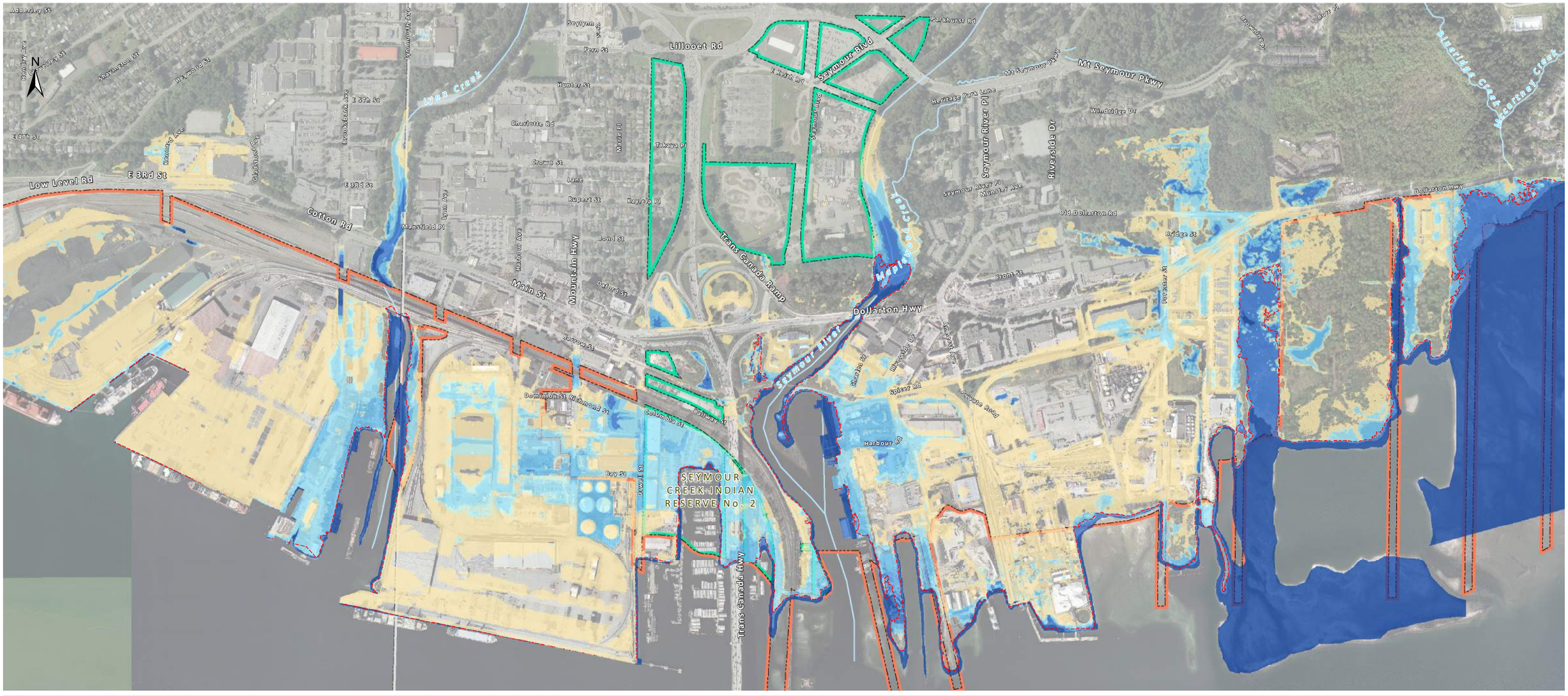
Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-7

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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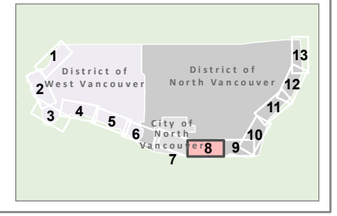
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Legend

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- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-8

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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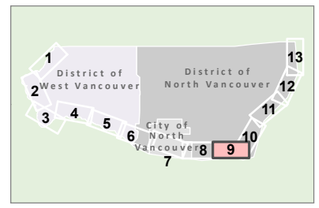
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-9

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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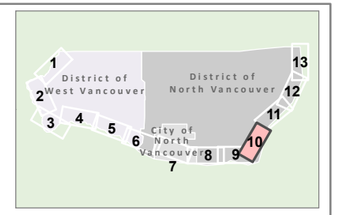
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

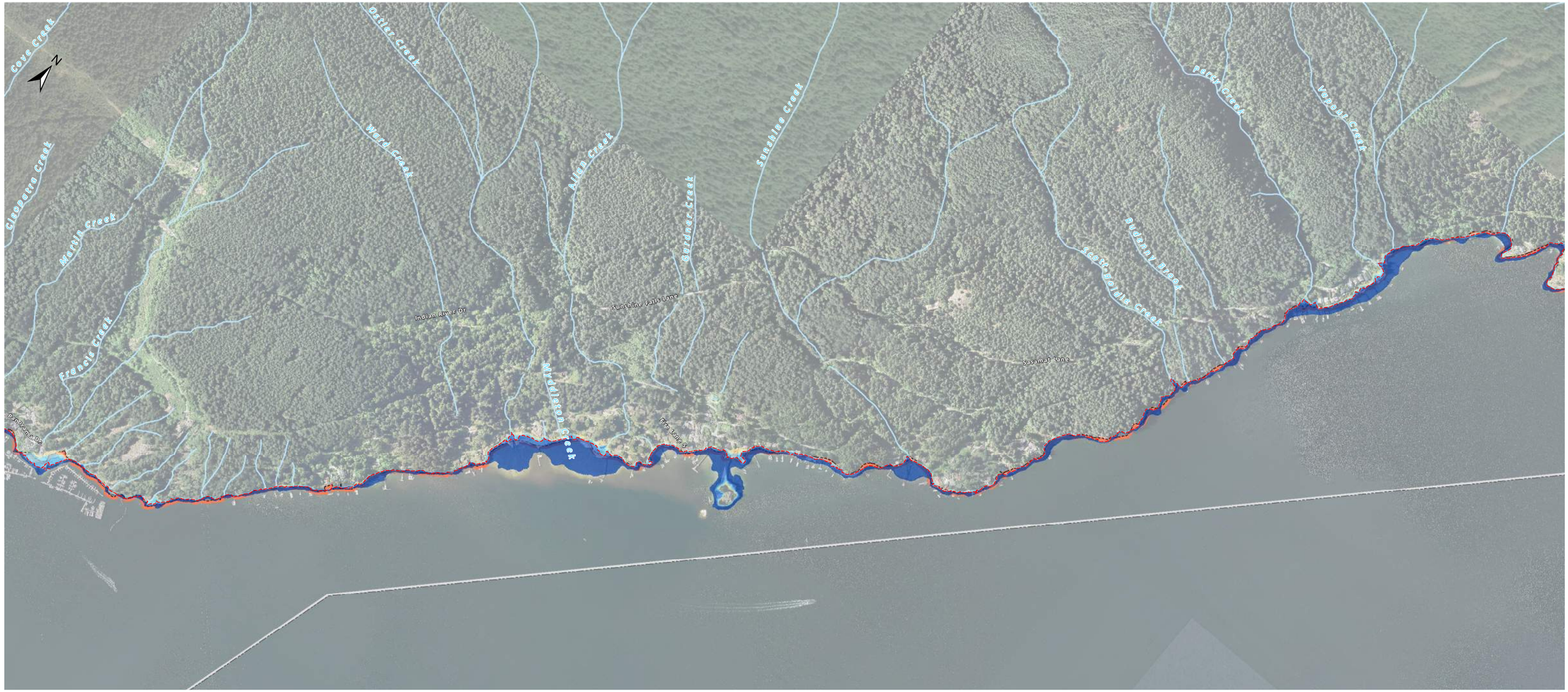
Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-10

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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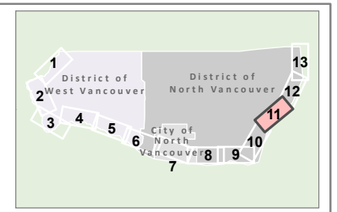
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

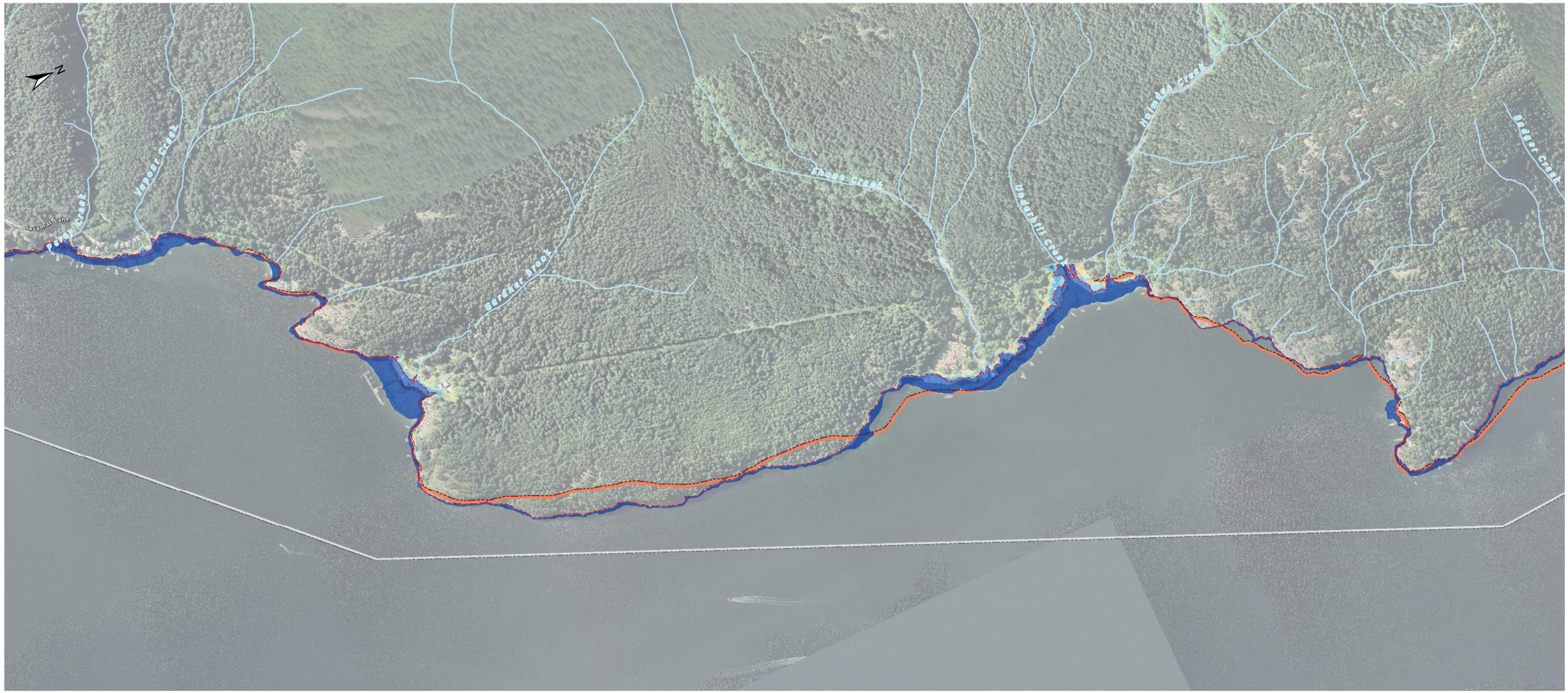
Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-11

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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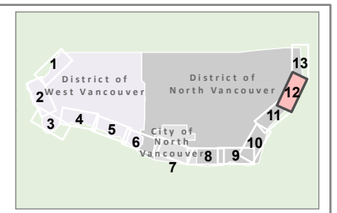
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

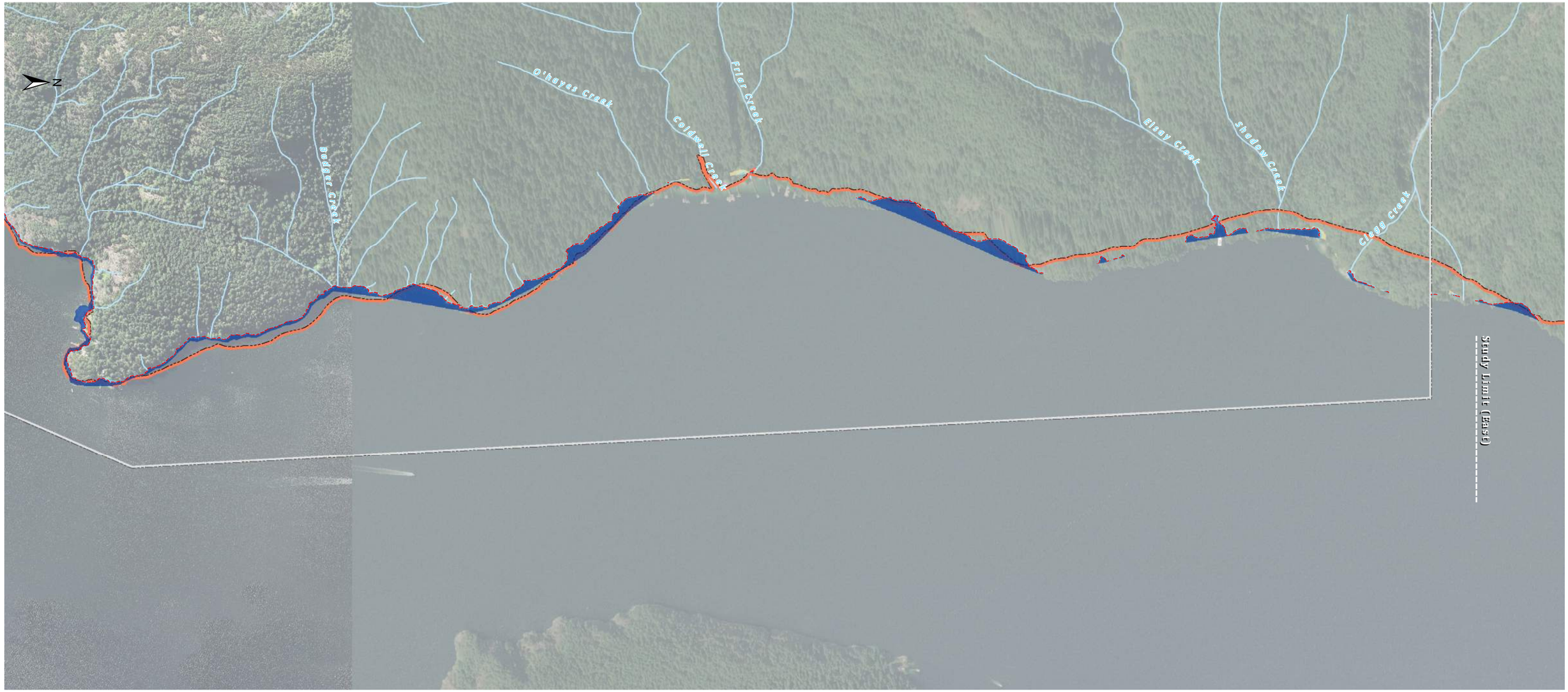
Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-12

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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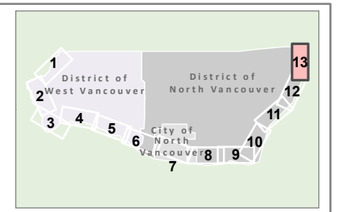
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario C: 1 m Sea Level Rise plus 10-Year Return Period (10% Annual Exceedance Probability)

Figure C-13

KERR WOOD LEIDAL
consulting engineers

Scenario D:

1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers


N
Dishrow Creek
Seymour Dr
Seascape Rd
Seascape Pl
Seascape Terr
Seascape Crt
Seascape Close
99 HWY
Pasco Rd
Bedora Pl
Lawrence Way
Anvil Pl
Seaview Dr
Seaview Pl
Seaview Crt
Seaview Close
Seaview Rd
Seaview Terr
Seaview Ave
Seaview Ln
Seaview Cres
Seaview Blvd
Seaview Way
Seaview Gate
Seaview Court
Seaview Drive
Seaview Lane
Seaview Street
Seaview Avenue
Seaview Road
Seaview Place
Seaview Circle
Seaview Square
Seaview Plaza
Seaview Park
Seaview Garden
Seaview Meadow
Seaview Field
Seaview Hill
Seaview Valley
Seaview Ridge
Seaview Mountain
Seaview Forest
Seaview Lake
Seaview River
Seaview Creek
Seaview Bay
Seaview Harbour
Seaview Port
Seaview Dock
Seaview Pier
Seaview Wharf
Seaview Marina
Seaview Boat
Seaview Ship
Seaview Sail
Seaview Anchor
Seaview Rope
Seaview Knot
Seaview Buoy
Seaview Light
Seaview Lighthouse
Seaview Beacon
Seaview Tower
Seaview Bridge
Seaview Tunnel
Seaview Road
Seaview Highway
Seaview Freeway
Seaview Expressway
Seaview Boulevard
Seaview Avenue
Seaview Street
Seaview Lane
Seaview Drive
Seaview Court
Seaview Gate
Seaview Way
Seaview Blvd
Seaview Cres
Seaview Ln
Seaview Ave
Seaview Rd
Seaview Terr
Seaview Pl
Seaview Crt
Seaview Close
Seaview Dr

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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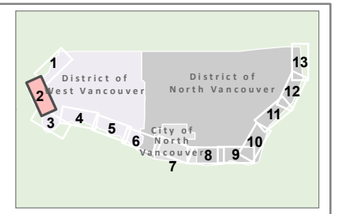
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Legend

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- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-2

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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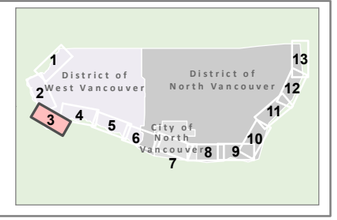
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-3

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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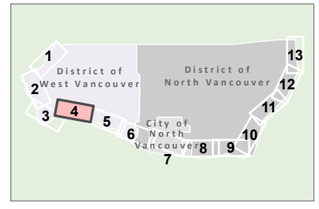
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-4

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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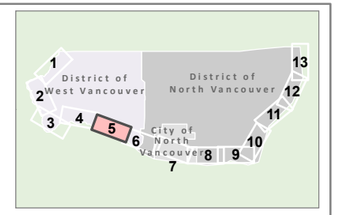
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

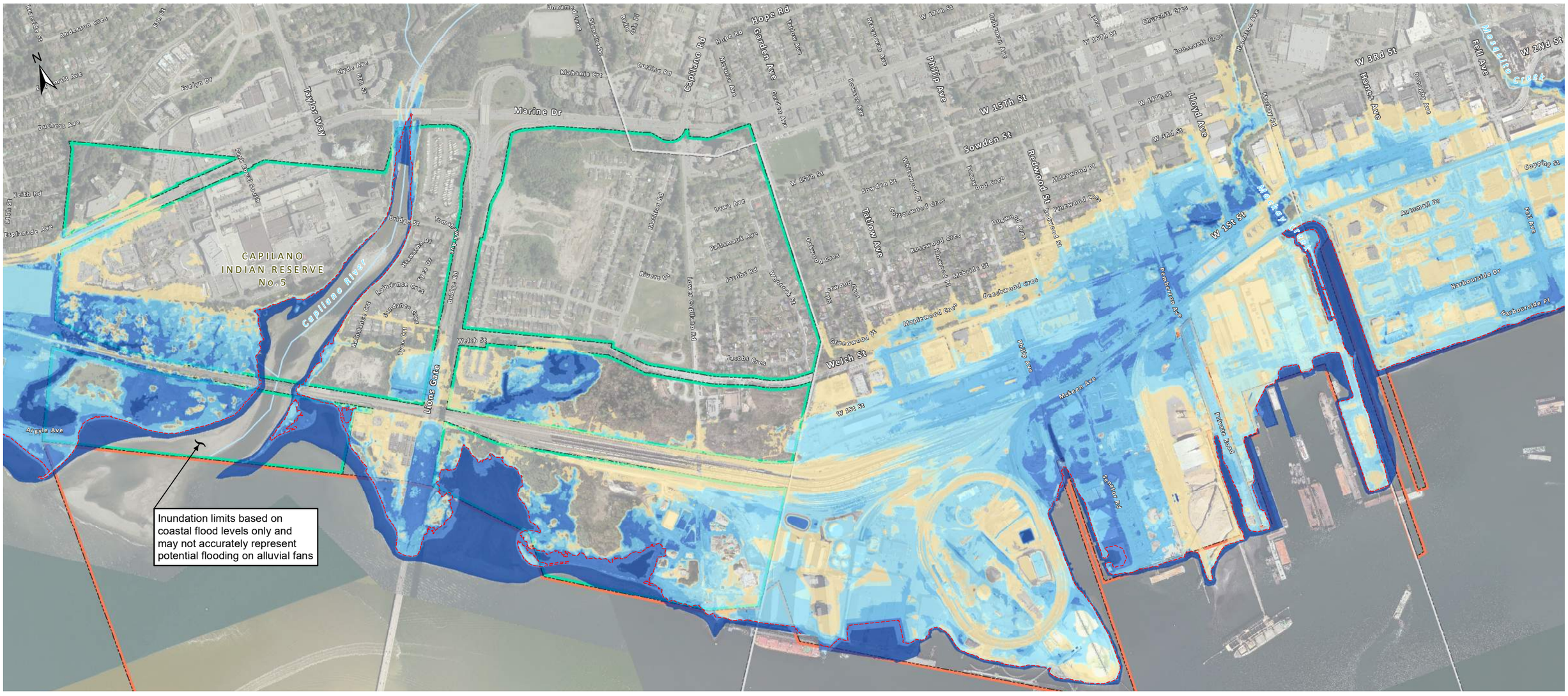
Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-5

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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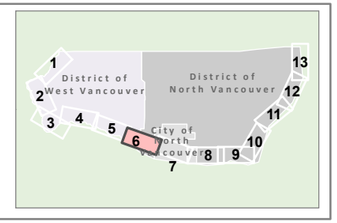
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-6

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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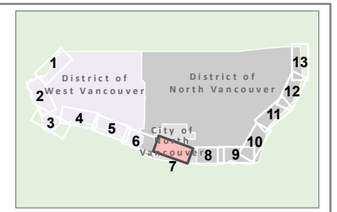
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

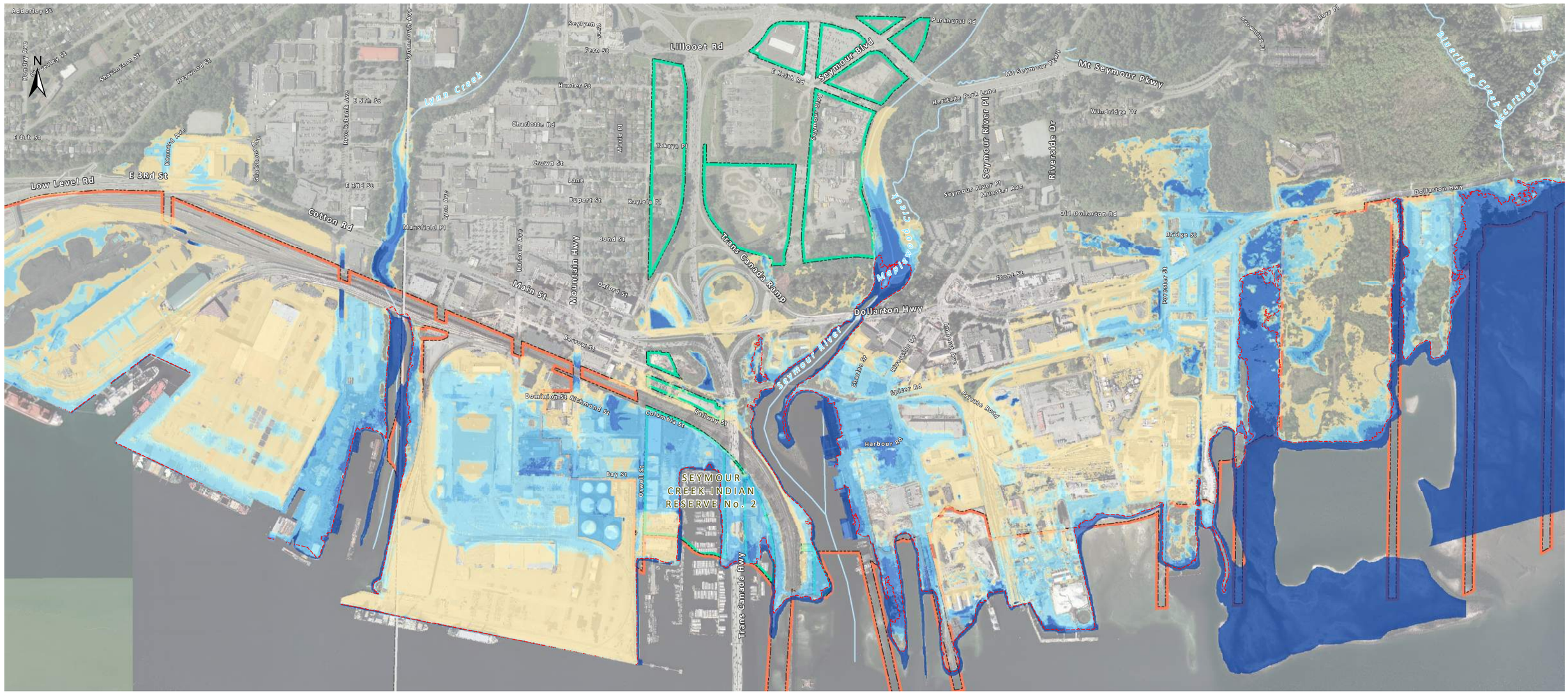
Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-7

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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Coordinate System: NAD 1983 UTM Zone 10N

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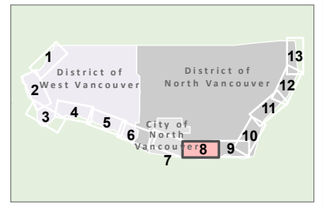
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-8

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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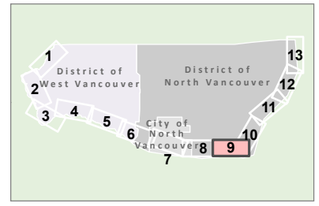
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-9

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

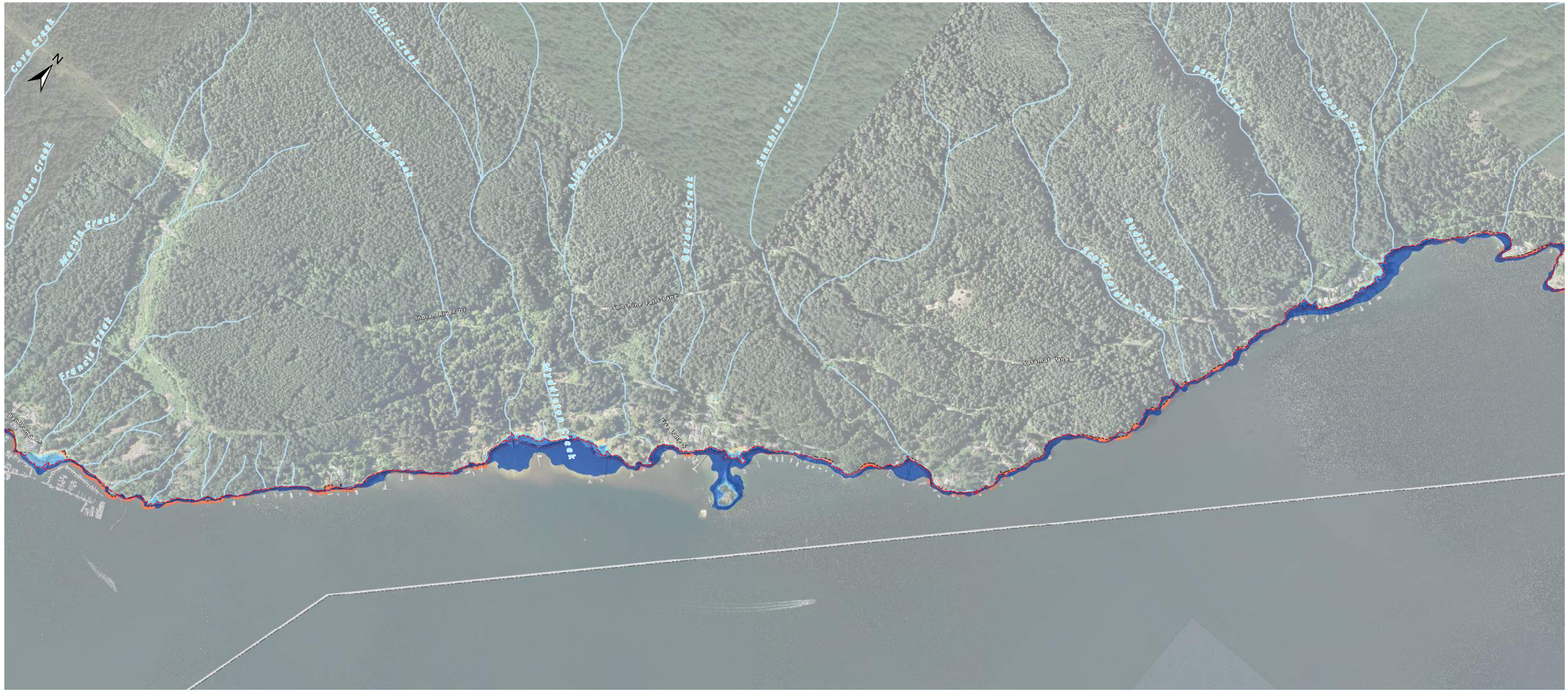
KERR WOOD LEIDAL consulting engineers


BURRARD INLET INDIAN RESERVE No. 3
Roche Point Creek
Panorama Creek
Kail Creek
Mathers Brook
Gawley Creek
Cove Creek
CleoDestra Creek
Mosquito Creek
Mosquito Creek
Fredrick Creek
Parkside Creek
Heard Creek
Mt Seymour Pkwy
Fairway Dr
Dollar Rd
Baker View St
Coldwell Rd
Deep Cove Rd
Banbury Rd
Rockcliff Rd
Cliffmont Rd
Gallant Creek
Nanaimo Ave
Gove Cliff Rd
Strathcona Rd
Roxbury Rd
Roche Point Dr
Beachview Dr
Lowry Lane
Keith Rd
Broadview Dr
Brockton Cres
Panorama Dr
Cliffwood Rd
Rockridge Rd
Parkside Lane
Lookaway Rd
Fairfield Rd
Naomi Pl
Caledonia Ave
Gallant Ave
Burns Ave
Eastern Ave
Russell Ave
Russell Rd
Dempsey Rd
Kinloch Lane
Strathcona Way
Strathcona Ave
Strathcona Pl
Wickenden Rd
Roxbury Pl
Cove Cliff Pl
Carolina Cres
Lucas Pl
Gulf Dr
Fulton Rd
Fulton Pl
Parkway Dr
Parkway Pl
Parkgate Ave
Parkgate Pl
Parkgate Lane
Parkgate Way
Parkway Lane
Parkway Pl
Ermindale Pl
Gordon Rd
Greenwood Cres
Bayfield Dr
Rosevelt Blvd
Beachview Dr
Lowry Lane
Lane
Derby Rd
Sea Shell Lane
Carey Park Rd
N Dollarton Hwy
Dempsey Rd
Ridgeway Dr
Ridgeway Pl
Ridgeway Cres
Ridgeway Ave
Ridgeway Rd
Ridgeway Pl

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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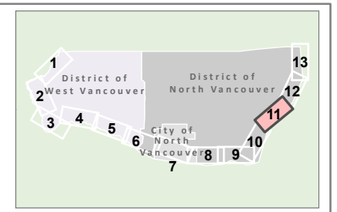
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Legend

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- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m)

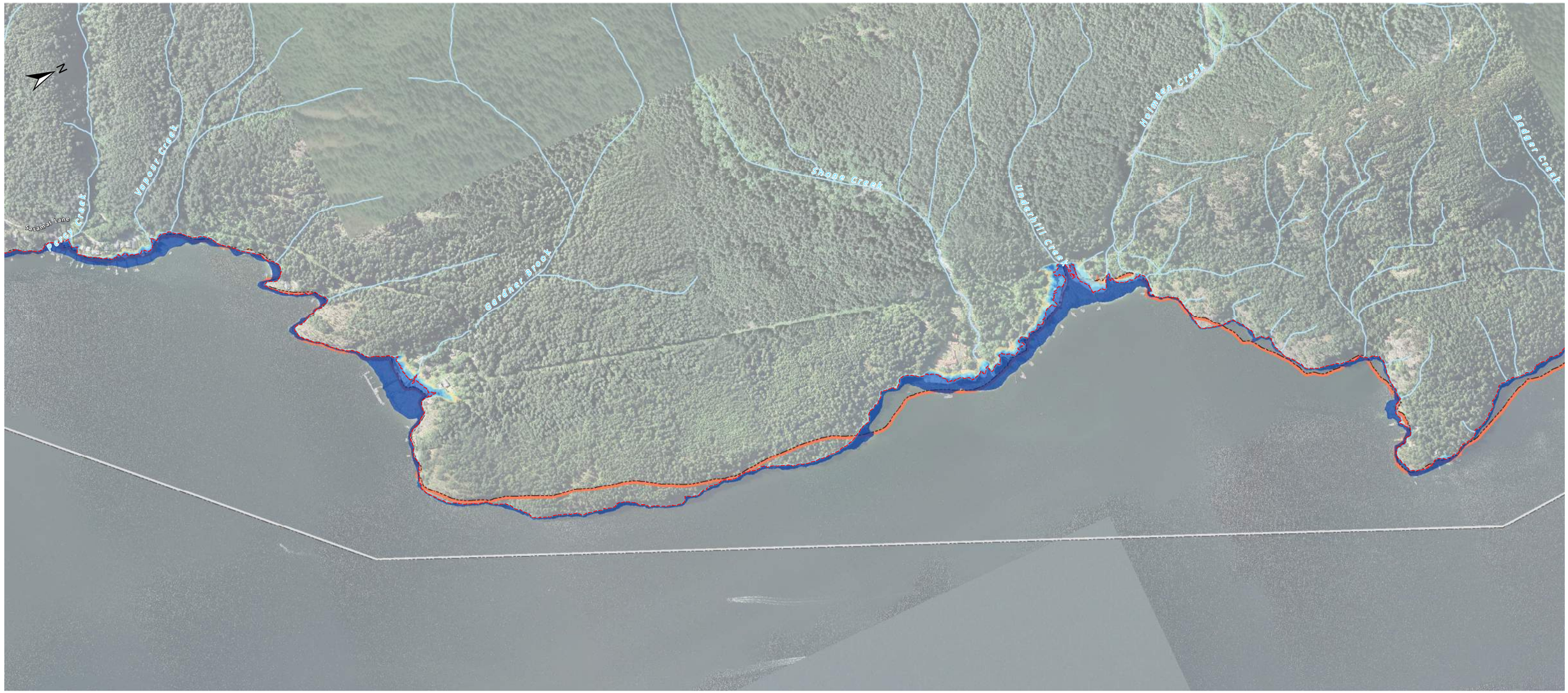
Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-11

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

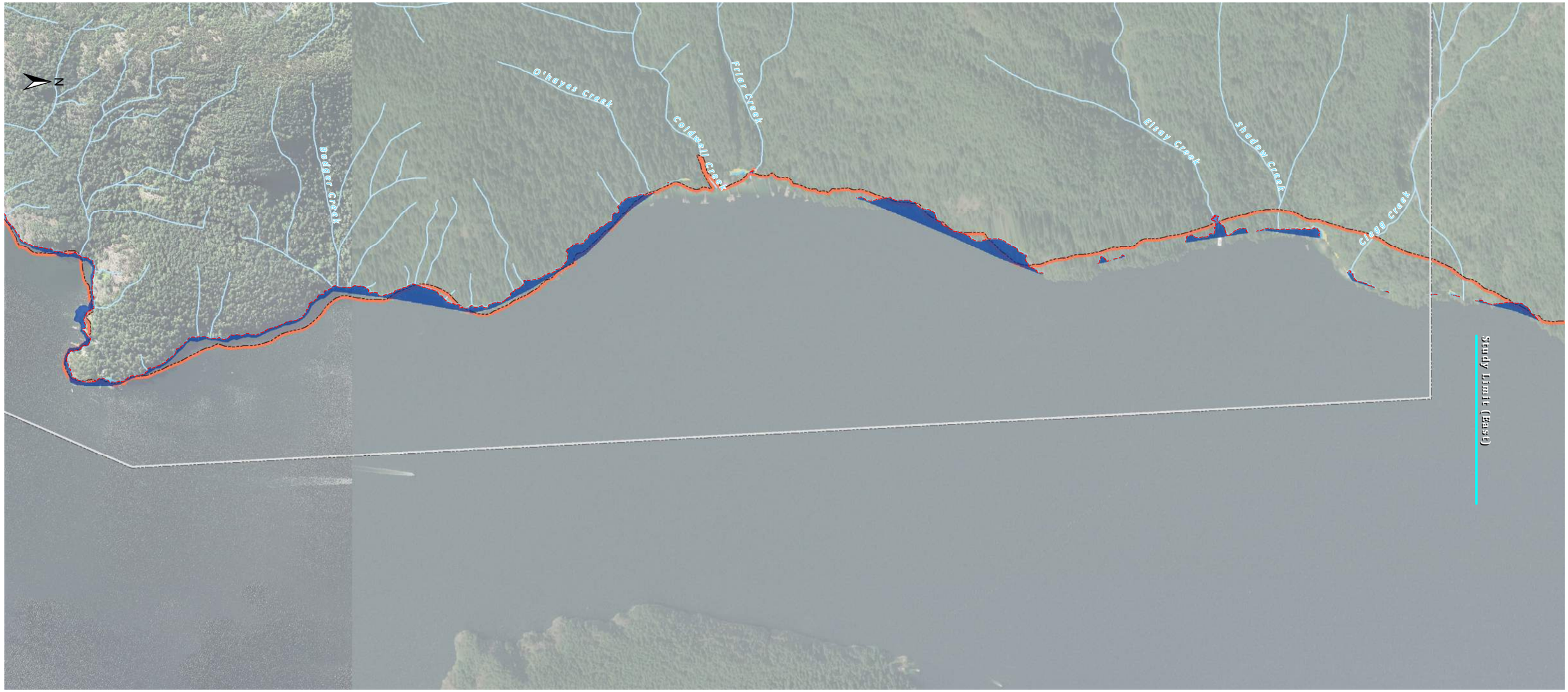
KERR WOOD LEIDAL consulting engineers


Mosquito Creek
Lynn Creek
Pipeline Road
Seymour River
Capilano River
Capilano Road
Mission Point Road
Mission Point
Dollarton Highway
Indian River Drive
Mount Seymour Parkway
Keith Road
Fern Street
Lillooet Road
Old Dollarton Road
Riverside Drive
Riverside Drive
Mount Seymour Road
Capilano Road
Forbes Avenue
Forbes Avenue
Forbes Avenue

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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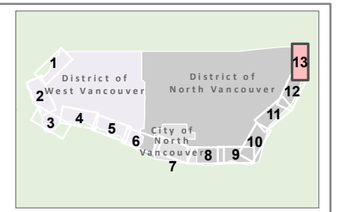
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Legend

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- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (1 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario D: 1 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure D-13

KERR WOOD LEIDAL
consulting engineers

Scenario E:

2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016), and EMBC (2016).

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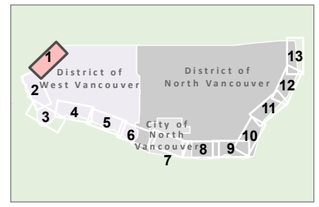
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-1

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016), and EMBC (2016).

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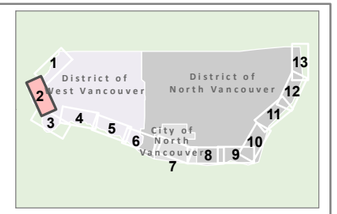
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-2

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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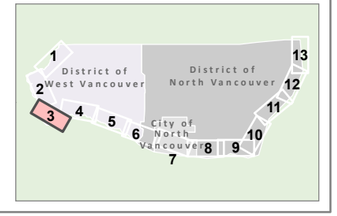
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-3

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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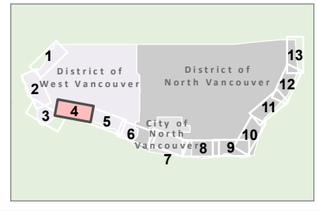
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-4

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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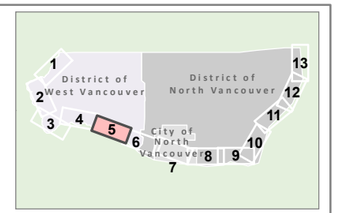
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

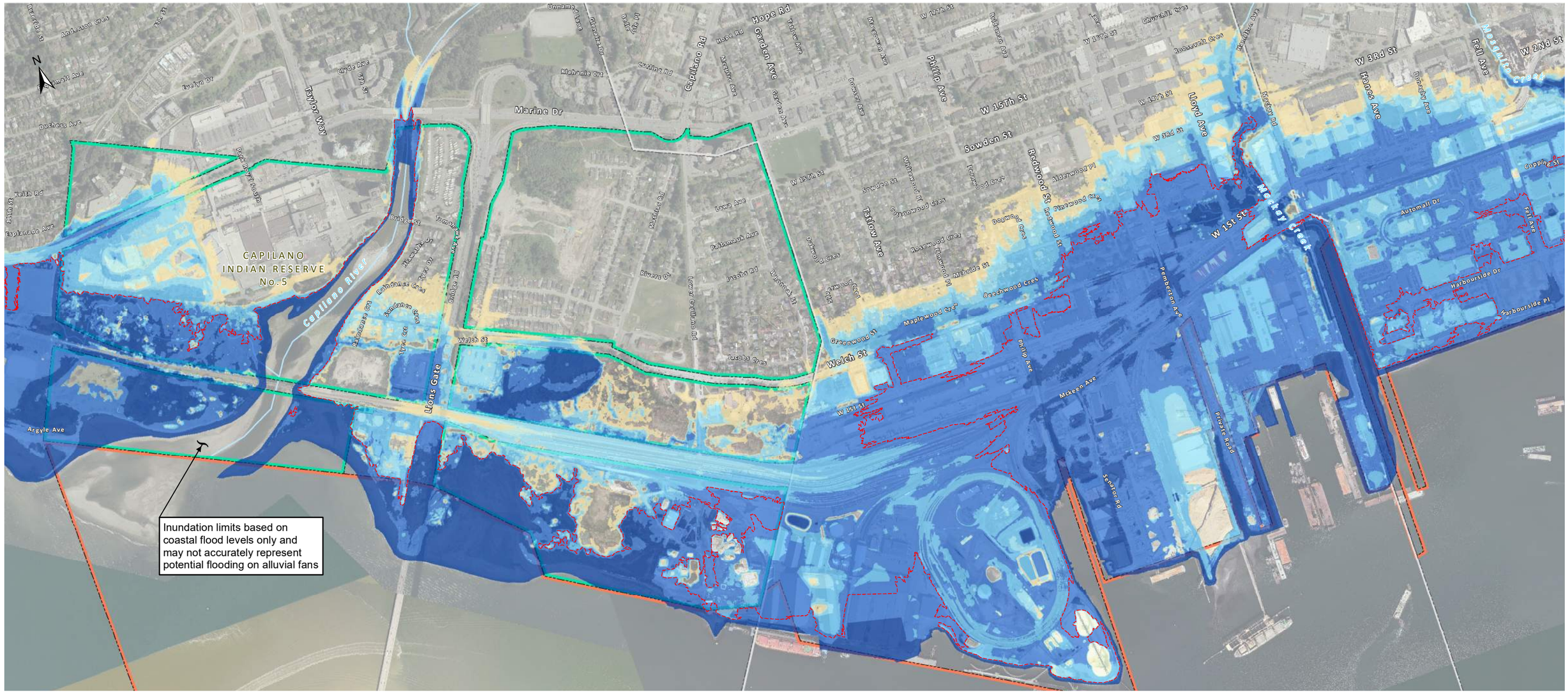
Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-5

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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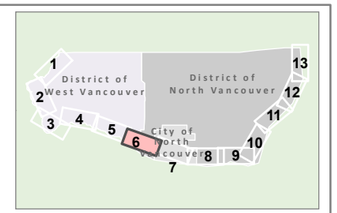
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-6

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

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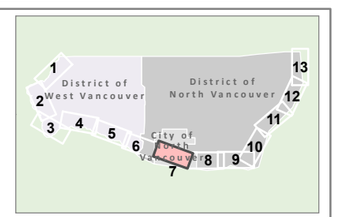
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

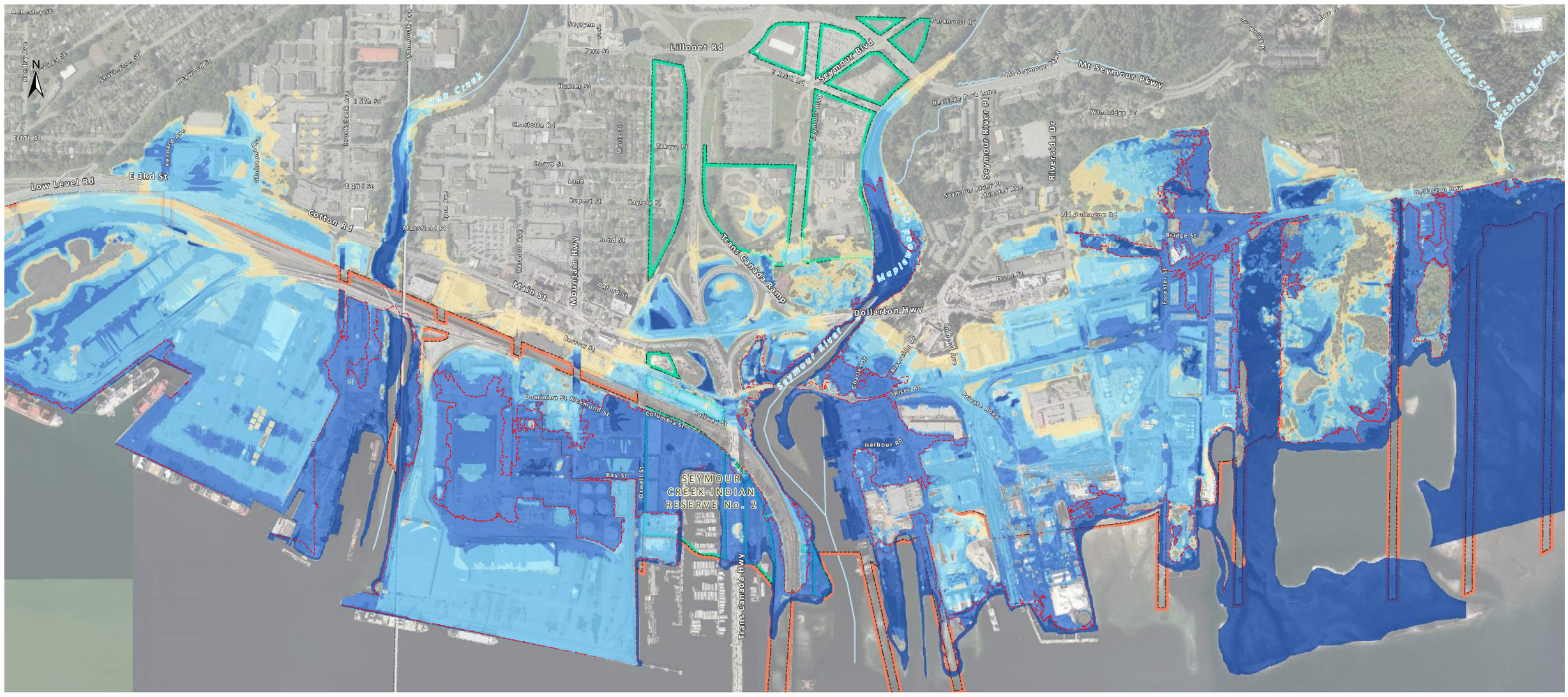
Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-7

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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Coordinate System: NAD 1983 UTM Zone 10N

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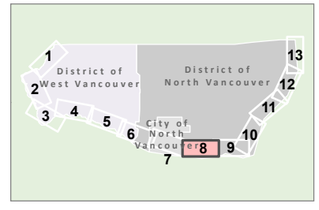
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-8

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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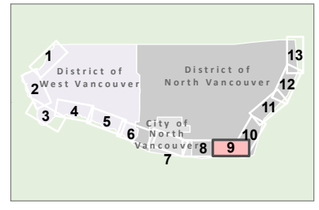
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Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-9

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



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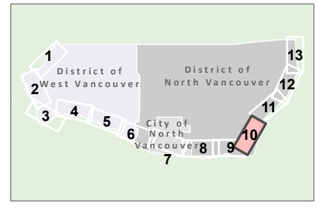
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Legend

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- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 (0 50 100 200 (m))

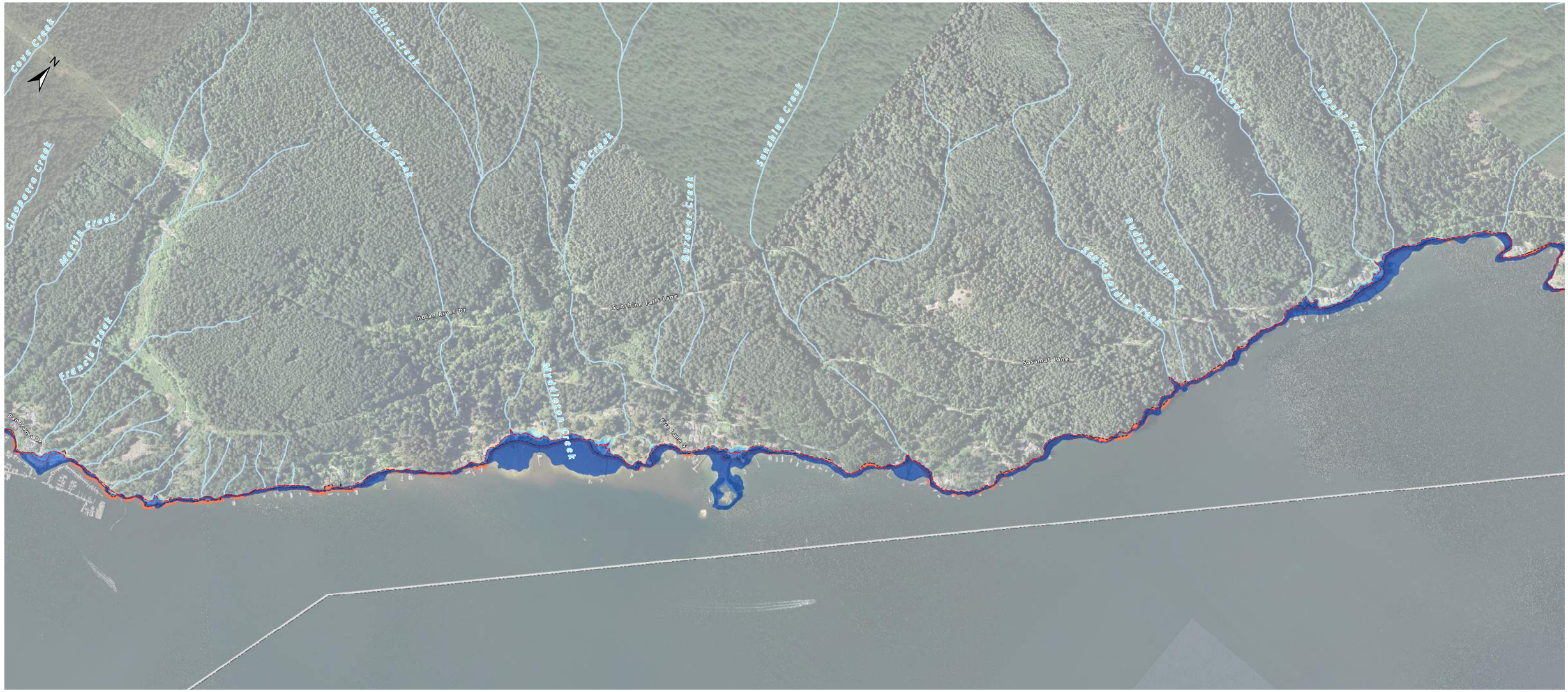
Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-10

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Data Sources: LiDAR - District of West Vancouver (2016), District of North Vancouver (2013), and EMBC (2016). Vertical datum is assumed to be Canadian Geodetic Vertical Datum of 1928 (CGVD28). Orthophoto - District of West Vancouver (2016), District of North Vancouver (2016); and EMBC (2016).

Coordinate System: NAD 1983 UTM Zone 10N

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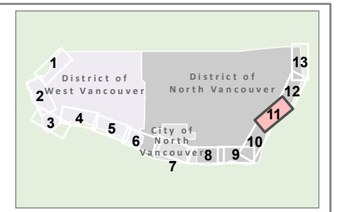
1. This inundation map is part of the development of an adaptive management strategy for risks associated with coastal flooding, including sea level rise. The map is not intended for floodplain regulation by the local government.
2. Inundation limits are based on consideration of coastal stillwater (excluding wave effects) flood levels only (no flooding of creeks and rivers has been assumed).
3. Users must note the dates of base mapping, aerial photography, ground or bathymetric surveys and issue of mapping relevant to dates of development in the map area. Subsequent developments or changes within the floodplain or channel will affect flood levels and render site-specific map information obsolete.
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5. The floodplain limits are not established on the ground by legal survey. A site survey is required to reconcile property location, ground elevations and designated flood level information.
6. Under the provisions of the Local Government Act (Sections 473, 488, 490, 491, 500 and 524), the Community Charter (Section 56) and the Land Title Act (Sections 86 and 219), local governments have the role of and responsibility for making decisions about local floodplain development practices, including decisions about floodplain bylaws within their communities. Information on floodplain management guidelines can be found in the Flood Hazard Area Land Use Management Guidelines (MLWAP 2004).

Legend

- Municipal Boundary
- First Nations Reserves
- Vancouver Fraser Port Authority Boundary
- Watercourse
- Future Average High Tide (2 m sea level rise)
- Additional Area Flooded with 0.6 m Freeboard

Stillwater Flood Maximum Depth (m)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- > 2



Project No. 031.548

Date January 2020

Scale 1:10,000 0 50 100 200 (m)

Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-11

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

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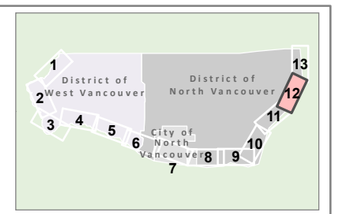
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Scale 1:10,000 0 50 100 200 (m)

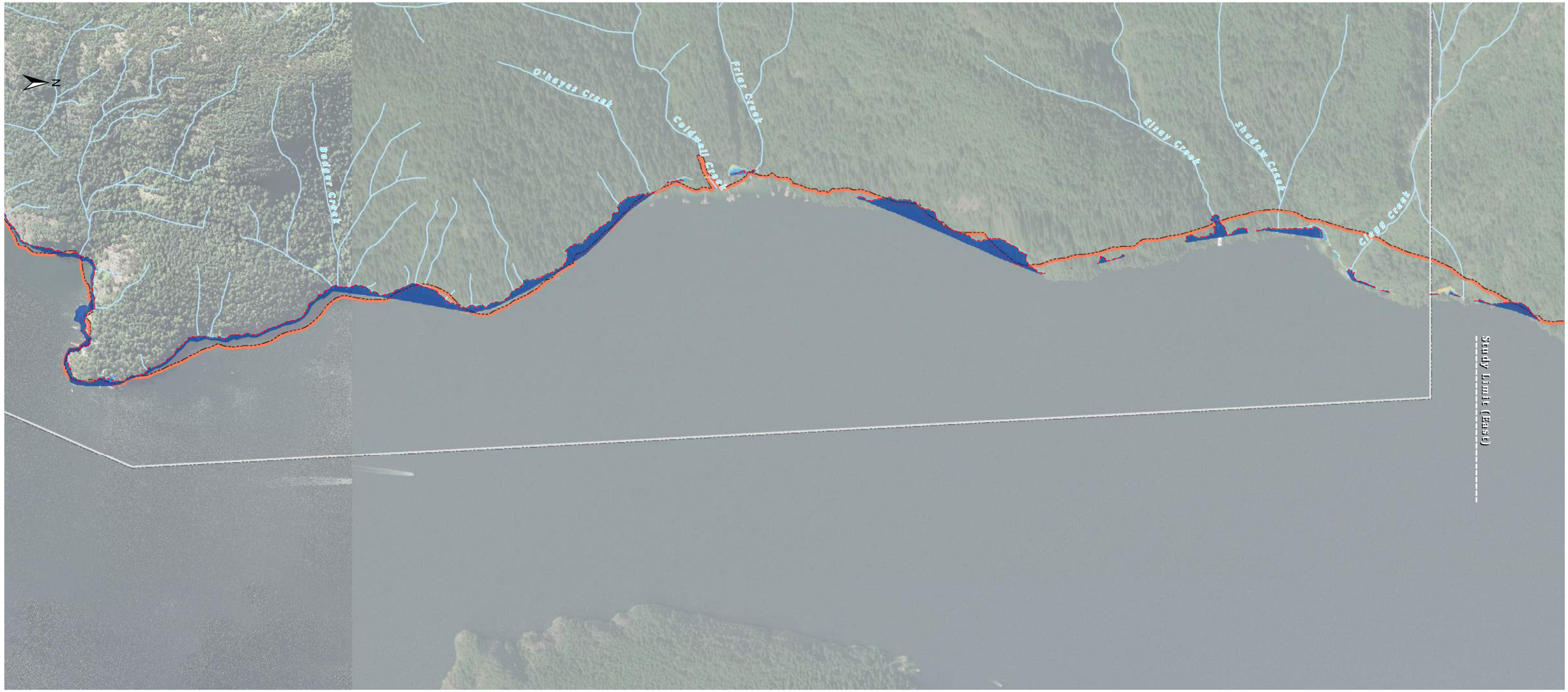
Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-12

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

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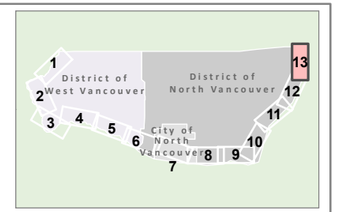
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Sea Level Rise Flood Inundation Map
Scenario E: 2 m Sea Level Rise plus 200-Year Return Period (0.5% Annual Exceedance Probability)

Figure E-13

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Appendix C

Flood Consequence Assessment

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Appendix C-1
Flood Consequence Assessment Methods and Limitations

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1. Flood Consequence Assessment Methods and Limitations

A flood consequence assessment was conducted to identify and estimate the location and magnitude of potential consequences from coastal stillwater flooding. This appendix provides details on these assessment approaches and data limitations. This appendix does not discuss the methods and limitations related to the specific economic impact assessment conducted for the Port of Vancouver's North Shore terminal operators, which is provided in Appendix E.

1.1 Objectives

The objective of the assessment is to estimate the potential impacts of sea level rise related coastal flooding to support the justification for adaptation planning/implementation and to support prioritization of adaptation planning initiatives.

The assessment focused on two coastal stillwater flood scenarios:

- Scenario C: 1 m sea level rise, 10% annual probability stillwater level (10-year return period); and
- Scenario E: 2 m sea level rise, 0.5% annual probability stillwater level (200-year return period).

For both scenarios, it was assumed that no new adaptation measures are in place (i.e., status quo) and that current day demographic/land use conditions (e.g., population, land use, etc.) remain the same. Accordingly, it is important to note that the goal of this assessment is not to provide the most accurate prediction of the losses that would incur from the flooding associated with these scenarios because there simply is not enough information available about how the population and assets will be distributed in the long-term future and there remains high uncertainty around the rate at which sea-level will rise. Instead, the overarching goal of this assessment is to provide information to support the prioritization of the adaptation planning efforts by showing how population and assets in different parts of the study area can be affected relative to other parts of the study area. Once those priority areas and concerns are identified, more detailed and localized assessment can be conducted to evaluate the relative performance of different management or adaptation options, where one may account for potential changes in local population or land use.

1.2 Variables and Methods

A total of 24 consequence variables (presented in Table 1) representing the following 6 sectors were assessed: social services, environment; culture and heritage; buildings and infrastructure; economy; and transportation.

Table 1: Consequence Assessment Variables (By Sector)

Sector	Consequence Variable	Unit
Social Services	1. Population displaced by inundation	Persons
	2. Vulnerable population (age <16 and >65, income <$20,000) exposed to inundation and/or power outage	Persons
	3. Healthcare facilities (hospital, clinic, pharmacy) exposed to inundation or power outage	Facilities
	4. Education/daycare facilities (public/private schools and daycares) exposed to inundation or power outage	Facilities

Sector	Consequence Variable	Unit
	5. Social services facilities (churches, meal providers, education centres, and community centres) exposed to inundation or power outage	Facilities
Environment	6. Hazardous waste generating/storage sites exposed to inundation	sites
	7. Contaminated sites exposed to inundation	sites
	8. Debris generated by building and contents damage	tonnes
	9. Parks exposed to inundation	area (ha)
Culture and Heritage	10. Registered archaeological and historic sites exposed to inundation	sites
	11. Heritage buildings exposed to inundation	buildings
Buildings and Infrastructure	12. Buildings exposed to inundation	buildings
	13. Emergency service (fire, police, ambulance) and municipal operations facilities exposed to inundation or power outage	facilities
	14. Squamish Nation-owned buildings exposed to inundation or power outage	buildings
	15. Wastewater and stormwater pump stations exposed to inundation	pump stations
	16. Port terminal operators exposed to inundation	sites
	17. Population impacted by power outage	persons
Economy	18. Building damage and contents replacement cost ($)	$
	19. Temporary non-port business disruption due to inundation or power outage	businesses
Transportation	20. Emergency routes exposed to inundation (km)	route length (km)
	21. Major routes exposed to inundation	route length (km)
	22. Bus routes exposed to inundation	route length (km)
	23. Bus stops exposed to inundation	bus stops
	24. Gas stations exposed to inundation or power outage	gas stations

The selection of these consequence variables is a result of a balance between the following goals for the assessment:

- Estimate primary direct impacts including general population impacts and building damage;
- Capture the potential exposure of various infrastructure and services that are crucial for the communities to cope with the flood impacts (e.g., access to health care facilities, electricity, disaster routes);
- Account for population that are more vulnerable to the flood impacts (e.g., elderly) and the services they rely upon (e.g., health care facilities); and
- Balance a consistent and reasonable level of data quality across the study region to provide meaningful high-level assessment.

The following 2 general methods were used to assess the consequences for each variable for each scenario:

1. GIS-based spatial exposure analysis; and
2. Model-based impact analysis.

These methods are described below.

1.3 GIS-based Spatial Exposure Analysis

GIS-based spatial exposure analysis involved comparing flood extent maps to maps of sector variables to determine the number of exposed elements for each variable. For some variables, power outage due to flood inundation was also considered and is described below. The analysis was conducted via ESRI ArcGIS software by overlaying the relevant flood extent information (including freeboard) from each scenario over the variable data and identifying (counting) the exposed elements under each variable.

Variables assessed for exposure to inundation and, inundation or power outage are listed in Table 2.

Table 2: Variables Assessed by Spatial Exposure Analysis Only

Inundation Exposure Only	Inundation and/or Power Outage Exposure
• Hazardous waste generating/storage sites • Contaminated sites • Parks • Archaeological sites (registered) • Historic sites • Heritage buildings • Wastewater and stormwater pump stations • Emergency routes • Major routes (roads) • Bus routes • Bus stops	• Vulnerable population • Healthcare facilities • Education/daycare facilities • Social service facilities • Emergency service and municipal operations facilities • Squamish Nation-owned buildings • Temporary non-port businesses • Gas stations • Port terminal operators

Most of the data for the exposure analysis was gathered from the project partners with direct coordination between KWL and the relevant GIS department staff at each partner organization. Some of the data for the exposure analysis was derived from the Canadian Census (2011) via the HAZUS software package in conjunction with the quantitative impact analysis methods; this is discussed further in the next sub-section.

Additional data was collected from the provincial governments (DataBC, Ministry of Environment, and Ministry of Forests, Lands, and Natural Resource Operations and Rural Development, BC Hydro, and Translink. Social service facility data was gathered from the North Shore Community Flood Asset Map (North Shore Table Matters Network).

Power Outage Exposure

Power outages were assessed at the dissemination block (DB) spatial scale; DB mapping is available from the Canadian Census via Statistics Canada. Estimating power outages at the DB scale shows the general spatial variability without delving into a household-by-household analysis which would not be appropriate for this high-level assessment.

KWL staff engaged with BC Hydro staff to develop the following conditions for estimating when a coastal flood will trigger a power outage:

- Power within a DB is proactively shut down by BC Hydro for safety purposes when more than 50% of the DB is inundated; and
- Power within a DB is assumed to disrupted when the substation servicing the DB is exposed to more than 1 m of flood depth, which would cause damage that would result in prolonged power outages. For this condition, KWL staff engaged with BC Hydro to acquire substation network maps for the North Shore. Detailed network maps are not reproduced in this report due to confidentiality reasons.

The power outage analysis does not consider other potential causes of outages that may be related to coastal floods, including extreme wind events which may result in trees falling onto power lines. Additionally, the flooding of individual at-grade transformers and kiosks was not assessed; however, the 50% inundation of DB condition stated above may account for this. The power outage analysis should be considered as a high-level analysis which likely represents a lower-bound estimate of actual power outage potential in a major coastal flood event.

1.4 Model-Based Impact Analysis

Computer models and code packages were used to estimate certain population, economic, and environmental consequence variables that involve calculations that go beyond a simple exposure analysis.

The following consequence variables were assessed using computer models and code packages:

- Cost of building damage and contents (HAZUS model);
- Building and content damage debris generation (HAZUS model);
- General population displacement (HAZUS model); and
- Business disruption (Chang et al., 2008 model).

HAZUS

HAZUS is a model commonly used for flood consequence assessments. It was originally developed for use in the United States by the Federal Emergency Management Agency (FEMA) as a standardized method for assessing hazard damage losses in a GIS platform (the model operates as an add-in to ArcGIS software). HAZUS has been adapted for Canada by Natural Resources Canada (NRCan) [1]. Version HAZUS-MH 2.1 was used for this assessment; it is understood that this represents the most recent (2016) version of the model.

Building Damage Data, Methods, and Economic Adjustment Factor

HAZUS uses census building data and simplified algorithms to estimate expected damage from multiple hazards at the DB scale. Although HAZUS can assess different kinds of hazards, the coastal flood hazard module is the only module that is relevant for this assessment. Each partner organization, except the Port, was modelled as separate regions within HAZUS. However, since the jurisdiction boundaries of the Port do not align with the DBs and their areas overlaps with DBs of DNV, CNV, and SN at various proportions, the HAZUS results for the Port were extracted such that it is proportional to the area the Port area overlaps with the DBs. This also means that the result for the Port may include some damage or losses that actually belongs to the overlapping municipality or Indian Reserve, and vice versa.

While HAZUS has a comprehensive set of stage-damage functions (SDFs) which are used for assessing damage, they were developed based on data from the 1980s and from communities in the mid-western and southern US [2] where building stock can be quite different to those in highly urbanized coastal cities such as those in the North Shore. Therefore, where applicable, the default SDFs in HAZUS were replaced by those of the Multi-colored Manual (MCM) that was based on more recent data, originated in 2005 and revised in 2013 and 2018[3], and from more urbanized communities in the United Kingdom (UK).

Not all the HAZUS default stage-damage functions were replaced with MCM stage-damage functions as some building types in HAZUS are not represented in the MCM data. For example, there is no SDFs for high-rise residential buildings with 50 or more units in the MCM SDFs. Since the MCM SDFs are absolute damage functions rather than relative damage functions, the estimated damage is measured in terms of British Pounds instead of percentage of the building damaged. Therefore, the MCM SDFs were modified to relative terms (i.e., percentage of damage) by dividing the estimated damage cost at each flood depth by the maximum damage cost in the corresponding SDF. However, since the maximum flood depth in the MCM SDFs is 3 m (UK standard), this conversion method may result in the overestimation of building damage in high-rise buildings. The final SDFs used in this study are summarized in Table 4, provided at the end of this appendix.

[1] Nastev, M., & Todorov, N. (2013). HAZUS: A standardized methodology for flood risk assessment in Canada. Canadian Water Resources Journal, 38(3), 223-231.

[2] Federal Emergency Management Agency. (2009). Multi-hazard Loss Estimation Methodology, Flood Model, HAZUS®-MH Technical Manual

[3] Penning-Rowsell, E., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2018) Handbook for economic appraisal – Flood and Coastal Erosion Risk Management. Multi-coloured Manual. Flood Hazard Research Centre, Middlesex University.

Within each DB, census building data is grouped by structure type, occupancy type, and first-floor elevation. Buildings within each group are assumed to be evenly spaced throughout the DB regardless of their actual location. This simplification means that the model cannot predict damages to specific properties.

HAZUS calculates the percentage of each DB flooded to a given depth. Because buildings are assumed to be evenly spaced throughout the DB, the model applies the flood depth to the same percentage of the building inventory. For example, if 25 per cent of the DB area is inundated to a depth of 1 m, HAZUS assumes 25 per cent of the buildings in each building group are also inundated to a depth of 1 m. Inundation depth is converted to economic damages (i.e., repair and replacement costs) using FEMA depth-damage relationships specific to each type of building.

HAZUS damage estimates are based on 2011 census building stock and are calculated using US national average replacement costs in 2006 US dollars. Damage calculations need to be converted to Canadian dollars, localized to the North Shore, and inflated to present day. Adjustments were made for location, inflation, and currency. Adjustments reflect work conducted by KWL for the District of Squamish's Integrated Flood Hazard Management Plan.

Adjustments for location and inflation were obtained from construction cost indices published by RS Means. US national averages were converted to Vancouver, BC metrics then brought forward from 2006 to 2018 dollars. The adjustment from US national average to Vancouver local data is 1.10. The Vancouver local adjustment from 2006 to 2018 dollars is 1.32.

US currency was converted to Canadian currency using a factor of 1.25. This factor is within four percent of the current exchange rate as of October 2018 (approximately 1.29), the 5-year average exchange rate (1.26), the 20-year average (1.24), and the 30-year average (1.26). It is conservative relative to the 10-year average exchange rate (1.15).

Economic valuation adjustments are summarized in Table 3. A final adjustment factor of 1.81 was applied.

Table 3: HAZUS-MH Flood Damage Adjustment Factors

Description	Source	Adjustment Factor
US Average to Vancouver (2006)	RS Means	1.10
Vancouver Local Inflation (2006-2018)	RS Means	1.32
Currency Conversion (USD to CAD)	Exchange Records	1.25
Total Adjustment for Location, Date and Currency		1.81

While an inflation adjustment factor was incorporated, it should be noted that the building damage estimates may be considered as a lower estimate since it is based on the building stock represented in the 2011 Canadian Census. Additional building stock associated with the increased population in the study region is not accounted for.

Debris Generation

At each DB, HAZUS estimates the amount of debris generated from building damage (in tonnes), which is made up of three building components: building finishes, structural components, and foundation materials. Based on the flood depth distribution throughout the DB and the square footage of a given building type, HAZUS determines how much of that building type's floor area are exposed to different flood depths. Then, the total amount of debris generated is determined based on the typical amount of debris generated from the three components of a given building type.

Population Displacement

The population displaced at a given dissemination block is a function of the total population of the dissemination block and the percentage of the block's area that is inundated, as determined by the flood extent mapping (including freeboard) for each scenario. This assumes that population is evenly spread throughout the block.

Business Disruption Model

A large portion of economic losses after a disaster is attributable to business losses associated with temporary closure. In this study, business disruption is assessed in terms of the number of businesses expected to experience temporary closure due to power outage and/or direct building damage induced by the flooding. The business disruption model developed by Chang and colleagues[4] is adapted and used to assess the business disruption in each flood scenario.

Although this model was developed based on loss data from earthquake events rather than flooding, it is designed to be adapted for other hazards because the model inputs (i.e., direct building damage, lifeline disruptions) can be estimated for specific hazard events.

This business disruption model estimates whether a business of a given sector would experience temporary closure due to the overall level of disruptiveness from power outage, water outage, and building damage. Since there is insufficient evidence to suggest how water supply can be affected in the Lower Mainland during an overland flood event, the model is adapted to only account for disruptions due to power outage and building damage.

The level at which a business is disrupted from a given level of disruption (from power outage or building damage) is also based on the business' sector, which can be:

- Retail and wholesale;
- Construction and transportation;
- Financial and real estate;
- Service industry;
- Manufacturing; and
- Agriculture.

[4] Chang, S. E., Pasion, C., Tatebe, K., & Ahmad, R. (2008). Linking Lifeline Infrastructure Performance and Community Disaster Resilience: Models and Multi-Stakeholder Processes Multidisciplinary Centre for Earthquake Engineering Research (MCEER) Technical Report, (07-004), 9-32.

For example, the model uses the probability distribution of construction sector businesses (derived from empirical data of past disasters) that closed temporarily to estimate whether a given construction business would close temporarily given a certain level of building damage and power outage associated with the given hazard event. A Monte Carlo approach is also used to determine the most likely operating status of the business.

1.5 Appropriate Level of Interpretation for Results

There are potential limitations in the interpretation of assessment results due to data quality, availability, and the limited scope of the assessment which prevented the KWL team from investigation of data quality issues. Some data quality issues were observed by the technical steering committee and were addressed where possible with additional data and updating of maps. However, it's likely that there are other data issues given the high-level and coarse methods and the large study area.

The appropriate level of interpretation is as follows:

- Results should be interpreted in a relative sense and not as absolute values.
- Consequence assessments are complex and practitioners find what they look for. This means that the results will emphasize the variables that were included in the study. It is important to consider that there are other variables that will also show consequences. No data does not necessarily mean no consequence.

In summary, it should be emphasized that the goal of this assessment is not to provide the most accurate prediction of the losses that would incur from the flooding associated with these scenarios. This would not be possible given the data availability and quality, and the uncertainty of sea level rise and future development. Instead, the overarching goal of this assessment is to provide information to support prioritization of the adaptation planning efforts by showing how population and assets at different parts of the study regions can be affected relative to other parts of the study region. Once those priority areas and concerns are identified, more detailed and localized assessment can be conducted to evaluate the relative performance of different management or adaptation options, where one may account for potential changes in local population or land use.

Table 4: HAZUS Stage Damage Curve Summary Table

HAZUS Building Type	Description	HAZUS Default SDF #	Source Used	MCM Building Type
R11N	one floor, no basement, Structure, A-Zone	105	HAZUS	
R11B	one floor, w/ basement, Structure, A-Zone	106	MCM	Detached
R12N	two floors, no basement, Structure, A-Zone	107	MCM	Detached
R12B	two floors, w/ basement, Structure, A-Zone	108	MCM	Detached

HAZUS Building Type	Description	HAZUS Default SDF #	Source Used	MCM Building Type
R13N	three or more floors, no basement, Structure, A-Zone	109	MCM	Detached
R13B	three or more floors, w/ basement, Structure, A-Zone	110	MCM	Detached
R1SN	split level, no basement, Structure, A-Zone	111	MCM	Detached
R1SB	split level, w/ basement, Structure, A-Zone	112	MCM	Detached
RES2	Mobile	[189] FIA - Mobile Home, structure, A-Zone	HAZUS	
RES3A	Duplex	[204] USACE - Chicago - Apartment unit grade, Structure	MCM	Semi-detached
RES3B	Units 3-4	[204] USACE - Chicago - Apartment unit grade, Structure	MCM	Semi-detached
RES3C	Units 5-9	[204] USACE - Chicago - Apartment unit grade, Structure	MCM	Terrace
RES3D	Units 10-19	[204] USACE - Chicago - Apartment unit grade, Structure	MCM	Flat
RES3E	Units 20-49	[204] USACE - Chicago - Apartment unit grade, Structure	MCM	Flat
RES3F	Units 50plus	[204] USACE - Chicago - Apartment unit grade, Structure	HAZUS	
RES4	Units 10-22	[209] USACE - Galveston Average hotel and motel, structure	HAZUS	
RES5	Institutional Dorms	[214] USACE - Galveston Nursing Home, structure	HAZUS	

HAZUS Building Type	Description	HAZUS Default SDF #	Source Used	MCM Building Type
RES6	Nursing Home	[214] USACE - Galveston Nursing Home, structure	HAZUS	
COM1	Retail trade	[217] USACE Galveston, Average Retail, Structure	MCM	Retail
COM2	Wholesale trade	[341] USACE Galveston Average Wholesale, Structure	MCM	Warehouses
COM3	Personal & Repair services	[375] USACE - Average Personal & Repair Services, Structure	HAZUS	
COM4	Business / Prof / Tech Services	[431] USACE - Galveston, Average Prof/Tech Services, Structure	MCM	Office
COM5	Depository Institution	[467] USACE - Bank, Structure	HAZUS	
COM6	Hospitals	[474] USACE - Galveston - Hospital, Structure	HAZUS	
COM7	Medical Clinic / Offices	[475] USACE - Galveston - Average Medical Office, Structure	MCM	Office
COM8	Entertainment / Recreation	[493] USACE - Galveston - Average Entertainment/Recreation, Structure	MCM	Leisure
COM9	Theatres	[534] USACE - Galveston - Indoor theater, Structure	HAZUS	
COM10	Parking	[543] USACE - Galveston - Garage, Structure	MCM	Car park
IND1	Heavy	[545] USACE - Galveston - Average heavy industrial, Structure	HAZUS	
IND2	Light	[559] USACE - Galveston - Average light industrial, Structure	MCM	Industry

HAZUS Building Type	Description	HAZUS Default SDF #	Source Used	MCM Building Type
IND3	Food / Drugs / Chemicals	[575] USACE - Galveston - Average Food/Drug/Chem, Structure	HAZUS	
IND4	Metal / Mineral processing	[586] USACE - Galveston - Average Metals/Minerals processing, Structure	HAZUS	
IND5	High Technology	[591] USACE - Galveston - Average High Tech, Structure	HAZUS	
IND6	Construction	[592] USACE - Galveston - Average Construction, Structure	DamageScanner	Construction site
AGR1	Agriculture	[616] USACE - Galveston - Average Agriculture, Structure	DamageScanner	Agriculture
REL1	Church / Membership Organizations	[624] USACE - Galveston - Church, Structure	MCM	Public buildings
GOV1	General Services	[631] USACE - Galveston - Average Government Services, Structure	MCM	Public building
GOV2	Emergency Response	[640] USACE - Galveston - Average emergency response, Structure	HAZUS	
EDU1	Schools / Library	[643] USACE - Galveston - Average School, Structure	HAZUS	
EDU2	Colleges / University	[652] USACE - Galveston - Average College/University, Structure	HAZUS	

Statement of Limitations

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Revision History

Revision #	Date	Status	Revision	Author
0	2021-02-28	Final	Addressed December 2019 comments	ATAL

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Appendix C-2
Flood Consequence Assessment Results: Tabular

						Scenario C (1 m SLR, 10% AEP Event) Results											
Sector	**Variable #**	**Variable Name**	**Sub-variables**	**Unit**	**Data Source**	**CNV**		**DNV**		**DWV**		**SN**		**Port**		**North Shore Total**	
						Absolute Value	**Relative Value**	**Absolute Value**	**Relative Value**	**Absolute Value**	**Relative Value**	**Absolute Value**	**Relative Value**	**Absolute Value**	**Relative Value**	**Absolute Value**	**Relative Value**
Social Services	1	**Population displaced by inundation**		People	Hazus (Census 2011)	**148**	0.3%	**431**	0.5%	**608**	1.4%	**157**	4.6%			**1,344**	0.8%
	2	**Vulnerable population exposed to inundation / power outage**		People		**59**	0.4%	**147**	0.5%	**269**	1.5%	**64**	4.8%			**539**	0.8%
	3	**Healthcare facilities exposed to inundation / power outage**	Clinic	Facility	DataBC	-	0.0%	-	0.0%	-	0.0%	-	0.0%			-	0.0%
			Pharmacy	Facility		-	0.0%	-		-	0.0%	-	0.0%			-	0.0%
			Hospital	Facility		-	0.0%	-		-		-				-	0.0%
			Total	Facility		-	-	-	-	-		-				-	0.0%
	4	**Schools and daycares exposed to inundation / power outage**	Schools	Facility		**1**	14.3%	-	0.0%	-	0.0%	-	0.0%			**1**	1.6%
			Daycares	Facility		**3**	3.7%	**1**	0.6%	**3**	7.9%	-	0.0%			**7**	2.4%
			Total	Facility		**4**	**0**	**1**	0.6%	**3**	7.9%	-	0.0%	-	0.0%	**8**	2.3%
	5	**Social services facilities exposed to inundation / power outage**	Count	Facility	North Shore Community Food Asset Map	-	0.0%	-	0.0%	-	0.0%	**1**	11.1%			**1**	0.9%
Environment	6	**Park areas exposed to inundation**		Hectare	DataBC	**6**	3.4%	**32**	0.2%	**40**	1.5%	**4**	21.7%			**81**	0.5%
	7	**Debris generated from building damage**		Tonnes	Hazus (Census 2011)	**3,845**		**6,387**		**2,488**		**2,523**		**3,666**		**18,908**	
	8	**Hazardous waste storage and generating sites exposed to inundation**	Storage sites	Registered Waste Unit	DataBC	**1**	100.0%	-		-		-		**1**	50.0%	**2**	66.7%
			Generating sites	Registered Waste Unit	BC MoE	**4**	3.7%	**28**	28.0%	**4**	20.0%	**2**	14.3%	**33**	67.3%	**71**	24.3%
			Total	Registered Waste Unit		**5**	4.5%	**28**	28.0%	**4**	20.0%	**2**	14.3%	**34**	66.7%	**73**	24.7%
	9	**Contaminated sites exposed to inundation**	Federal	Registered Site	Federal Contaminated Sites Inventory	-	0.0%	**1**	16.7%	-	0.0%	**8**	32.0%	-		**9**	22.5%
			Provincial	Registered Site	DataBC	**9**	4.7%	**17**	4.3%	**7**	1.4%	-	0.0%	**1**	8.3%	**34**	3.1%
			Total	Registered Site		**9**	4.7%	**18**	4.5%	**7**	1.4%	**8**	29.6%	**1**	8.3%	**43**	3.8%
Culture & Heritage	10	**Archaeological and historic sites exposed to inundation**	Archaeological	Registered Site	BC MFLNRORD	**2**	100.0%	**9**	52.9%	**7**	53.8%	**3**	75.0%			**21**	58.3%
			Historic	Registered Site		**4**	3.4%	**4**	2.9%	**10**	25.6%	**1**	100.0%			**19**	6.4%
	11	**Heritage structures exposed to inundation**		Registered Structure	CNV and DNV (no data from DWV, SN, Port)	**2**	0.7%	**4**	1.6%	-		-				**6**	1.1%
Buildings & Infrastructure	12	**Population exposed by prolonged power outage due to inundation**		People	BC Hydro, Hazus (Census 2011)	**63**	0.1%	**114**	0.1%	**185**	0.4%	**71**	2.1%			**433**	0.2%
	13	**Direct building damage count**	All	Buildings		**17**	0.2%	**58**	0.3%	**73**	0.6%	**67**	8.1%	**4**	5.7%	**219**	0.5%
			Residential	Buildings		**5**	0.1%	**27**	0.1%	**68**	0.6%	**14**	2.4%	**1**	21.7%	**115**	0.3%
			Public/Governmental	Buildings		-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
			Commercial	Buildings		**12**	1.1%	**25**	1.4%	**5**	0.4%	**51**	24.2%	**3**	5.9%	**96**	2.2%
			Industrial	Buildings		-	0.0%	**3**	1.3%	-	0.0%	**2**	13.3%	-	0.0%	**5**	1.2%
			Agricultural	Buildings		-	0.0%	-	0.0%	-		-		-		-	0.0%
	14	**Squamish Nation operated buildings exposed to inundation / power outage**		Facility	SN							**6**	27.3%			**6**	26.1%
	15	**Emergency service facilities exposed to inundation / power outage**	Fire	Facility	DataBC	-	0.0%	-	0.0%	-	0.0%	-				-	0.0%
			Police	Facility		-	0.0%	-	0.0%	-	0.0%	-	0.0%			-	0.0%
			Ambulance	Facility		-	0.0%	-	0.0%	-	0.0%	-				-	0.0%
			Operation centres	Facility	DWV, DNV, CNV, SN	**1**	100.0%	-	0.0%	-	0.0%	**1**	100.0%			**2**	22.2%
			Total	Facility		**1**	20.0%	-	0.0%	-	0.0%	**1**	50.0%	-		**2**	7.1%
	16	**Wastewater and stormwater pump stations exposed to inundation**	Wastewater	Facility		**6**	60.0%	**14**	38.9%	**15**	50.0%	**1**	100.0%			**36**	46.8%
			Stormwater	Facility		-	0.0%	**1**	50.0%	-		-				**1**	33.3%
			Total	Facility		**6**	54.5%	**15**	39.5%	**15**	50.0%	**1**	100.0%	-		**37**	46.3%
	17	**Port terminal operators exposed to inundation / power outage**	Total	Facility	Port									**5**	45.5%	**5**	45.5%
Economy	18	**Business disruption (number of business closures)**	All Business Types	Business	DWV, DNV, CNV business license data	**118**	3.7%	**196**	4.6%	**95**	1.9%	**59**	9.7%			**468**	3.6%
			Finance and Real Estate	Business		**3**	0.5%	**2**	0.7%	**7**	0.3%	**6**	9.5%			**18**	0.6%
			Health Services	Business		**3**	0.7%	-	0.0%	**15**	5.6%	**1**	4.5%			**19**	2.2%
			Mining, Construction, Transportation, and Utilities	Business		**27**	4.9%	**40**	4.5%	**4**	0.7%	**1**	2.5%			**72**	3.6%
			Manufacturing	Business		**12**	13.0%	**25**	18.5%	-		-				**37**	16.3%
			Service Industry	Business		**51**	4.9%	**89**	4.0%	**41**	2.5%	**23**	9.1%			**204**	4.0%
			Wholesale and Retail	Business		**22**	4.8%	**40**	7.6%	**28**	7.7%	**28**	12.2%			**118**	7.5%
			Others	Business		-		-	0.0%	-		-				-	0.0%
	19	**Building damage replacement cost ($thousand)**	All	$ thousands	Hazus (Census 2011)	**242,924**	2.0%	**258,834**	1.6%	**70,860**	0.8%	**151,557**	12.6%	**190,642**	10.2%	**914,817**	2.4%
			Residential	$ thousands		**9,134**	0.1%	**13,821**	0.1%	**25,002**	0.4%	**4,802**	1.0%	**519**	18.0%	**53,277**	0.2%
			Public/Governmental	$ thousands		**881**	0.3%	**2,579**	0.5%	**954**	0.4%	**4,936**	9.6%	**1,476**	17.6%	**10,826**	1.0%
			Commercial	$ thousands		**214,556**	4.6%	**158,163**	4.7%	**42,135**	1.8%	**128,539**	20.3%	**175,313**	9.9%	**718,706**	6.6%
			Industrial	$ thousands		**18,353**	6.3%	**81,445**	13.7%	**2,769**	2.0%	**13,280**	21.1%	**13,334**	15.1%	**129,182**	11.8%
			Agricultural	$ thousands		-	0.0%	**2,827**	23.1%	-		-		-		**2,827**	22.9%
Transportation	20	**Emergency routes exposed to inundation**		Segments	DataBC											**26**	3.2%
				Kilometers												**2**	
	21	**Major routes exposed to inundation**		Segments												**360**	4.4%
				Kilometers												**36**	
	22	**Number of bus routes exposed to inundation**		Count	Translink											**30**	13.2%
	23	**Transportation points (bus stops) exposed to inundation**		Bus stops	Translink											**21**	2.3%
	24	**Gas stations exposed to inundation / power outage**		Count	DWV, DNV, CNV, SN	-	0.0%	**2**	15.4%	**4**	25.0%	**2**	66.7%	-		**8**	21.1%

Notes:
1. Spatial data has not been ground-truthed and totals may include duplicates.
2. Refer to Appendix B for discussion of methods and limitations.
3. For Port jurisdiction results on variables aggregated at the census dissemination block level (e.g. building damage count and cost, debris generated), there are double counts with other overlapping municipalities due to a lack of data at a finer scale.

				Scenario E (2 m SLR, 0.5% AEP Event) Results											
Sector	**Variable #**	**Variable Name**	**Sub-variables**	**CNV**		**DNV**		**DWV**		**SN**		**Port**		**North Shore Totals**	
				Absolute Value	**Relative Value**	**Absolute Value**	**Relative Value**	**Absolute Value**	**Relative Value**	**Absolute Value**	**Relative Value**	**Absolute Value**	**Relative Value**	**Absolute Value**	**Relative Value**
Social Services	1	**Population displaced by inundation**		**220**	0.5%	**892**	1.1%	**1,103**	2.6%	**559**	16.5%			**2,774**	1.6%
	2	**Vulnerable population exposed to inundation / power outage**		**263**	1.6%	**2,458**	8.6%	**8,704**	49.1%	**1,198**	89.2%			**12,623**	19.8%
	3	**Healthcare facilities exposed to inundation / power outage**	Clinic	-	0.0%	**1**	50.0%	**3**	100.0%	**2**	50.0%			**6**	50.0%
			Pharmacy	-	0.0%	-		-	0.0%	**3**	100.0%			**3**	37.5%
			Hospital	-	0.0%	-		-		-				-	0.0%
			Total	-		**1**	50.0%	**3**	75.0%	**5**	71.4%			**9**	42.9%
	4	**Schools and daycares exposed to inundation / power outage**	Schools	**1**	14.3%	**1**	3.1%	**12**	57.1%	**1**	100.0%			**15**	24.6%
			Daycares	**5**	6.2%	**26**	15.7%	**28**	73.7%	**1**	50.0%			**60**	20.9%
			Total	**6**	20.5%	**27**	18.8%	**40**	130.8%	**2**	66.7%	-	0.0%	**75**	21.6%
	5	**Social services facilities exposed to inundation / power outage**	Count	-	0.0%	**3**	7.0%	**23**	88.5%	**5**	55.6%			**31**	26.7%
Environment	6	**Park areas exposed to inundation**		**9**	5.1%	**49**	0.4%	**44**	1.6%	**4**	21.7%			**106**	0.7%
	7	**Debris generated from building damage**		**11,354**		**11,639**		**7,513**		**8,372**		**13,005**		**51,883**	
	8	**Hazardous waste storage and generating sites exposed to inundation**	Storage sites	**1**	100.0%	-		-		-		**2**	100.0%	**3**	100.0%
			Generating sites	**16**	14.7%	**63**	63.0%	**4**	20.0%	**11**	78.6%	**38**	77.6%	**132**	45.2%
			Total	**17**	15.5%	**63**	63.0%	**4**	20.0%	**11**	78.6%	**40**	78.4%	**135**	45.8%
	9	**Contaminated sites exposed to inundation**	Federal	-	0.0%	**1**	16.7%	**4**	50.0%	**8**	32.0%	-		**13**	32.5%
			Provincial	**11**	5.8%	**39**	9.9%	**18**	3.7%	**3**	150.0%	**2**	16.7%	**73**	6.7%
			Total	**11**	5.8%	**40**	10.0%	**22**	4.4%	**11**	40.7%	**2**	16.7%	**86**	7.6%
Culture & Heritage	10	**Archaeological and historic sites exposed to inundation**	Archaeological	**1**	50.0%	**11**	64.7%	**8**	61.5%	**3**	75.0%			**23**	63.9%
			Historic	**2**	1.7%	**4**	2.9%	**6**	15.4%	**1**	100.0%			**13**	4.4%
	11	**Heritage structures exposed to inundation**		**6**	2.0%	**4**	1.6%	-		-				**10**	1.8%
Buildings & Infrastructure	12	**Population exposed by prolonged power outage due to inundation**		**793**	1.6%	**6,829**	8.1%	**20,875**	48.9%	**2,771**	82.0%			**31,268**	17.5%
	13	**Direct building damage count**	All	**38**	0.5%	**198**	0.9%	**170**	1.4%	**162**	19.6%	**26**	37.3%	**594**	1.4%
			Residential	**8**	0.1%	**112**	0.6%	**147**	1.4%	**59**	10.1%	**2**	43.4%	**328**	0.9%
			Public/Governmental	-	0.0%	-	0.0%	-	0.0%	**1**	6.7%	-	0.0%	**1**	0.5%
			Commercial	**30**	2.7%	**77**	4.2%	**23**	2.0%	**100**	47.4%	**21**	41.0%	**251**	5.8%
			Industrial	-	0.0%	**9**	3.8%	-	0.0%	**2**	13.3%	**3**	23.2%	**14**	3.3%
			Agricultural	-	0.0%	-	0.0%	-		-		-		-	0.0%
	14	**Squamish Nation operated buildings exposed to inundation / power outage**								**15**	68.2%			**15**	65.2%
	15	**Emergency service facilities exposed to inundation / power outage**	Fire	-	0.0%	**1**	16.7%	**1**	25.0%	-				**2**	18.2%
			Police	-	0.0%	-	0.0%	**1**	100.0%	-	0.0%			**1**	16.7%
			Ambulance	-	0.0%	-		**1**	100.0%	-				**1**	50.0%
			Operation centres	**1**	100.0%	-	0.0%	-	0.0%	**1**	100.0%			**2**	22.2%
			Total	**1**	20.0%	**1**	7.1%	**3**	42.9%	**1**	50.0%	-		**6**	21.4%
	16	**Wastewater and stormwater pump stations exposed to inundation**	Wastewater	**8**	80.0%	**18**	50.0%	**24**	80.0%	**1**	100.0%			**51**	66.2%
			Stormwater	-	0.0%	**2**	100.0%	-		-				**2**	66.7%
			Total	**8**	72.7%	**20**	52.6%	**24**	80.0%	**1**	100.0%	-		**53**	66.3%
	17	**Port terminal operators exposed to inundation / power outage**	Total									**11**	100.0%	**11**	100.0%
Economy	18	**Business disruption (number of business closures)**	All Business Types	**386**	12.2%	**381**	9.0%	**862**	17.4%	**273**	45.0%			**1,902**	14.7%
			Finance and Real Estate	**24**	4.1%	**8**	2.6%	**20**	0.9%	**10**	15.9%			**62**	2.0%
			Health Services	**27**	6.1%	**3**	2.7%	**110**	40.9%	**11**	50.0%			**151**	17.8%
			Mining, Construction, Transportation, and Utilities	**71**	12.9%	**76**	8.6%	**98**	17.9%	**12**	30.0%			**257**	12.7%
			Manufacturing	**32**	34.8%	**33**	24.4%	-	#DIV/0!	-				**65**	28.6%
			Service Industry	**137**	13.0%	**184**	8.2%	**498**		**122**	48.4%			**941**	18.2%
			Wholesale and Retail	**95**	20.8%	**77**	14.6%	**136**	37.2%	**118**	51.5%			**426**	27.0%
			Others	-		-	0.0%	-		-				-	0.0%
	19	**Building damage replacement cost ($thousand)**	All	**780,674**	6.5%	**583,172**	3.6%	**191,779**	2.2%	**320,321**	26.6%	**834,580**	44.8%	**2,710,526**	7.2%
			Residential	**16,364**	0.2%	**42,658**	0.4%	**54,354**	0.9%	**28,366**	6.2%	**1,056**	36.6%	**142,798**	0.6%
			Public/Governmental	**1,578**	0.5%	**7,190**	1.4%	**3,144**	1.2%	**10,833**	21.0%	**3,420**	40.7%	**26,165**	2.3%
			Commercial	**728,264**	15.8%	**354,514**	10.6%	**120,883**	5.1%	**253,261**	40.1%	**788,766**	44.7%	**2,245,687**	20.5%
			Industrial	**34,469**	11.8%	**175,097**	29.4%	**13,398**	9.5%	**27,861**	44.2%	**41,338**	46.8%	**292,163**	26.8%
			Agricultural	-	0.0%	**3,712**	30.3%	-		-		-		**3,712**	30.0%
Transportation	20	**Emergency routes exposed to inundation**												**54**	6.7%
														5	
	21	**Major routes exposed to inundation**												**581**	7.1%
														57	
	22	**Number of bus routes exposed to inundation**												**31**	13.7%
	23	**Transportation points (bus stops) exposed to inundation**												**36**	4.0%
	24	**Gas stations exposed to inundation / power outage**		-	0.0%	**3**	23.1%	**7**	43.8%	**2**	66.7%	-		**12**	31.6%

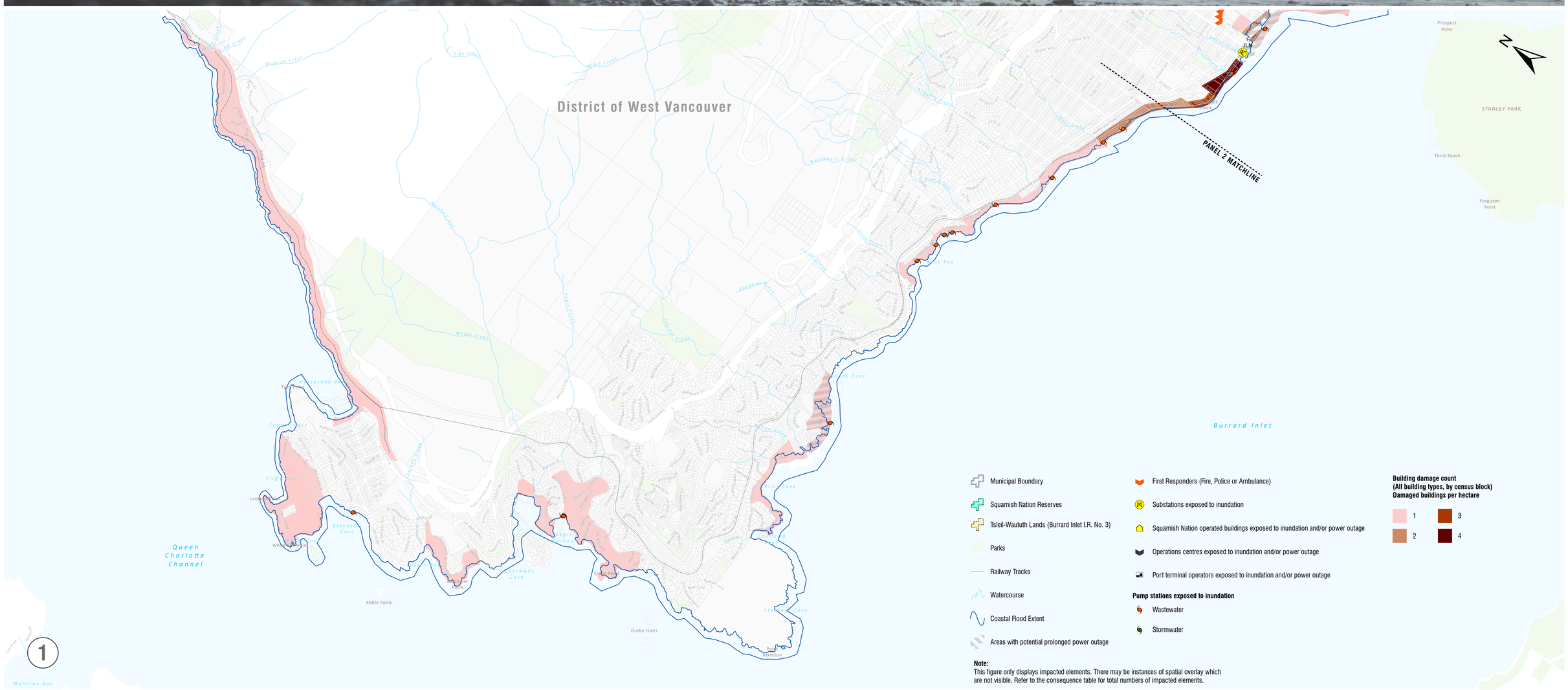
Notes:
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2. Refer to Appendix B for discussion of methods and limitations.
3. For Port jurisdiction results on variables aggregated at the census dissemination block level (e.g. building damage count and cost, debris generated), there

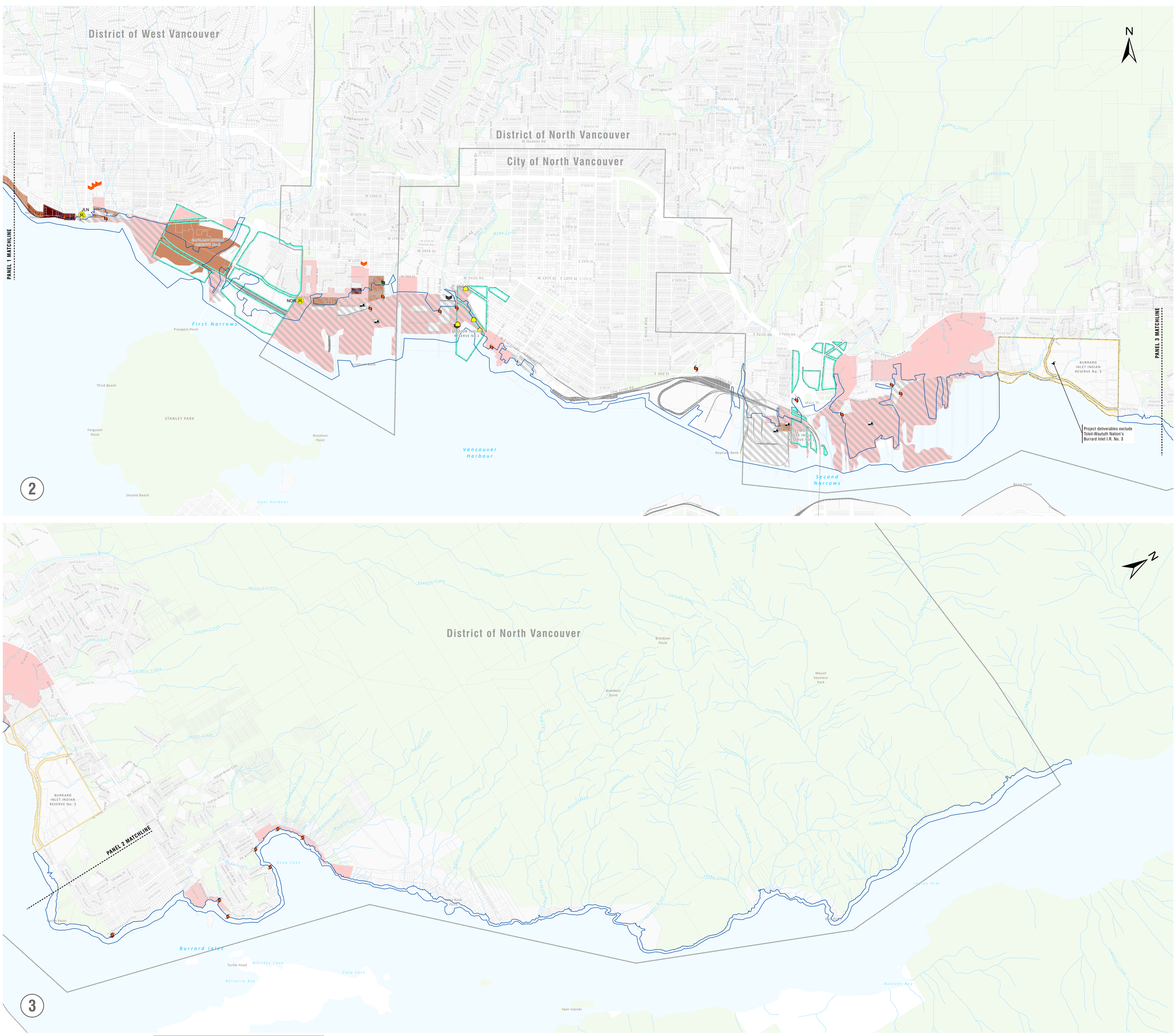
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Appendix C-3
Flood Consequence Assessment Results: Spatial Figures

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy





Municipal Boundary

Squamish Nation Reserves

Tsleil-Waututh Lands (Burrard Inlet I.R. No. 3)

Parks

Railway Tracks

Watercourse

Coastal Flood Extent

Areas with potential prolonged power outage

First Responders (Fire, Police or Ambulance)

Substations exposed to inundation

Squamish Nation operated buildings exposed to inundation and/or power outage

Operations centres exposed to inundation and/or power outage

Port terminal operators exposed to inundation and/or power outage

Pump stations exposed to inundation

Wastewater

Stormwater

Building damage count
(All building types, by census block)
Damaged buildings per hectare

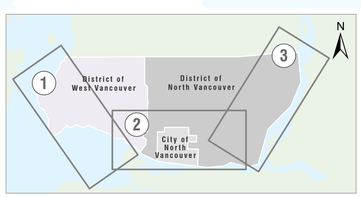
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SCENARIO C

(1 m Sea Level Rise 10-Year Return Period Flood)

Building and Infrastructure Sector Exposure

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy



District of West Vancouver

PANEL 2 MATCHLINE

Lower Caulfeild Heritage Conservation Area

Queen Charlotte Channel

Burrard Inlet

Municipal Boundary
Squamish Nation Reserves
Tsleil-Waututh Lands (Burrard Inlet I.R. No. 3)
Parks
Railway Tracks
Watercourse
Coastal Flood Extent
Heritage buildings exposed to inundation (DNV and CNV Only)
Protected historic site exposed to inundation

Note:
This figure only displays impacted elements. There may be instances of spatial overlay which are not visible. Refer to the consequence table for total numbers of impacted elements.

1

District of West Vancouver

District of North Vancouver

City of North Vancouver

PANEL 1 MATCHLINE

CAPILANO INDIAN RESERVE No. 5

MISSION INDIAN RESERVE No. 1

SEYMOUR CREEK INDIAN RESERVE No. 2

BURRARD INLET INDIAN RESERVE No. 3

PANEL 3 MATCHLINE

Project deliverables exclude Tsleil-Waututh Nation's Burrard Inlet I.R. No. 3

First Narrows

Vancouver Harbour

Second Narrows

2

District of North Vancouver

BURRARD INLET INDIAN RESERVE No. 3

PANEL 2 MATCHLINE

Deep Cove

Burrard Inlet

Indian Arm

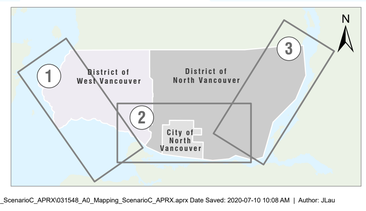
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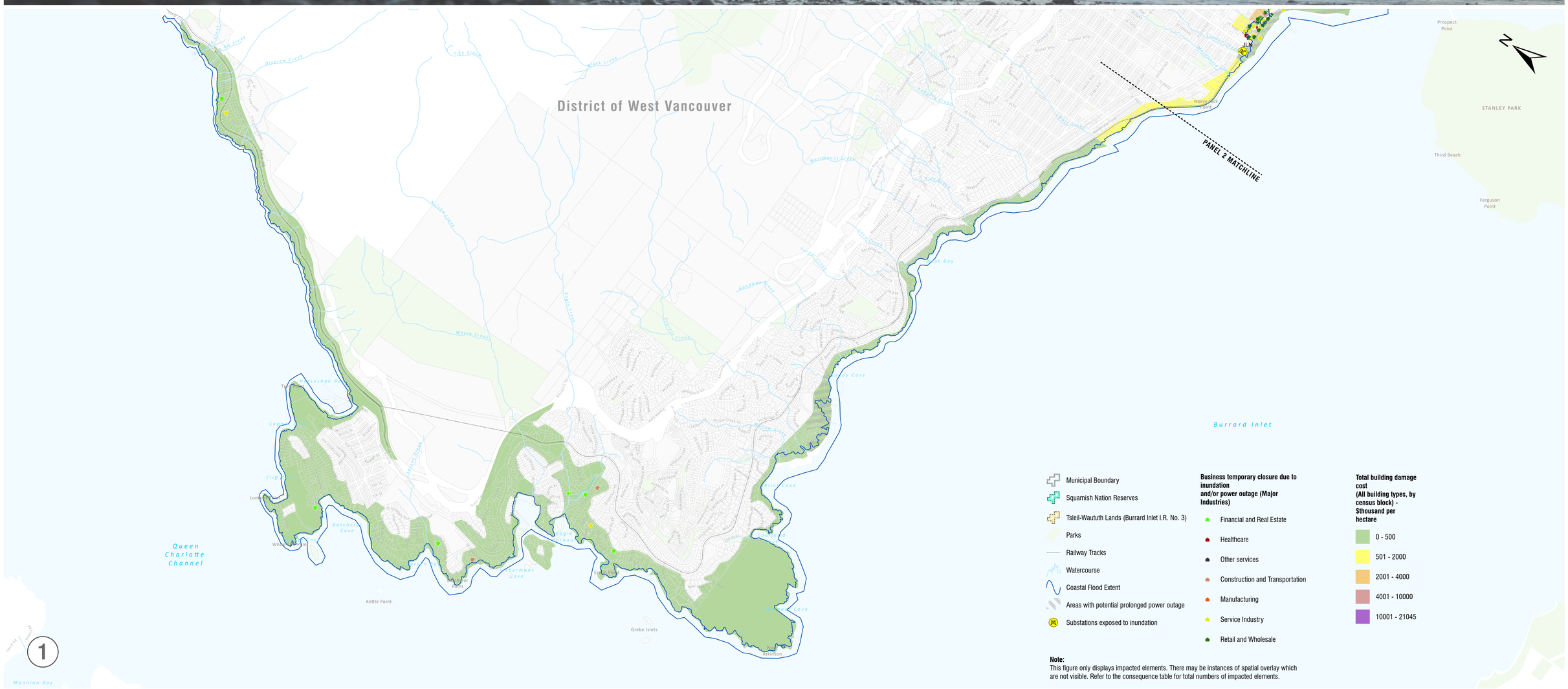
SCENARIO C

(1 m Sea Level Rise 10-Year Return Period Flood)

Culture and Heritage Sector Exposure

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy



Municipal Boundary
Squamish Nation Reserves
Tsleil-Waututh Lands (Burrard Inlet I.R. No. 3)
Parks
Railway Tracks
Watercourse
Coastal Flood Extent
Areas with potential prolonged power outage
Substations exposed to inundation

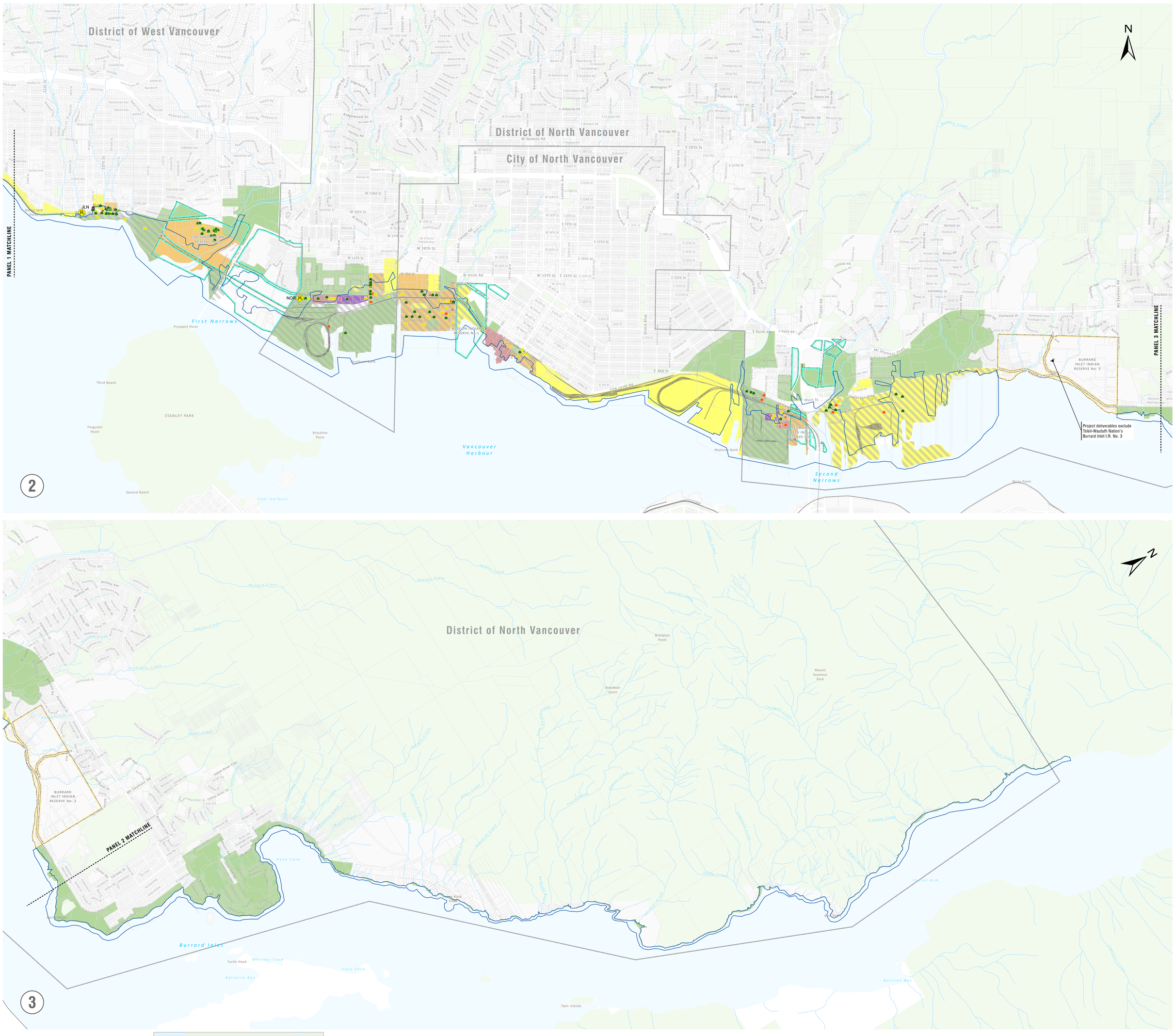
Business temporary closure due to inundation and/or power outage (Major Industries)

- Financial and Real Estate
- Healthcare
- Other services
- Construction and Transportation
- Manufacturing
- Service Industry
- Retail and Wholesale

Total building damage cost (All building types, by census block) - $thousand per hectare

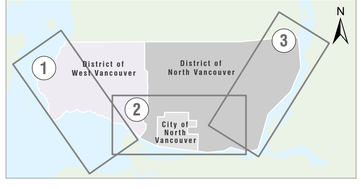
- 0 - 500
- 501 - 1000
- 2001 - 4000
- 4001 - 10000
- 10001 - 21045

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SCENARIO C

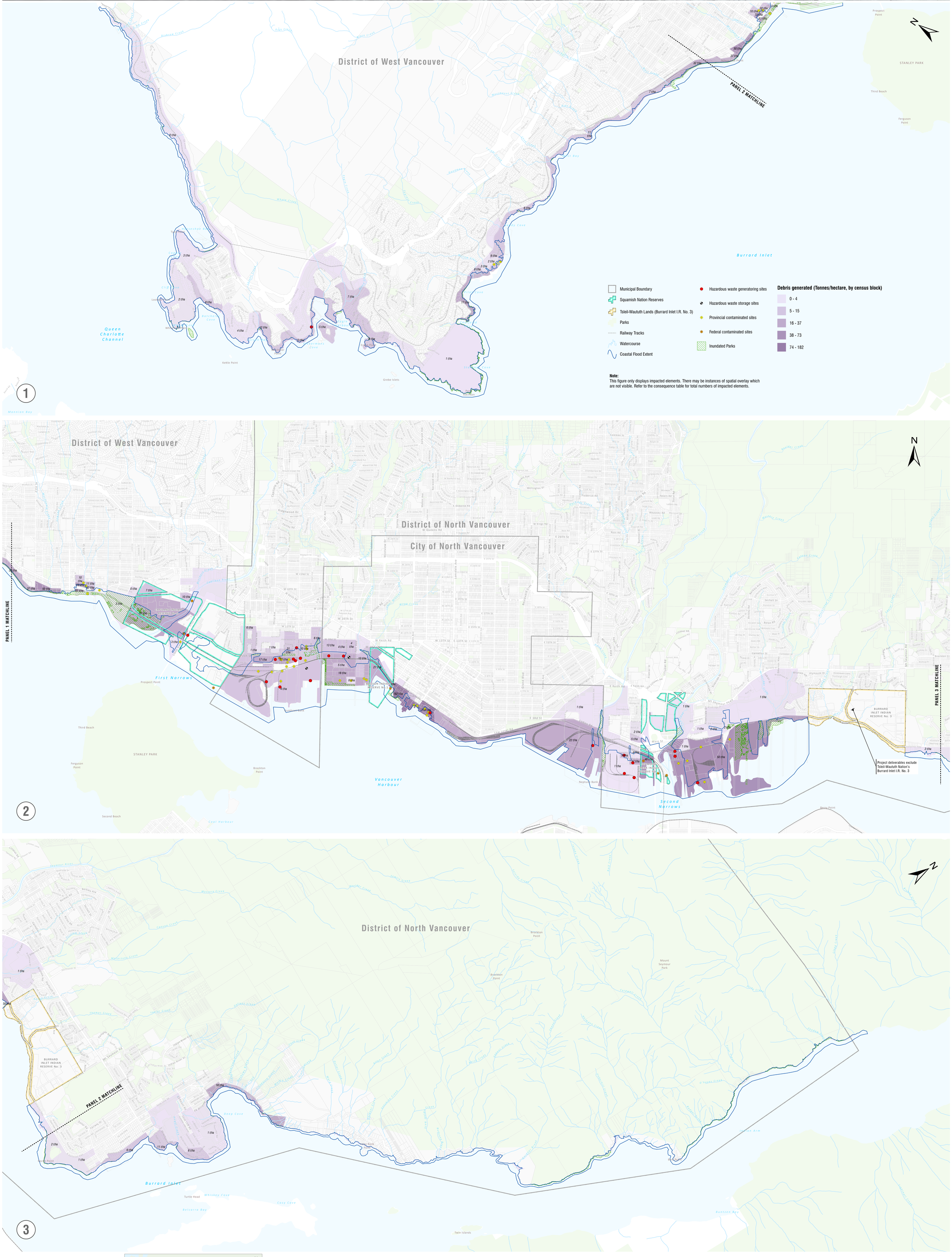
(1 m Sea Level Rise 10-Year Return Period Flood)

Economic Sector Exposure

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy





Municipal Boundary
Squamish Nation Reserves
Tsleil-Waututh Lands (Burrard Inlet I.R. No. 3)
Parks
Railway Tracks
Watercourse
Coastal Flood Extent

Hazardous waste generatoring sites
Hazardous waste storage sites
Provincial contaminated sites
Federal contaminated sites
Inundated Parks

Debris generated (Tonnes/hectare, by census block)

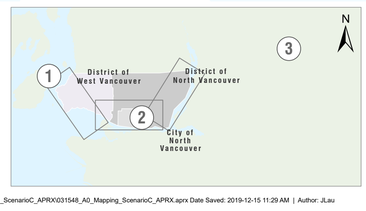
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38 - 73
74 - 182

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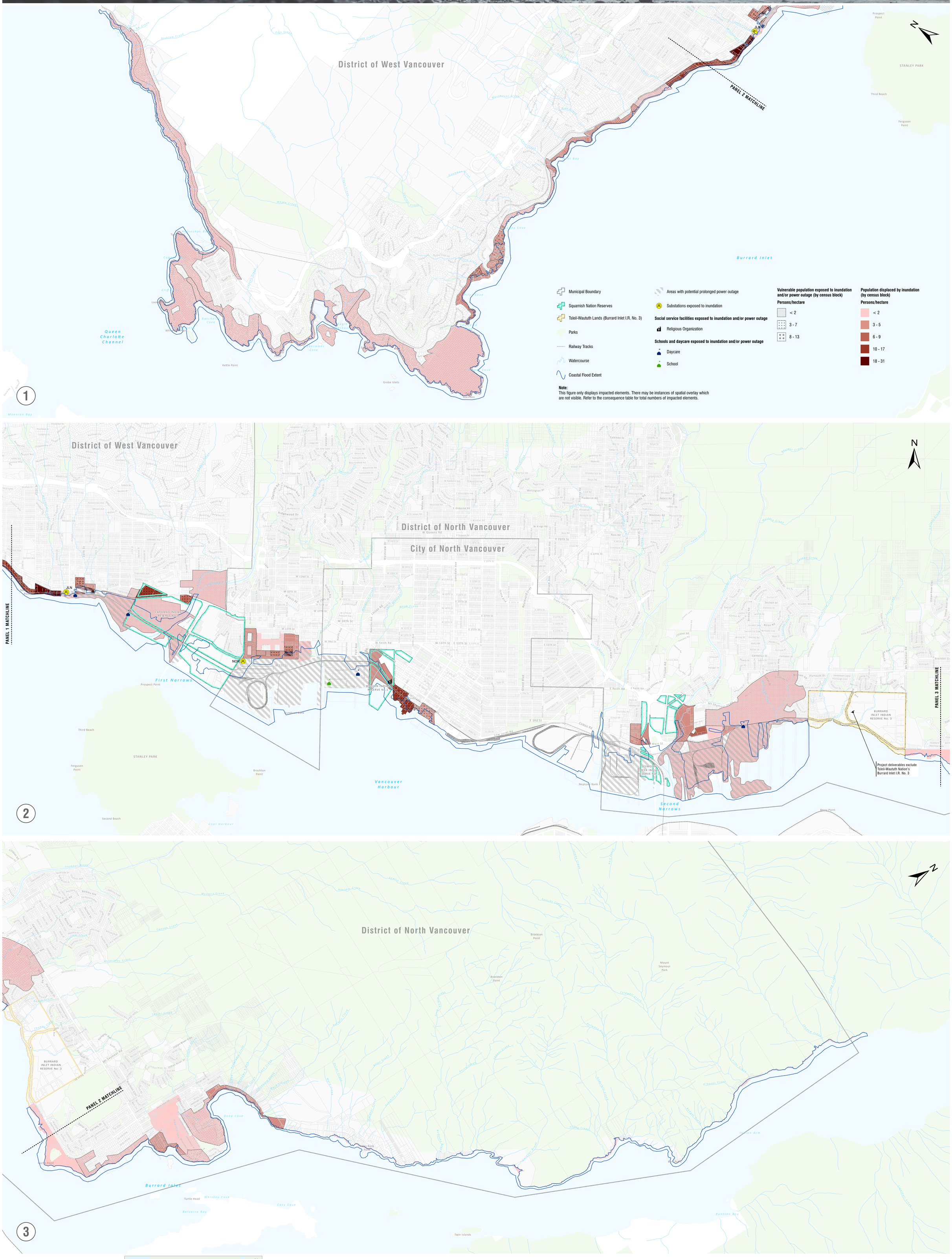
SCENARIO C

(1 m Sea Level Rise 10-Year Return Period Flood)

Environment Sector Exposure

District of North Vancouver

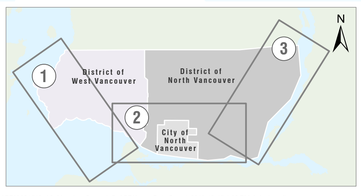
North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy



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SCENARIO C

(1 m Sea Level Rise 10-Year Return Period Flood)

Social Sector Exposure

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

District of West Vancouver

Queen Charlotte Channel

Burrard Inlet

PANEL 2 MATCHLINE

Municipal Boundary

Squamish Nation Reserves

Tsleil-Waututh Lands (Burrard Inlet I.R. No. 3)

Parks

Railway Tracks

Watercourse

Coastal Flood Extent

Areas with potential prolonged power outage

Gas stations exposed to inundation and/or power outage

Bus stops exposed to inundation

Emergency routes exposed to inundation

Bus routes exposed to inundation

Inundated

Major roads exposed to inundation

Inundated

Note:
This figure only displays impacted elements. There may be instances of spatial overlay which are not visible. Refer to the consequence table for total numbers of impacted elements.

1

District of West Vancouver

District of North Vancouver

City of North Vancouver

PANEL 1 MATCHLINE

PANEL 3 MATCHLINE

CAPILANO INDIAN RESERVE No. 5

MISSION INDIAN RESERVE No. 1

SEYMOUR CREEK INDIAN RESERVE No. 2

BURRARD INLET INDIAN RESERVE No. 3

First Narrows

Vancouver Harbour

Second Narrows

Londsdale Quay Sea Bus Terminal (Underground Facility)

Project deliverables exclude Tsleil-Waututh Nation's Burrard Inlet I.R. No. 3

2

District of North Vancouver

PANEL 2 MATCHLINE

Deep Cove

Burrard Inlet

Indian Arm

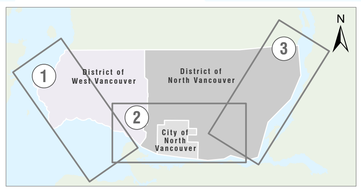
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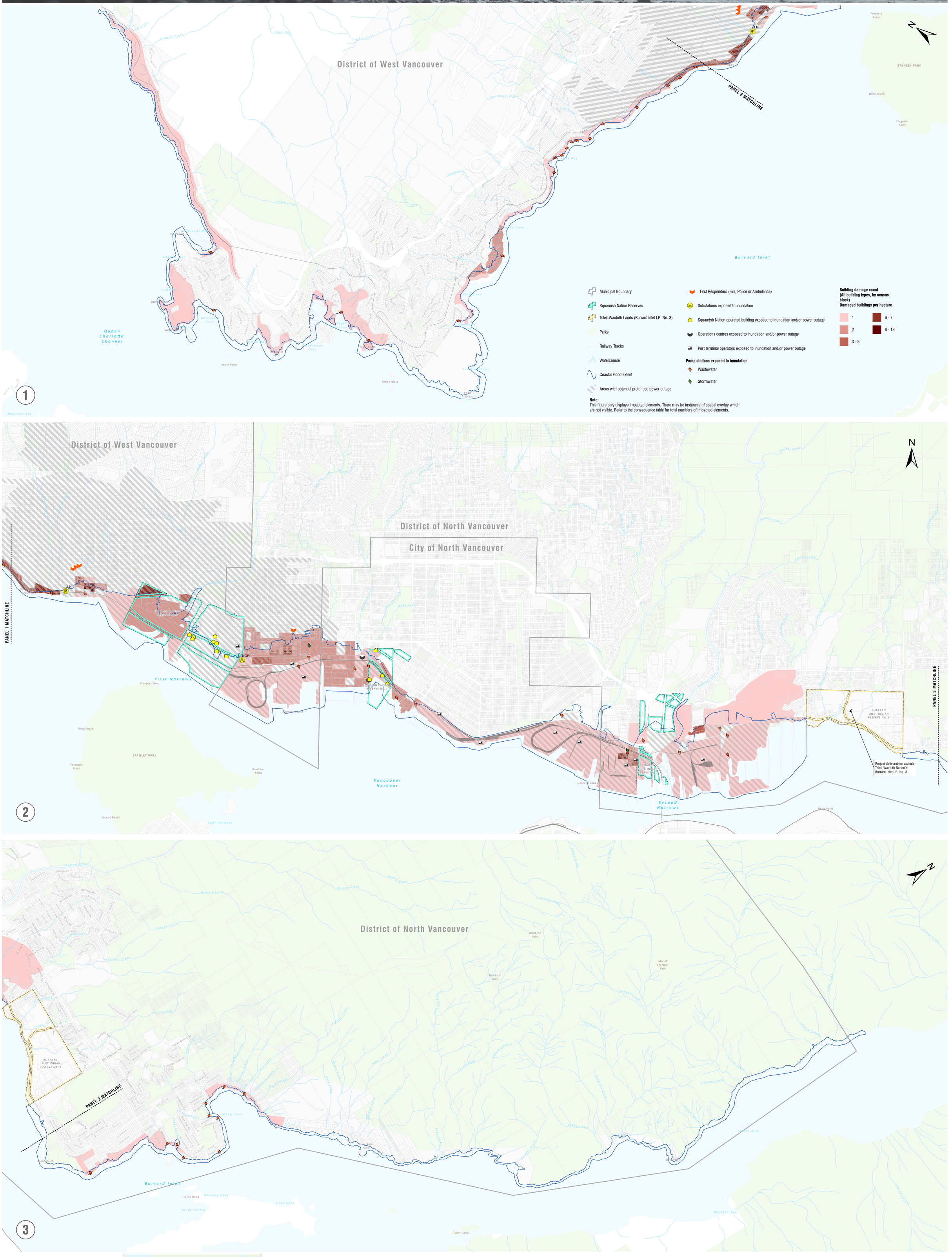
SCENARIO C

(1 m Sea Level Rise 10-Year Return Period Flood)

Transportation Sector Exposure

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy



- Municipal Boundary
- Squamish Nation Reserves
- Tsleil-Waututh Lands (Burrard Inlet I.R. No. 3)
- Parks
- Railway Tracks
- Watercourse
- Coastal Flood Extent
- Areas with potential prolonged power outage
- First Responders (Fire, Police or Ambulance)
- Substations exposed to inundation
- Squamish Nation operated building exposed to inundation and/or power outage
- Operations centres exposed to inundation and/or power outage
- Port terminal operators exposed to inundation and/or power outage

Pump stations exposed to inundation

- Wastewater
- Stormwater

Building damage count
(All building types, by census block)
Damaged buildings per hectare

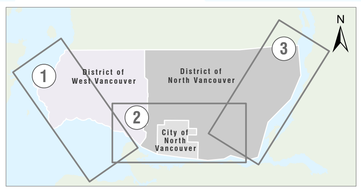
- 1
- 2
- 3 - 5
- 6 - 7
- 8 - 18

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SCENARIO E

(2 m Sea Level Rise 200-Year Return Period Flood)

Building and Infrastructure Sector Exposure

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

District of West Vancouver

PANEL 2 MATCHLINE

Lower Caulfeild Heritage Conservation Area

Queen Charlotte Channel

Kettle Point

Grebe Islets

Burrard Inlet

Municipal Boundary

Squamish Nation Reserves

Tsleil-Waututh Lands (Burrard Inlet I.R. No. 3)

Parks

Railway Tracks

Watercourse

Coastal Flood Extent

Heritage buildings exposed to inundation (DNV and CNV Only)

Protected historic site exposed to inundation

Note:
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1

District of West Vancouver

District of North Vancouver

City of North Vancouver

PANEL 1 MATCHLINE

PANEL 3 MATCHLINE

CAPILANO INDIAN RESERVE NO. 5

MISSION INDIAN RESERVE NO. 1

SEYMOUR CREEK INDIAN RESERVE NO. 2

BURRARD INLET INDIAN RESERVE No. 3

First Narrows

Vancouver Harbour

Second Narrows

Project deliverables exclude Tsleil-Waututh Nation's Burrard Inlet I.R. No. 3

2

District of North Vancouver

PANEL 2 MATCHLINE

BURRARD INLET INDIAN RESERVE No. 3

Deep Cove

Burrard Inlet

Indian Arm

3

Project No. 031.548

Date July 2020

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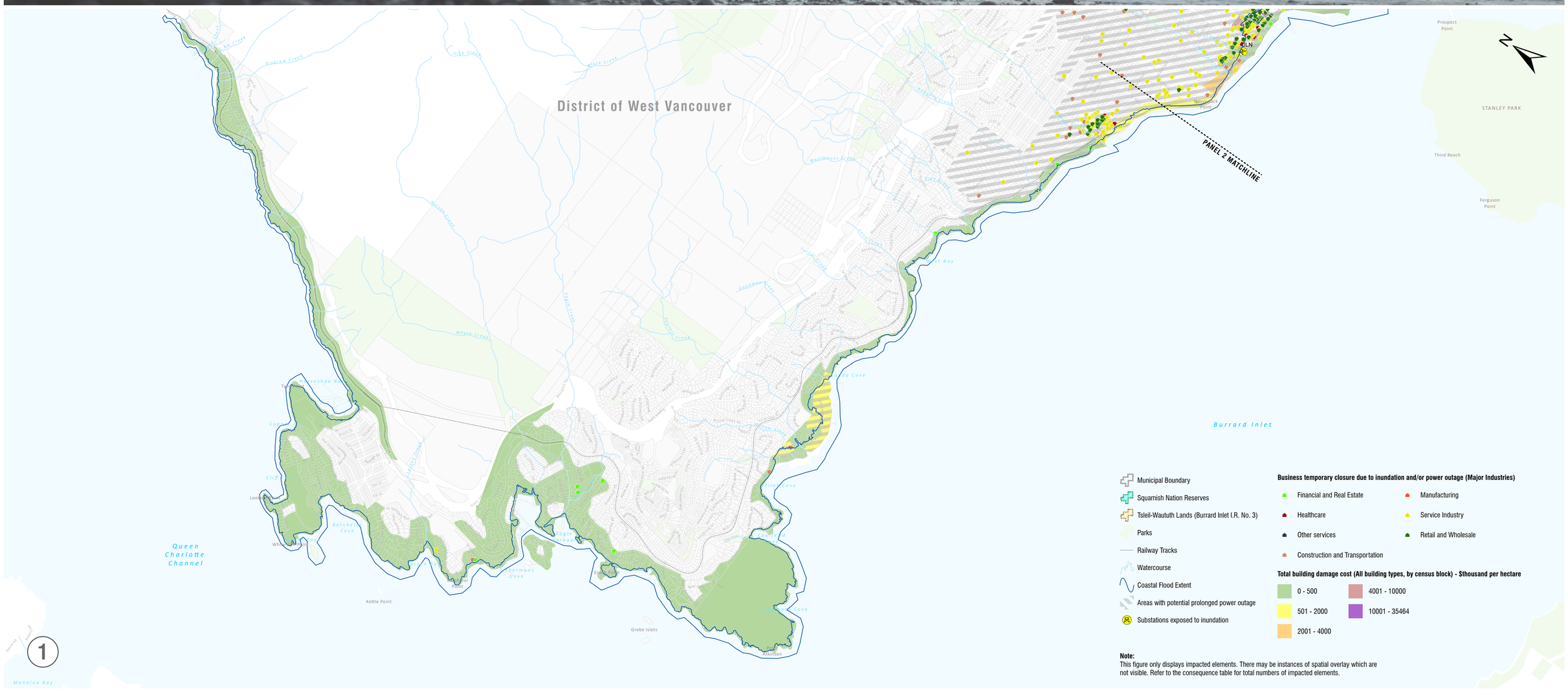
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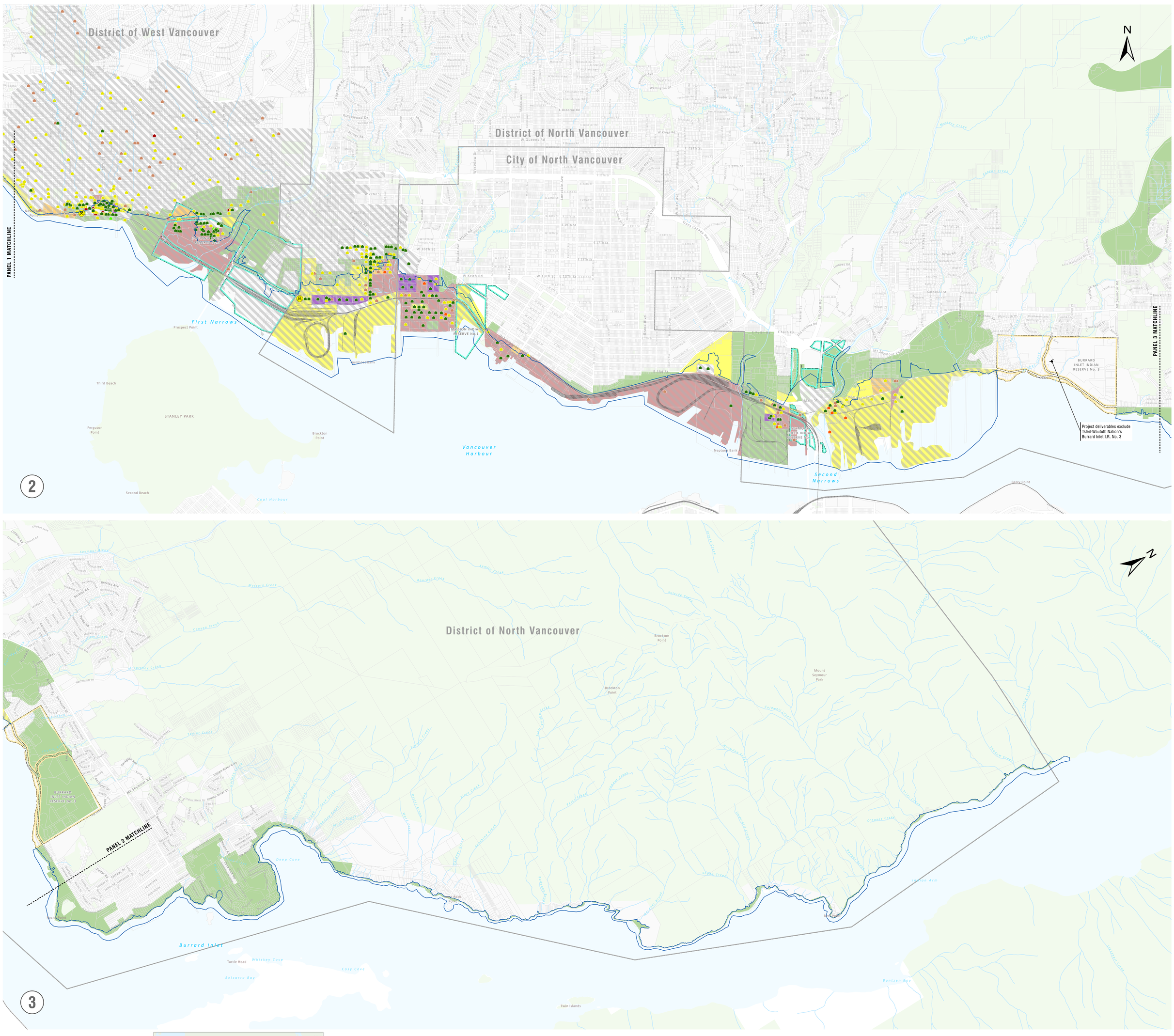
(2 m Sea Level Rise 200-Year Return Period Flood)

Culture and Heritage Sector Exposure

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

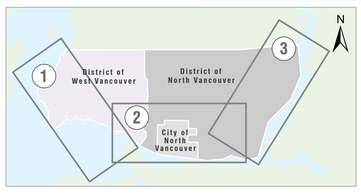




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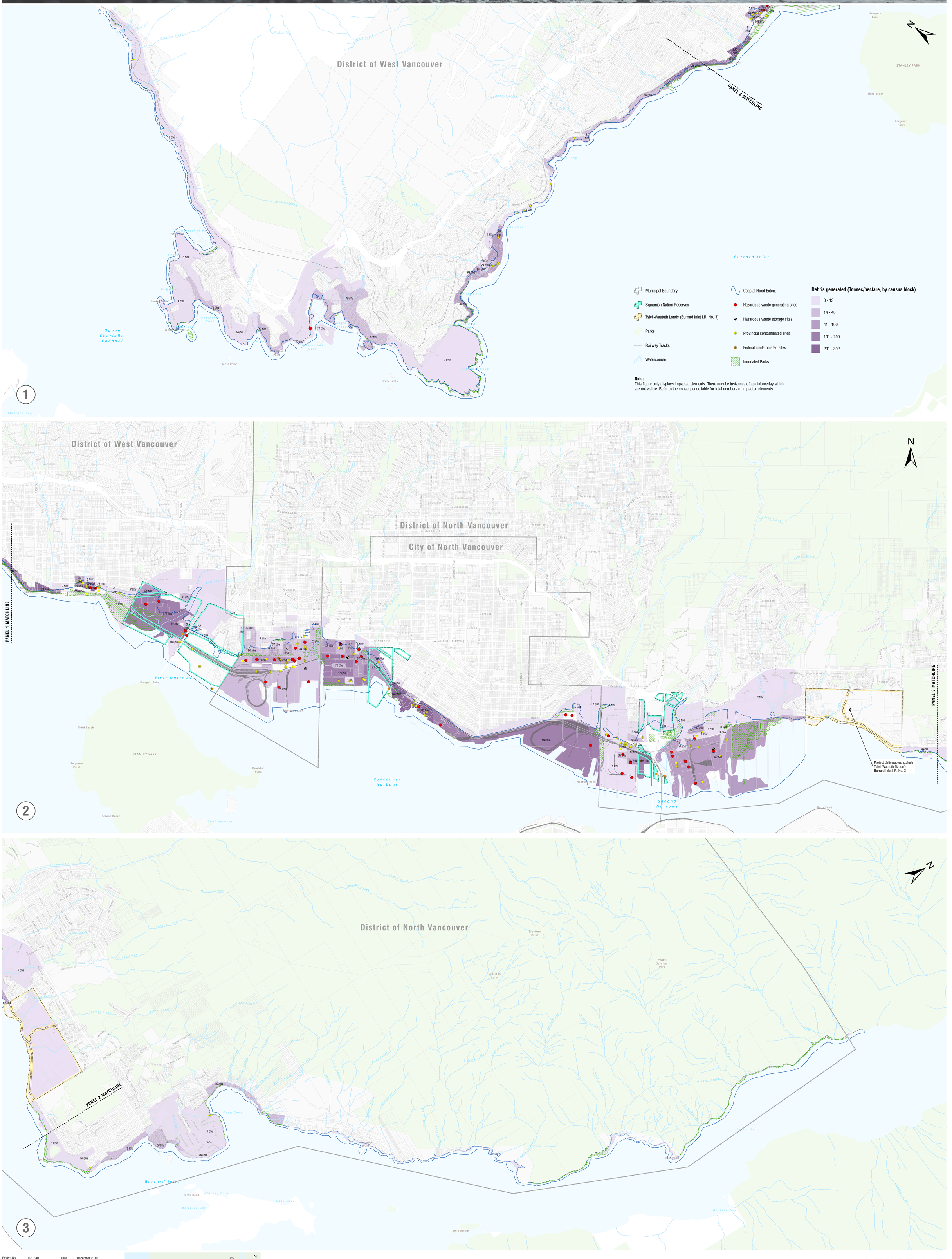
SCENARIO E

(2 m Sea Level Rise 200-Year Return Period Flood)

Economic Sector Exposure

District of North Vancouver

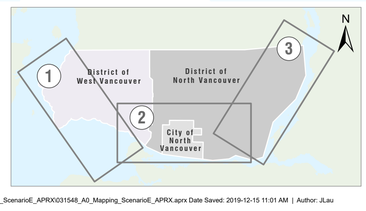
North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy



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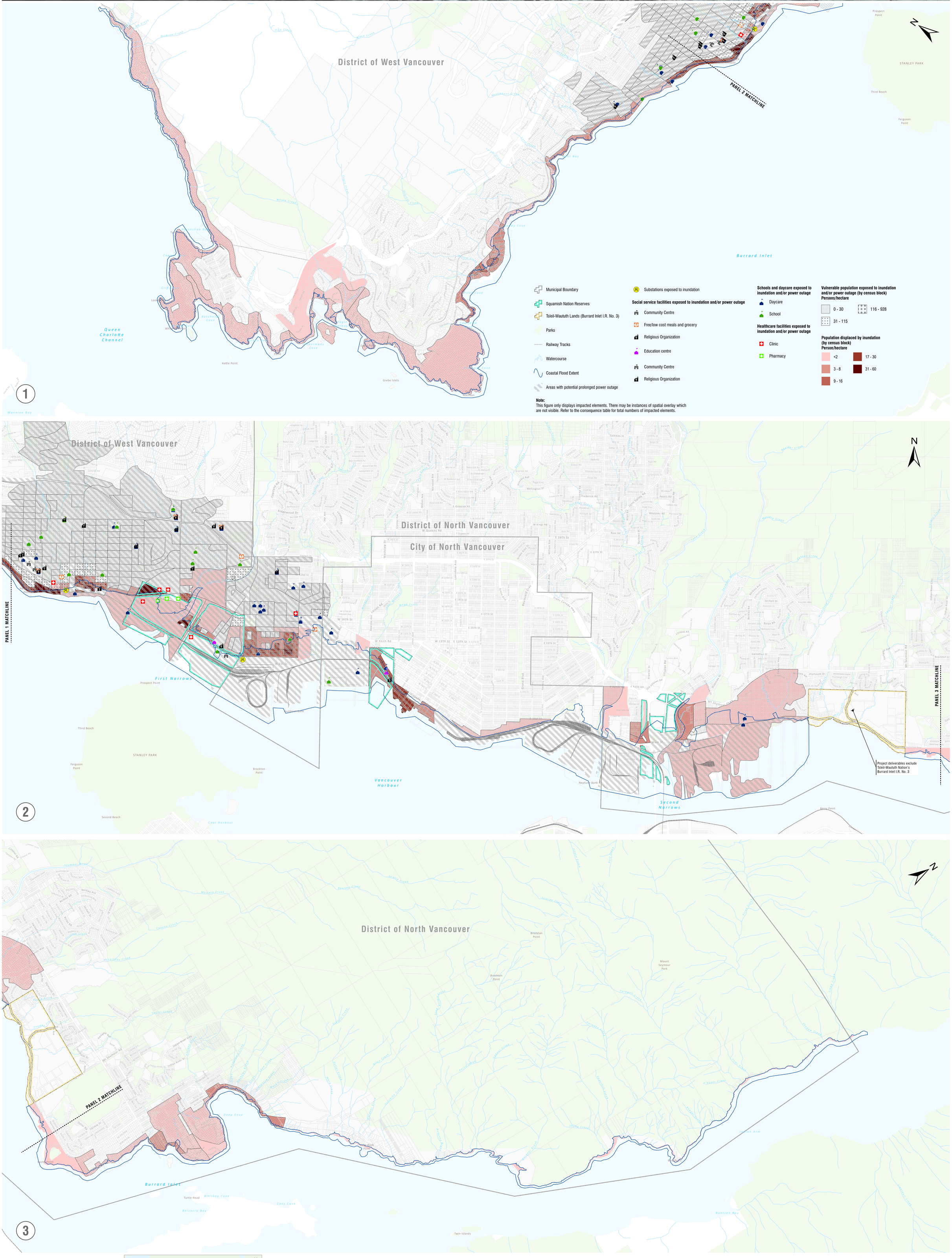
SCENARIO E

(2 m Sea Level Rise 200-Year Return Period Flood)

Environment Sector Exposure

District of North Vancouver

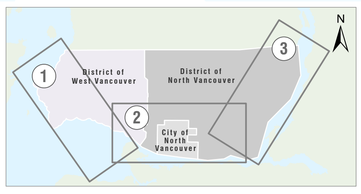
North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy



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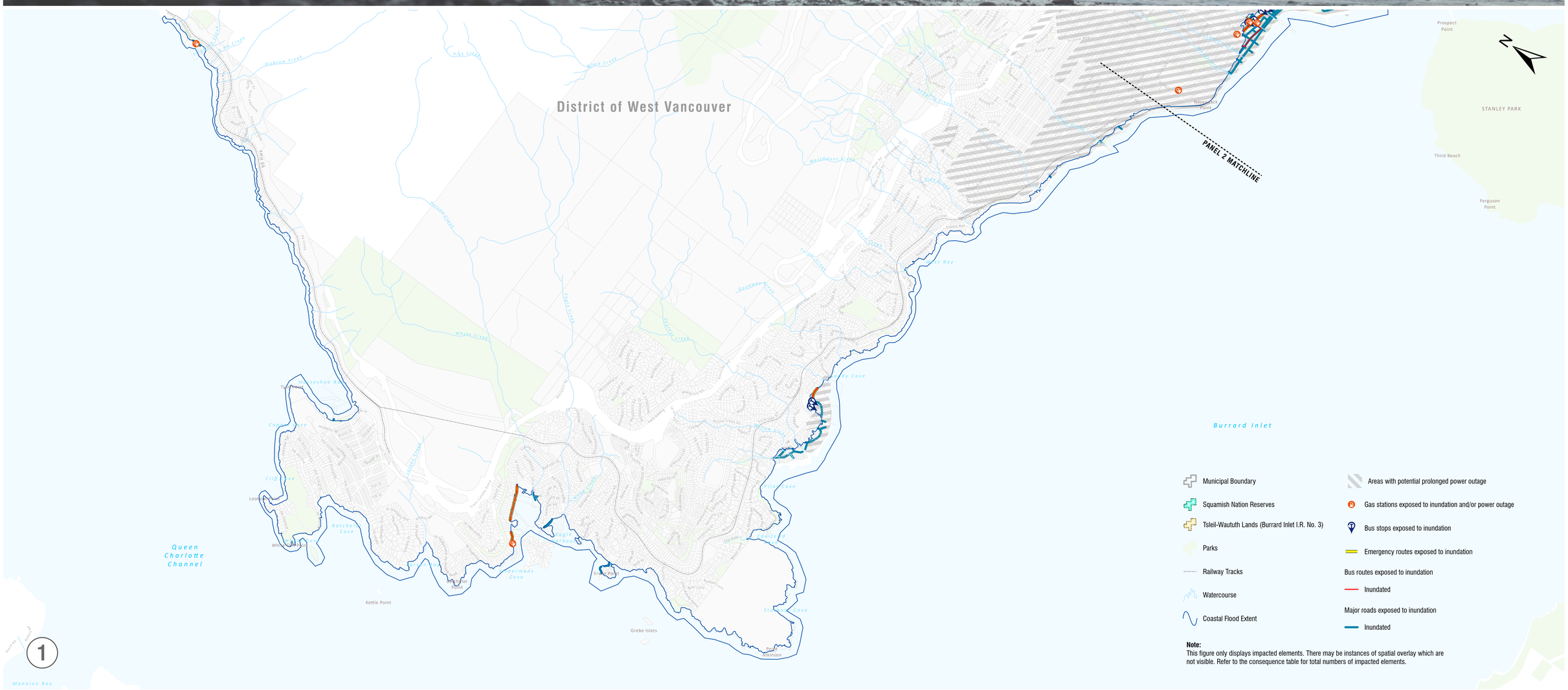
SCENARIO E

(2 m Sea Level Rise 200-Year Return Period Flood)

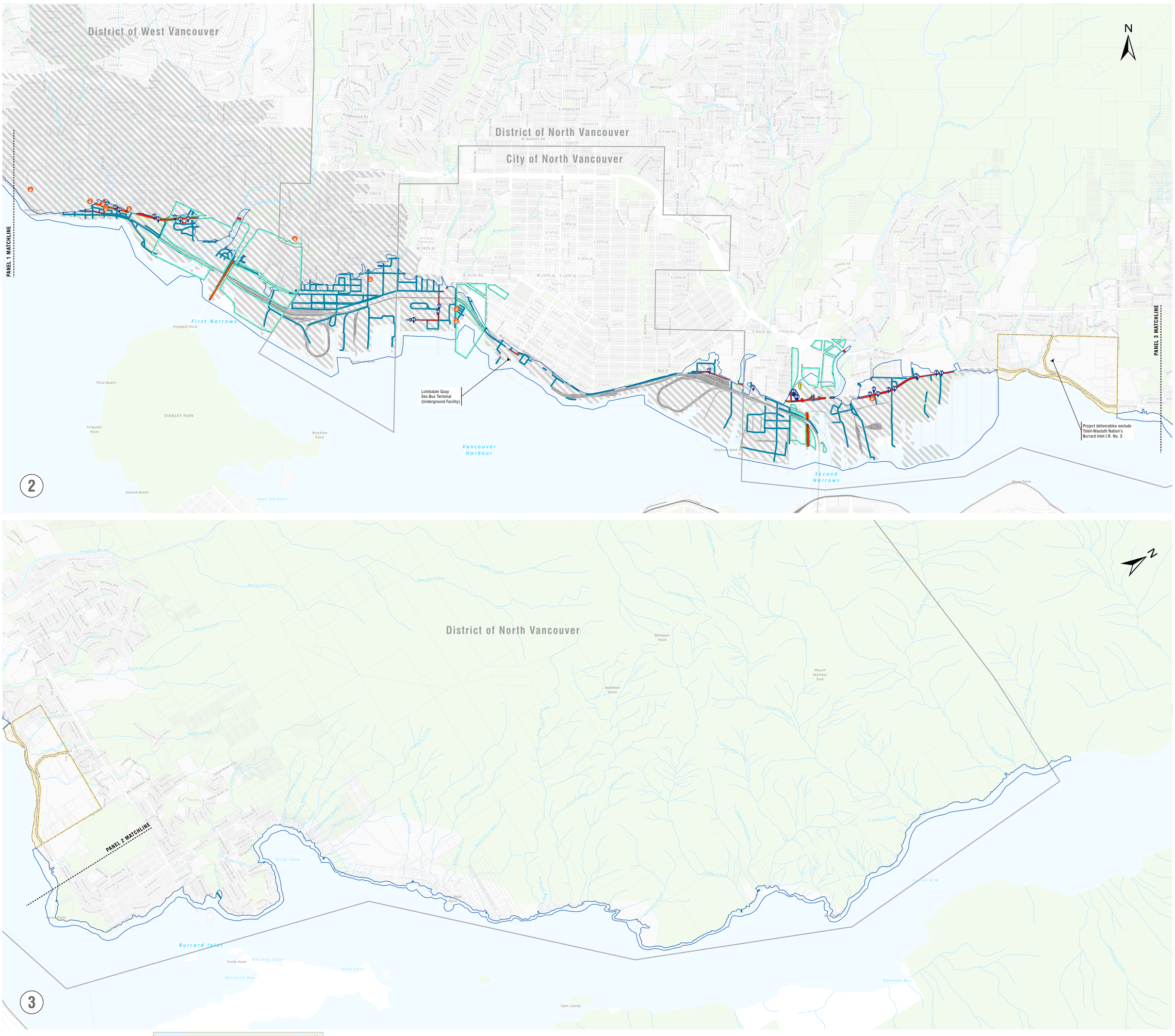
Social Sector Exposure

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy



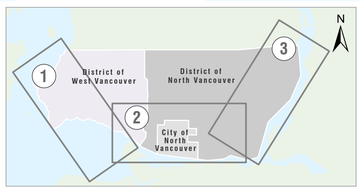
Note:
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SCENARIO E

(2 m Sea Level Rise 200-Year Return Period Flood)

Transportation Sector Exposure

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Appendix C-4
Flood Consequence Assessment Results: Bullet Point Summary - Key Results by Partner Jurisdiction

Contents

1. Summary of Key Results by Sector for Each Partner 1
1.1 Social Services 1
1.2 Environment 2
1.3 Culture and Heritage 4
1.4 Buildings and Infrastructure 4
1.5 Economy 6
1.6 Transporation 7

1. Summary of Key Results by Sector for Each Partner

This appendix provides a bullet point summary of the key flood consequence assessment results by sector for each partner jurisdiction. This bullet point summary is best read alongside the tabular results (Appendix C) and the spatial results figures (Appendix D). A summary and discussion of the results across the North Shore as a whole is presented in Section 4 of the report. Refer to Appendix B for information on the methodology for the consequence assessment.

1.1 Social Services

District of West Vancouver

- Displacement of 8,700 individuals within vulnerable populations (49%) under Scenario E, up from 270 people (2%) under Scenario C.
- Residential areas most impacted under Scenario E include the Sandy Cove and Dundarave neighbourhoods.
- Power outages would impact:
    - All 3 primary care clinics in DWV under Scenario E.
    - 12 schools (11 elementary and West Vancouver Secondary) are exposed to power outages under Scenario E, representing over half of the schools in the District.
    - 28 daycares are exposed to power outages under Scenario E, 2 of which are also within the inundation area.
    - 23 social service facilities, including churches, meal providers, education centres, and community centres are exposed to power outage under Scenario E.

Squamish Nation

- The Nation has the highest estimated rate of population displacement of all partners, with almost 5% of general and vulnerable populations displaced under Scenario C. This increases to 17% of the general population and 89% of vulnerable populations under Scenario E.
- 3 primary care clinics and 3 pharmacies are exposed to power outages under Scenario E. The primary care clinic on Welch Street is one of the clinics exposed to inundation.
- Xwemeich'stn School is exposed to power outage under Scenario E.
- 1 of the 2 community daycares is exposed to inundation and power outages under Scenario E.
- 5 social service facilities are exposed to power outage under Scenario E, with the Chief Joe Mathias Centre also exposed to inundation.

District of North Vancouver

- Displacement of 9% of vulnerable populations under Scenario E, primarily in Norgate, Pemberton Heights, Maplewood and Deep Cove, up from less than 1% in Scenario C.
- Power outages would impact:
    - Residential areas under Scenario E including the Norgate, Marine Drive, and Maplewood neighbourhoods.
    - Norgate Elementary School, under both scenarios.
    - 26 daycares are exposed to power outage under Scenario E, up from 1 daycare in Scenario C.

City of North Vancouver

- The only social service facility exposed to inundation or power outage is St. Paul's Parish in CNV.
- Displacement of fewer than 2% of the general population and vulnerable populations is expected under both scenarios.
- The residential area most impacted under Scenario E in CNV is the Lower Lonsdale neighbourhood.
- Bodwell High School is exposed to inundation and power outage area in both scenarios.

Port of Vancouver

The social service sector consequence assessment variables did not reveal any consequences within the Port of Vancouver's jurisdiction.

1.2 Environment

District of West Vancouver

- 4 hazardous waste generating sites (20% of all sites) in DWV would be exposed to inundation in Scenario C and E.
- In Scenario E, 4.4% of all contaminated sites (federal and provincial registered) would be inundated which is an increase from 1.4% of all sites in Scenario C.

Squamish Nation

- 22% of all parkland in Squamish Nation would be exposed to inundation (4 ha) in both Scenarios C and E.
- 14% of all hazardous waste generating sites in Squamish Nation would be exposed to inundation in Scenario C (2 sites affected of 14 total), and 78% of all sites would be exposed in Scenario E (11 sites affected).
- In Scenario C, 8 contaminated sites (of the 27 contaminated sites total within SN) would be exposed to inundation, while in Scenario E, 11 sites (which represents 41% of all sites) would be exposed.

District of North Vancouver

- In Scenario C, buildings generate 6,400 tonnes of debris, and in Scenario E, nearly double the amount of debris is produced (11,600 tonnes)
- 28% of all hazardous-waste-generating sites in DNV would be exposed to inundation in Scenario C and 63% of all sites would be exposed in Scenario E.
- In Scenario C, 18 contaminated sites (4.5% of all contaminated sites within DNV) would be exposed to inundation, while in Scenario E, 40 sites (10% of all sites) would be exposed.

City of North Vancouver

- 5% of CNV park land (9 ha) would be exposed to inundation in Scenario E.
- 1 hazardous waste storage site (the only site in CNV) would be exposed to inundation in Scenarios C and E.
- 8% of all hazardous-waste-generating sites in CNV would be exposed to inundation in Scenario C, increasing to 15% in Scenario E.
- In Scenario C, 11 contaminated sites (6% of all contaminated sites within CNV) would be exposed to inundation, while in Scenario E, 29 sites (15% of all sites) would be exposed.

Port of Vancouver

- Buildings on Port lands produces 3,700 tonnes of debris in Scenario C, which is 19% of all debris generated in that scenario; however, in Scenario E, the amount of debris produced by the Port nearly quadruples to 13,000 tonnes, increasing the Port's share to 25% of all debris generated. However, the debris generation analysis is based on HAZUS' Census-based building information which is likely least reliable or largerly underestimates buildings within the Port lands. An inventory of buildings is not available to confirm which types of buildings are not covered by the census. Refer to Appendix B for additional discussion on methods and uncertainty/limitations.
- 1 hazardous waste storage site (of the 2 storage sites in the Port) would be exposed to inundation in Scenario C, and both would be exposed in Scenario E.
- 67% of all hazardous-waste-generating sites in the Port would be exposed to inundation in Scenario C increasing to 78% in Scenario E.
- Of the contaminated sites within the Port, 1 of them (8.3%) would be inundated in Scenario C and 2 (17%) would be inundated in Scenario E.

1.3 Culture and Heritage

Note that archaeological site locations are not shown on the consequence maps, as this information may be sensitive.

District of West Vancouver

- 7 archaeological sites are exposed to inundation in scenarios C and E, which represents 54% of all archaeological sites in DWV.
- 8 historic sites are exposed in both scenarios, which represents 26% of all historic sites within DWV. 3 of these sites are in the Ambleside neighbourhood, and the rest are relatively evenly distributed along the entire DWV shoreline.

Squamish Nation

- 2 archaeological sites are exposed to inundation in Scenario C (both in Capilano I.R. No. 5) and 3 are exposed in Scenario E (2 in Capilano No. 5, 1 in Mission I.R. No.1) of the 4 sites total in SN.
- There is 1 historic site in Squamish Nation, and it is exposed to inundation in both scenarios.

District of North Vancouver

- 9 archaeological sites are exposed to inundation in Scenario C and 11 are exposed in Scenario E of the 17 archaeological sites present in DNV.
- In the Maplewood area, there are 3 archaeological sites, 1 historic site and 2 heritage buildings affected in Scenario E – otherwise, the affected sites are evenly distributed along the DNV shoreline.

City of North Vancouver

- In both scenarios, 1 archaeological site is exposed to inundation in CNV of the 2 sites present in the municipality. This site is within in the Lonsdale Quay comprehensive adaptation planning zone.

Port of Vancouver

- No cultural and heritage consequences have been identified for the Port.

1.4 Buildings and Infrastructure

District of West Vancouver

- Approximately half of the population of DWV (20,875 people) would be affected by prolonged power outage in Scenario E, as compared to 190 people (less than 1% of the population) in Scenario C.
- DWV's police station, fire station and ambulance service stations on Fulton Ave. and 16th St. would be exposed to prolonged power outage in Scenario E.

- Half of the wastewater pump stations in DWV would be exposed to inundation in Scenario C (15 stations affected of the 30 stations present in DWV) and 24 stations would be exposed in Scenario E.

Squamish Nation

- 82% of the population of Squamish Nation (2,771 people) would be affected by prolonged power outage in Scenario E.
- There are 27 band-owned buildings. Inundation would affect 4 band-owned buildings in Scenario C, and 9 in Scenario E, while power outage would affect respectively 6 and 15 buildings in each scenario.
- SN's only operation centre (in Mission I.R. No. 1) would be exposed to inundation in both scenarios.
- The single wastewater pump station in SN would be inundated in both scenarios.
- 8% of all buildings in SN would be damaged in Scenario C and 20% would be damaged in Scenario E.
- In Scenario C, 25% of all commercial buildings and 13% of all industrial buildings in SN would be damaged.
- In Scenario E, 47% of all commercial buildings, 13% of all industrial buildings and 10% of all residential buildings in SN would be damaged.
- Of the North Shore partners Squamish Nation has the highest proportion of population affected by power outage as well as percentage of buildings damaged.

District of North Vancouver

- 8% of the population of DNV (6,829 people) would be affected by prolonged power outage in Scenario E.
- 13 of the 36 wastewater pump stations in DNV would be inundated in Scenario C, and 18 (half of all) wastewater pump stations would be inundated in Scenario E.
- There are 2 stormwater pump stations in DNV. 1 would be inundated in Scenario C, and both would be inundated in Scenario E.

City of North Vancouver

- Only 2% of the population of CNV would be affected by prolonged power outage in Scenario E.
- CNV's only operation centre (on Bewicke Ave) would be exposed to power outage in Scenario C and inundation in Scenario E.
- There are 10 wastewater pump stations in CNV: 6 would be inundated in Scenario C, and in Scenario E, 7 would be inundated.

Port of Vancouver

- There are 11 Port terminal operators; of these, 5 operators would be exposed to power outage or inundation in Scenario C, and 10 would be exposed in Scenario E.
- 6% of all Port buildings would be damaged in Scenario C and 37% would be damaged in Scenario E.
- In Scenario C, 6% of all commercial buildings would be damaged.
- In Scenario E, 41% of all commercial buildings, and 23% of all industrial buildings would be damaged.

1.5 Economy

District of West Vancouver

- Major commercial areas, including Ambleside, Park Royal Village, and the Marine Drive area are exposed to inundation and power outage under Scenario C and E.
- There are 95 business closures in Scenario C, and 862 business closures in Scenario E. With 4,943 businesses within DWV, that represents 2% and 17% of all businesses closed for each scenario respectively. Of the closed businesses, the most impacted sector is the service sector, and the second most impacted sector is wholesale and retail.
- The building replacement cost for flood-damaged DWV industrial buildings in Scenario E is $13.3 million or 9.5% of their total value.
- Scenario E reflects flooding of a significant number of multi-family buildings.
- The majority of business disruption effects are concentrated in the Ambleside neighbourhood .

Squamish Nation

- There are 59 business closures in Scenario C, and 273 business closures in Scenario E. With 606 businesses within Squamish Nation, that represents 10% and 45% of all businesses closed for each scenario respectively. Of the closed businesses, the 2 sectors that are most impacted are classified as service industry and others, and wholesale and retail. Most of these closures are concentrated in Capilano IR No. 5.
- The building replacement cost for flood-damaged buildings in SN jurisdiction in Scenario C is $4.94 million or approximately 10% of the total value of the public/government buildings, $129 million or 20% of the total value of commercial buildings and $13.3 million or 21% of the total value of industrial buildings. Under Scenario E, this increases to $28.4 million or 6% of the total value of residential buildings, $10.8 million or 21% of the total value of the public/government buildings, $253 million or 40% of the total value of commercial buildings and $27.9 million or 44% of the total value of industrial buildings.

District of North Vancouver

- There are 196 business closures in Scenario C, and 381 business closures in Scenario E. With 4,217 businesses within DNV, that represents 5% and 9% of all businesses closed for each scenario respectively. Of the closed businesses, the most impacted sector is classified as service

industry and others, and the second most impacted sectors are wholesale and retail, and mining, construction, transport, and utilities. Most of these effects are concentrated in the Norgate and Maplewood areas.

- For Scenario C, DNV has the highest building replacement cost of all the partners of $258.8 million.
- The building replacement cost for flood-damaged buildings in DNV is $81.4 million or 14% of the total value of industrial buildings in Scenario C. Values are larger and more notable under Scenario E: $355 million or 10% of the total value of commercial buildings and $175 million or 29% of the total value of industrial buildings.

City of North Vancouver

- There are 188 business closures in Scenario C, and 386 business closures in Scenario E. With 3,171 businesses within CNV, that represents 4% and 12% of all businesses closed for each scenario respectively. Of the closed businesses, the most impacted sector is classified as service industry and others, and the second most impacted sectors are wholesale and retail, and mining, construction, transport, and utilities. The majority of these effects are concentrated in the Mosquito area, with some in the Lonsdale Quay consequence adaptation planning zone.
- The building replacement cost of industrial buildings is $18.4 million or 6% of the total value of industrial buildings in CNV under Scenario C and increases to $34.5 million or 12% under Scenario E. A similar trend exists for commercial buildings, where flood-damage replacements costs up to $728 million or 16% of the total value of commercial buildings in Scenario E.

Port of Vancouver

- For Scenario E, the Port has the highest building replacement cost of all the partners ($834.5 million), the majority of which is from the replacement of commercial buildings.

1.6 Transporation

District of West Vancouver

- Inundation under Scenario C and E would affect sections of Marine Drive, a major commercial corridor in the District. Affected areas include sections near Eagle Harbour and Ambleside.
- 4 of the 16 gas stations in DWV would be exposed to inundation or power outage in Scenario C, and 7 would be exposed in Scenario E
- In both scenarios, Marine Drive would be inundated east of Stearman Beach, in portions of the Eagle Harbour neighbourhood, and north of John Lawson Park in Ambleside.
- Several bus routes (Buses 250, 251, 252, 253, 257, and 258) running along Marine Drive near 15th St would be affected by flooding, as well as 2 bus stops in that area in Scenario C and 3 bus stops in Scenario E.

Squamish Nation

- 2 of the 3 gas stations in SN would be exposed to inundation or power outage in both scenarios. Both are in Mission IR No. 1.

- Marine Drive in the western portion of Capilano IR No. 5 would be inundated, as well as 2 bus stops in the same area in Scenario C and 3 bus stops in Scenario E.

District of North Vancouver

- All bus stops at Phibbs Exchange, which serves 18 bus routes, would be inundated in both scenarios. Highway 1 exit 23A will be shallowly flooded in Scenario C. In Scenario E, both the exit and the corresponding section of Main St will be inundated.
- 2 of the 13 gas stations in DNV would be exposed to inundation or power outage in Scenario C, and 3 would be exposed in Scenario E
- Dollarton Hwy would be inundated in both scenarios in the Maplewood area. In Scenario E, most of Dollarton Hwy from the Second Narrows Bridge to Maplewood Flats is inundated.
- Main St. at the Highway 1 overpass (Lower Lynn Exchange) is inundated under both scenarios, affecting buses routes 239 and 232 which run along Main St.
- West 1st Street is inundated under Scenarios C and E within the Norgate neighbourhood.

City of North Vancouver

- The Lonsdale Quay Seabus terminal is not inundated in Scenario C and Scenario E flood maps, but the below-grade facilities including the main ferry boarding area may be inundated under both scenarios. This is not confirmed because underground flooding was not mapped as part of the hazard assessment.
- The 231 bus at Harbourside Drive as well as 3 bus stops in that area would be inundated in Scenario C.
- Carrie Cates Court, which is the access road for the Lonsdale Quay transit exchange servicing 12 bus routes, is inundated in both scenarios.

Port of Vancouver

- Scenarios C and E cause inundation of the low-lying area near the Philip Ave. rail overpass, impacting both rail and road connectivity to operators.
- Road access to Lynnterm and Univar, via the Mountain Hwy underpass, is inundated in both Scenarios C and E.
- Brooksbank Ave at CN Rail would be inundated under both scenarios as well blocking access to G3 terminal.

Statement of Limitations

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Revision History

Revision #	Date	Status	Revision	Author
0	March 25, 2020	Final		ATAL

KERR WOOD LEIDAL
consulting engineers

Appendix D

Qualitative Flood Risk Assessment Methodology and Workshop Results

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1. Risk Assessment Methodology

A qualitative risk assessment was conducted by asking Technical Steering Committee members to evaluate the coastal flood consequence assessment results and how significant those impacts would be in their jurisdiction. This approach made it possible to identify which variables in each of the partners' jurisdictions are perceived as a higher concern and therefore a higher priority for adaptation planning.

As discussed in Chapter 4 of the project report, the assessment focused on the consequences associated with two climate scenarios:

- Scenario C: 1 m sea level rise (SLR), 10% annual probability stillwater level (10-year return period)
- Scenario E: 2 m sea level rise (SLR), 0.5% annual probability stillwater level (200-year return period)

Further details on why the Technical Steering Committee selected these two scenarios are provided in Section 4.1 of the project report.

1.1 Risk Matrix

The assessment uses a standard risk matrix, in which risk is a function of the consequence x likelihood of the flood event on a given variable. The methodology used in this project is based on international standards such as ISO 13000 and the UN's Sendai Framework for risk assessment. Figure 1-1 shows the risk matrix used in this assessment.

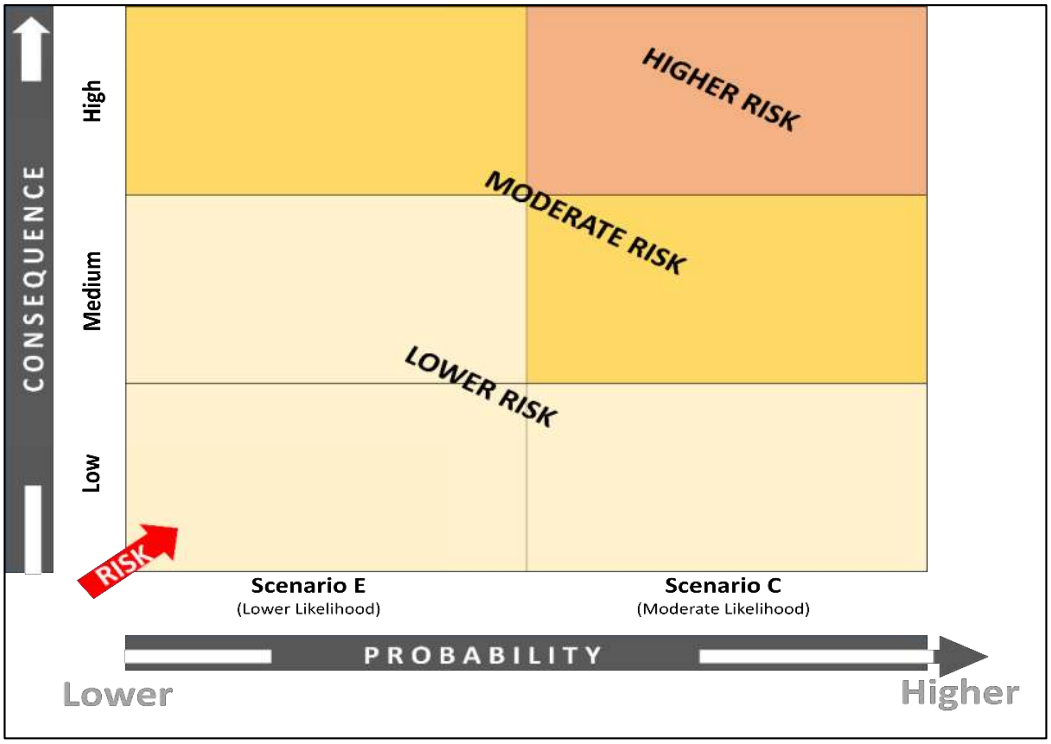


Figure 1-1: Risk Matrix

The matrix defines risk as different combinations of consequence severity and event probability. The definitions are relative (i.e. lower risk to higher risk) due to a lack of a regional definition of consequence severity (i.e. what constitutes a high consequence versus a low consequence for any variable). This limitation is further discussed later in this appendix.

In general, higher risk is the result of higher likelihood events causing a higher level of consequences and vice versa.

The North Shore project consequence assessment scope was limited to 2 flood events:

1. Scenario C: coastal flood event (10% AEP) with 1 m of sea level rise (higher probability/lower severity);
2. Scenario E: coastal flood event (0.5% AEP) with 2 m of sea level rise (lower probability/higher severity).

Scenario C is considered to have a higher probability because the coastal flood event probability is higher (10% likelihood of occurring in a given year) and 1 m of sea level rise corresponds with a closer date (year 2100), while the coastal flood event probability is lower (0.5% AEP) and the sea level rise projection is farther in the future (year 2200).

Using these two scenarios, a simplified, high-level risk assessment was completed where the severity of the consequence for each variable for each scenario was rated in relative, subjective terms. Accordingly, a risk score (probability-consequence product) is determined for each variable for each scenario compared to other variable scores. The overall risk rating for each variable is maximum of the risk score for each Scenario.

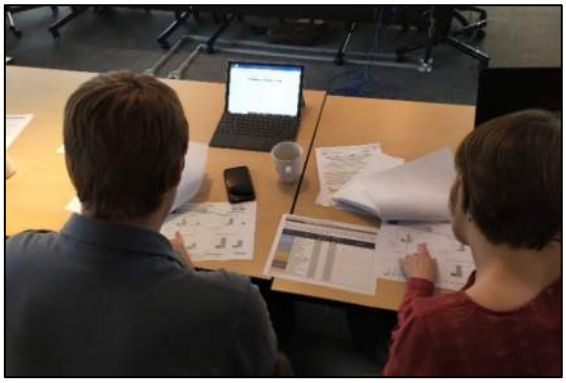
1.2 Workshop-Based Approach

The risk assessment for this project adopted a workshop-based approach, drawing on input from Technical Steering Committee members on how severely they felt consequences would affect their jurisdiction. The assessment involved a two-step process, with a preliminary questionnaire distributed to all Technical Steering Committee members in March 2019, followed by a Risk Assessment Workshop in June 2019 to confirm risk scores and overall risk ratings. This methodology is standard practice for many risk assessment models, including ISO 31000, Canadian Risk Management Model administered by the Global Risk Management Institute, and the Public Infrastructure Engineering Vulnerability Committee (PIEVC) administered by the Institute for Catastrophic Loss Reduction and Climate Risk Institute.

Technical Steering Committee members each assessed risk within their jurisdiction, including the District of North Vancouver (DNV), City of North Vancouver (CNV), Squamish Nation (SN), District of West Vancouver (DWV), and Vancouver Fraser Port Authority (Port). Technical Steering Committee members from North Shore Emergency Management (NSEM) participated in a supporting role.

The questionnaire asked each partner to evaluate the severity of the consequence results under Scenario C and Scenario E would be in their jurisdiction using a three-point scale (low, medium, high), and to outline existing controls for managing each consequence variable. High consequence ratings represent either a highly intolerable impact (e.g., significant proportion of businesses closed) compared to other variable consequences or a consequence with inadequate control measures in place for risk prevention, response, or recovery.

While most committee members completed the questionnaire on their own, DNV chose to complete the questionnaire with input from an internal workshop with other District staff from a range of departments in May 2019. Results from the questionnaire were used to create preliminary risk profiles for each partner, plotting responses on a risk matrix for each sector. The risk profile for each partner includes a collection of risk matrices, one per sector, showing the level of severity and overall relative risk for each variable assessed. The risk profiles provided to each partner during the workshop are available in Appendix G.

Risk Assessment Workshop (June 2019)

The final risk assessment results were recorded for each partner and combined to find the average risk score of each consequence across the North Shore overall for each scenario. Assessing risk at both the partner and regional level made it possible to see the unique contexts and priorities of each individual partner, while also highlighting variables with shared risk across the study area.

1.3 Limitations

It is important to acknowledge the subjectivity of risk, which requires actors to make value judgements about the relative significance of objective consequences on a scale (e.g. “low”, “medium”, or “high”). This inherent subjectivity is particularly true given the regional scope of the project, with each jurisdiction considered to have a distinct context, culture, and value system.

In the absence of a province-wide or regional standard for evaluating sea level rise consequences, each member of the Technical Steering Committee was asked to evaluate consequences according to their background knowledge on their jurisdiction and comparing the results of the consequence variables for their respective jurisdictions. This means that each jurisdiction evaluated the severity of consequences in their own way and allowed the perceived level of risk for each jurisdiction to be compared for each variable.

While this approach makes it possible for each partner to tailor their risk assessment to their local context, it makes it difficult to compare risk assessment results between partners. As a result, the risk assessment results described in this summary should be considered indicative of high-level priorities, which are used to inform adaptation priorities and conceptual design.

2. Study Area Risk Assessment Results

This sub-section summarizes the perceived risk of coastal flooding on each consequence variable across the North Shore. These results have been grouped by sector and show results in two graphical formats:

- **Simplified results** derived as an average of risk scores of each partner; and
- **Clustered results** showing the individual risk scores of each partner, clustered by sector.

North Shore risk assessment results for each sector and variable are described in the following sub-sections, drawing on consequence and risk ratings and qualitative comments provided through both the questionnaire and workshop.

A summary of consequence variables and results are provided in Section 4.1 of the project report. Full details on consequence results can be found in Appendix C.

2.1 Social Services

The simplified risk matrix for variables under the social services sector across the region is shown in Figure 2-1, while individual results for each partner are shown in Figure 2-2 and Figure 2-3.

Reviewing overall risk ratings, general population, vulnerable population, healthcare facilities, and social service facilities were considered to be at moderate risk. Schools and daycares were considered a lower risk overall.

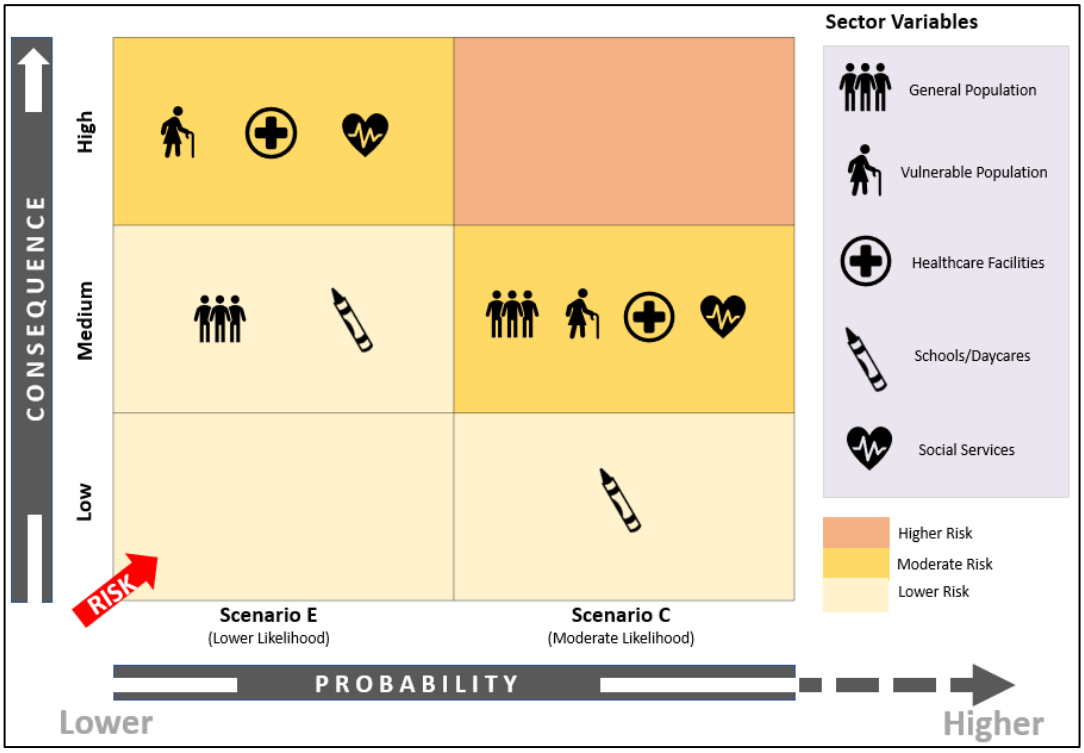


Figure 2-1: Simplified (Average) Risk Matrix - Social Services Sector

Reviewing individual scenario risk scores averaged across the North Shore from Figure 2-1, Technical Steering Committee members considered vulnerable populations, healthcare facilities, and socials services to face moderate risk in both Scenario C and E. These results suggest the high importance and vulnerability assigned to these variables, likely due in part to the important role healthcare and social service facilities play during emergecnies.

Displacement of the general population due to inundation was considered to have a moderate risk under Scenario C, and lower risk under Scenario E. This likely reflects the low relative increase in displacement between the two scenarios (0.8% in Scenario C, up to 1.6% in Scenario E). Inundation and power outage affecting educational facilities was considered to have a lower overall risk under both scenarios, despite the fact that schools and daycares were found to be the most severely impacted variable under Scenario C (2% affected), but one of the lower proportional impacts under Scenario E (22%). .

Figures 2-2 and 2-3 show risk scores for each social sector variable by each project partner for each scenario. This detailed summary shows how perceptions and priorities differ between partners.

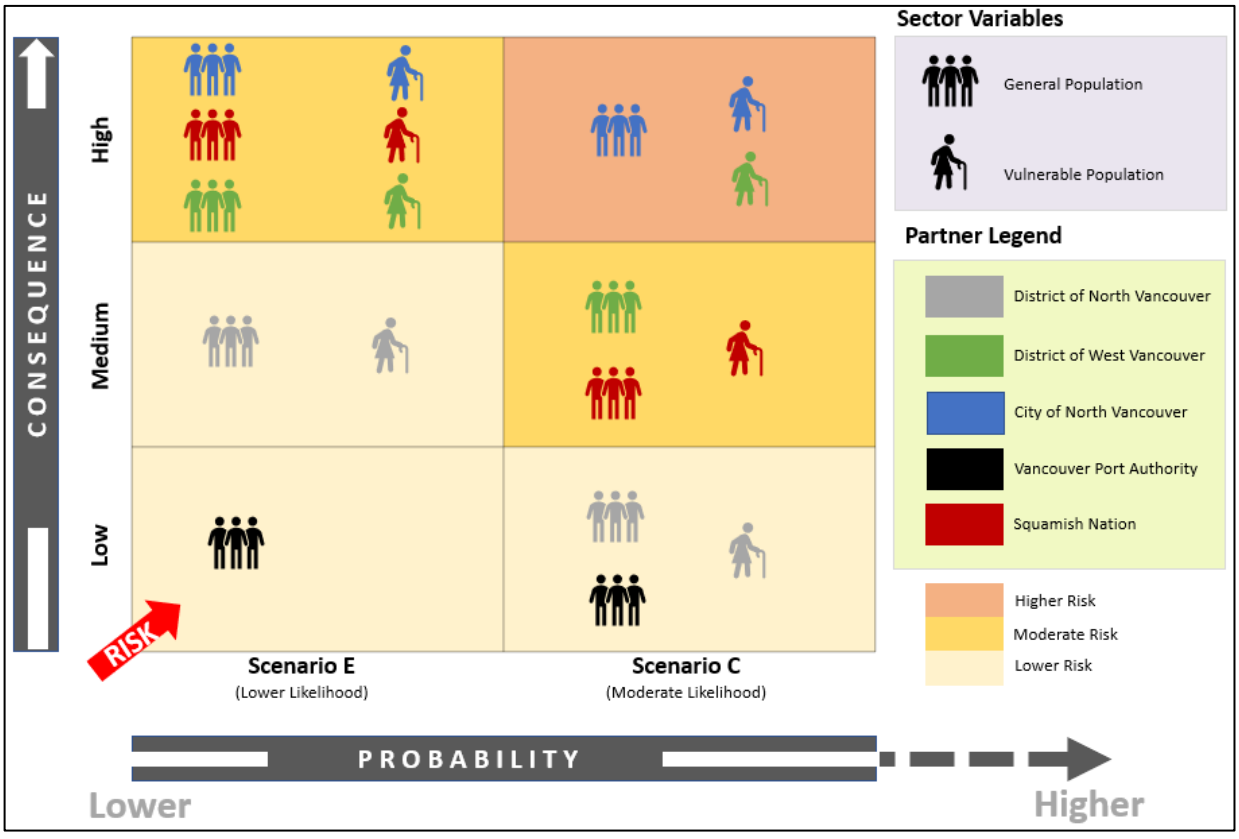


Figure 2-2: Clustered Risk Matrix - Social Services Sector (1)

While, on average, vulnerable populations and general population were considered to be at moderate risk, individual results show that the DWV and CNV consider these variables to be higher risk within their jurisdiction.

Technical Steering Committee members noted that general populations in the DWV and SN appear to be most significantly impacted overall by inundation and power outage in residential areas. In the DWV, 1% of the general population is expected to be displaced under Scenario C, increasing to 3% in Scenario E. In Squamish Nation, 5% of the general population faces displacement in Scenario C, increasing to 17% in Scenario E.

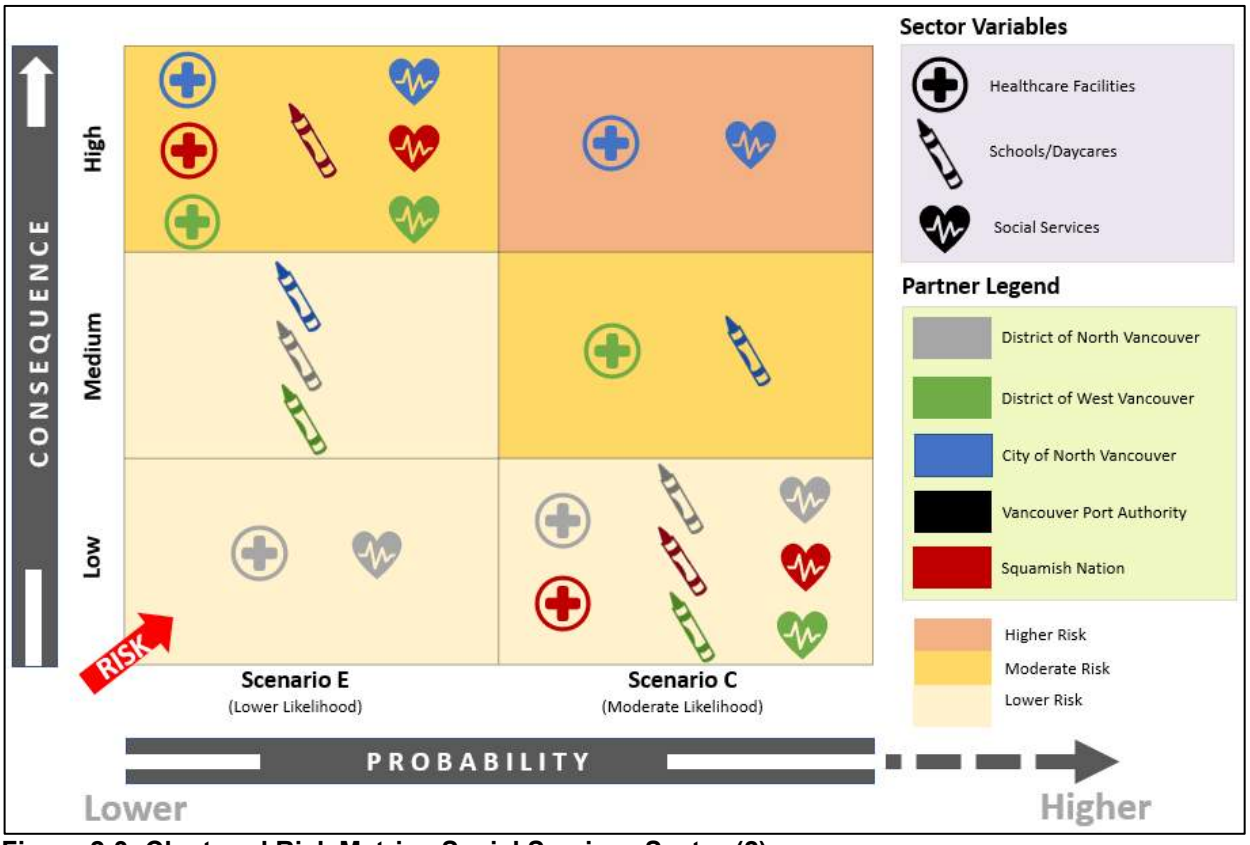


Figure 2-3: Clustered Risk Matrix - Social Services Sector (2)

Similarly, while most Technical Steering Committee members found healthcare and social service facilities to be at moderate risk under both scenarios, individual results show that the CNV considers these two variables to be at higher risk overall. However, while the SN and CNV found educational facilities to face moderate risk, all other partners rated this variable as lower risk.

The DNV identified impacts to healthcare and social service facilities as lower risk , reflecting the fact that a relatively lower proportion of these buildings within their jurisdiction would be impacted than in other jurisdictions.

2.2 Environment

Consequences from coastal flooding on parks and natural habitats were rated as lower to moderate risk by Technical Steering Committee members, on average, with consequence results remaining consistent across Scenarios C and E. Individual responses, however, varied more widely than average ratings. While the SN and DWV considering impacts to be lower risk, the DNV, Port, and CNV found impacts to be moderate – to higher risk in and around their jurisdictions, likely because the port terminals are located in low-lying areas of the DNV and CNV, within Port jurisdiction.

The simplified risk matrix for environmental consequences across the region, on average, is shown in Figure 2-4, while individual results for each partner are shown in Figure 2-5.

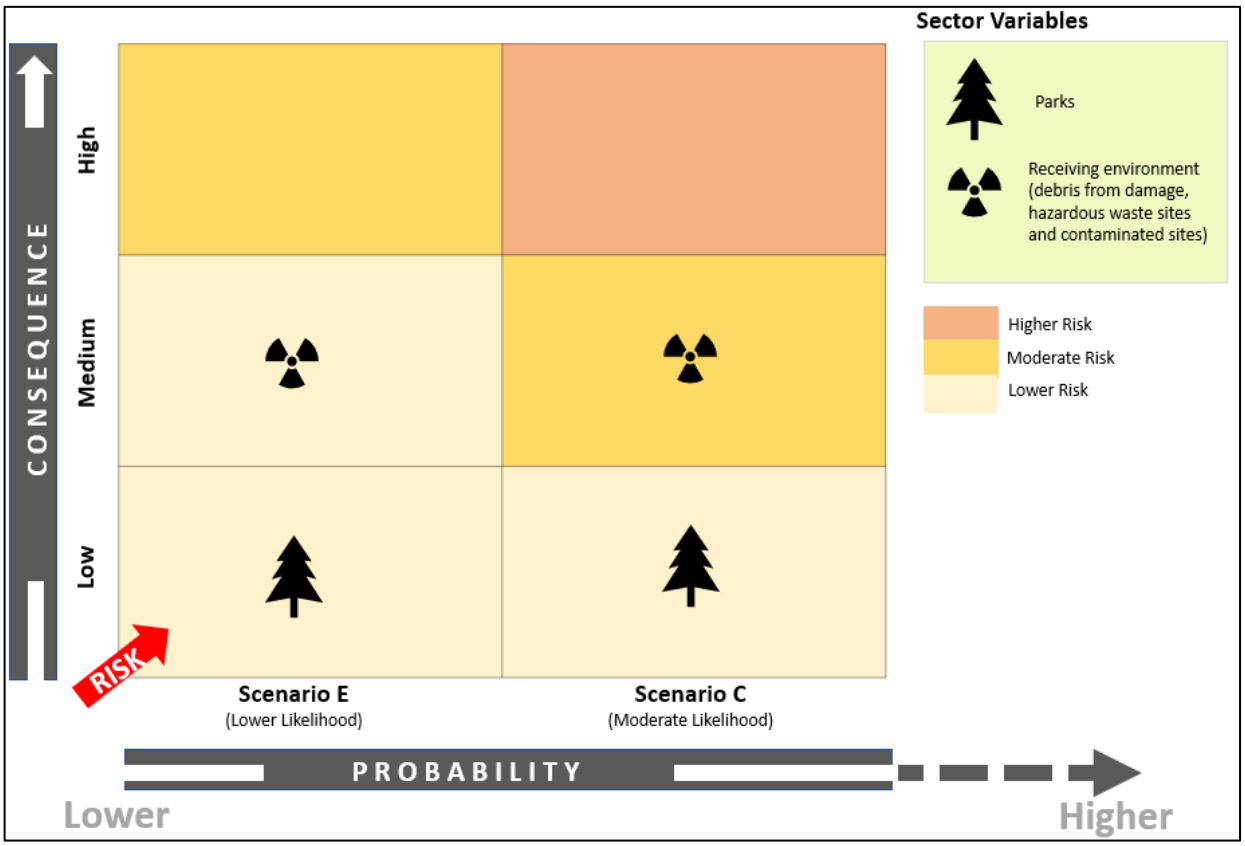


Figure 2-4: Simplified (Average) Risk Matrix - Environment Sector

As shown in Figure 2-4, Technical Steering Committee members generally considered coastal flood impacts on parks to be lower risk, likelybecause consequence outcomes, such as potential risk to human health and life, are lower compared to other consequence variables, while impacts to receiving environments as moderate risk. For both variables, consequence ratings were the same under both scenarios, with impacts to parks rated on average as low consequence and impacts to receiving environments as medium consequence.

Figure 2-5 shows risk ratings for each environmental sector variable by each project partner.

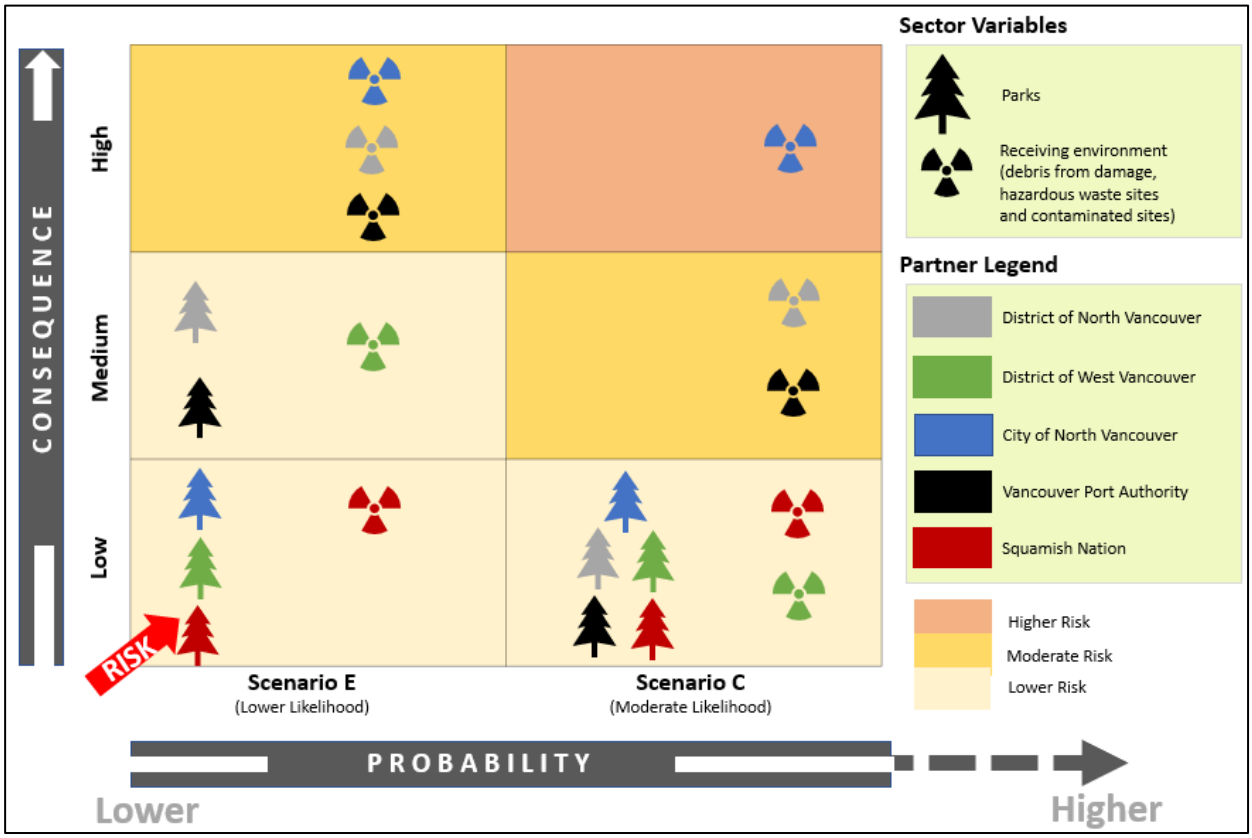


Figure 2-5: Clustered Risk Matrix - Environment Sector

As shown in Figure 2-5, the individual risk scores from each partner present a more varied picture of environmental risks than average results. Impacts to receiving environments were considered a higher risk by CNV, moderate risk by DNV and the Port, and lower risk by Squamish Nation.

In comments on the questionnaire and risk assessment workshop, the DWV indicated particular concern with the quantity of debris (52,000 tonnes) generated across the North Shore under Scenario E. Similarly, the Port highlighted concerns about the potential release of contamination from on-site fuel storage, wastewater treatment facilities, and bulk materials on Port lands.

Consistent with average results, most Technical Steering Committee members found coastal flood impacts on parks to be lower risk. Through comments at the workshop, Technical Steering Committee members noted that, while parks can better accommodate flooding, park closure can have significant impacts on recreational use and environmental habitats. The DNV also noted concern about Scenario E impacts from inundation and shoreline erosion to waterfront trails and parks, including boat launches, wharves, and street waterfront access.

2.3 Culture and Heritage

Consequences from coastal flooding on culture and heritage sites were rated as lower to moderate risk by most Technical Steering Committee members, with consequences remaining relatively consistent across Scenarios C and E.

The simplified risk matrix for culture and heritage sites across the region, on average, is shown in Figure 2-6. Individual results for each partner are shown in Figure 2-7.

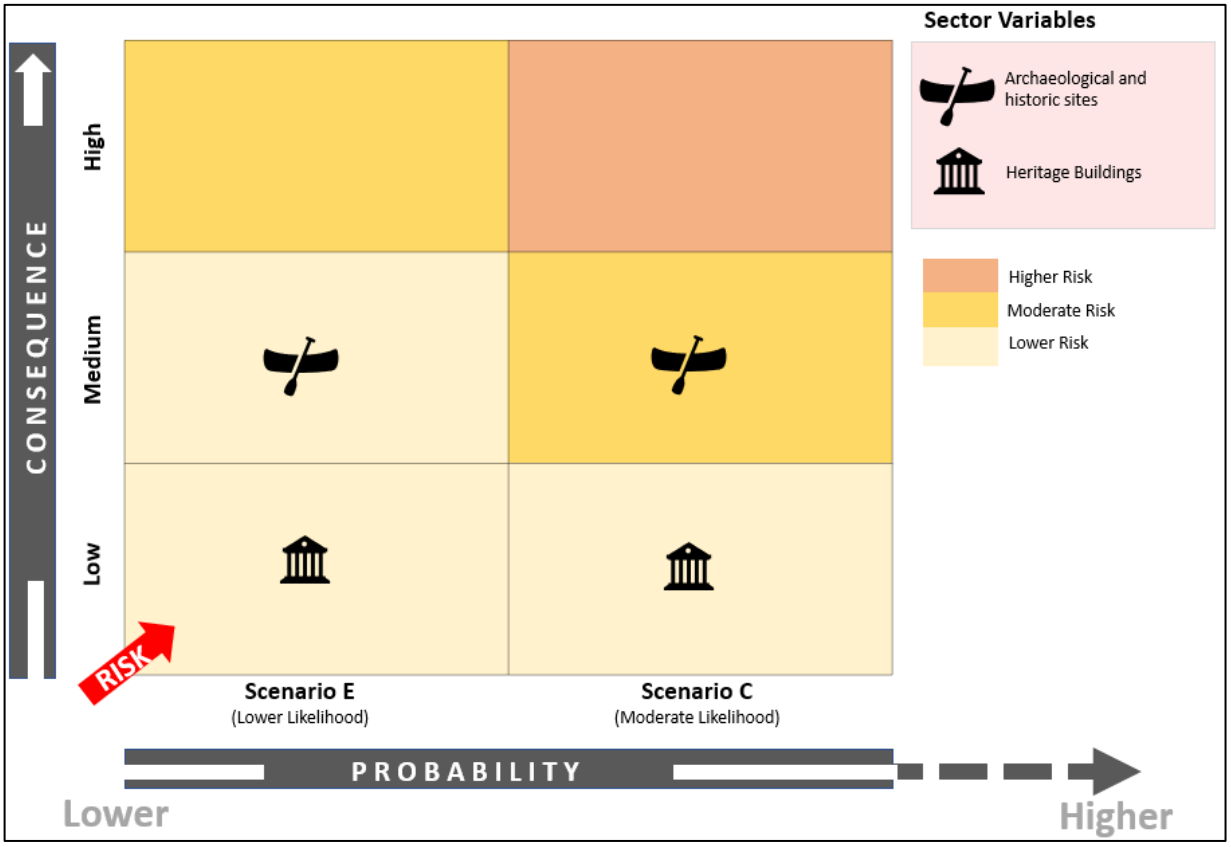


Figure 2-6: Simplified (Average) Risk Matrix - Culture and Heritage Sector

Technical Steering Committee members generally considered coastal flood impacts to pose a lower risk to heritage buildings, and a moderate risk to archaeological and historic sites. For both variables, consequence ratings were the same under both scenarios, with impacts to heritage buildings rated on average as low consequence and impacts to archaeological and historic sites as medium consequence.

Figure 2-7 shows risk ratings for each culture and heritage sector variable by each project partner.

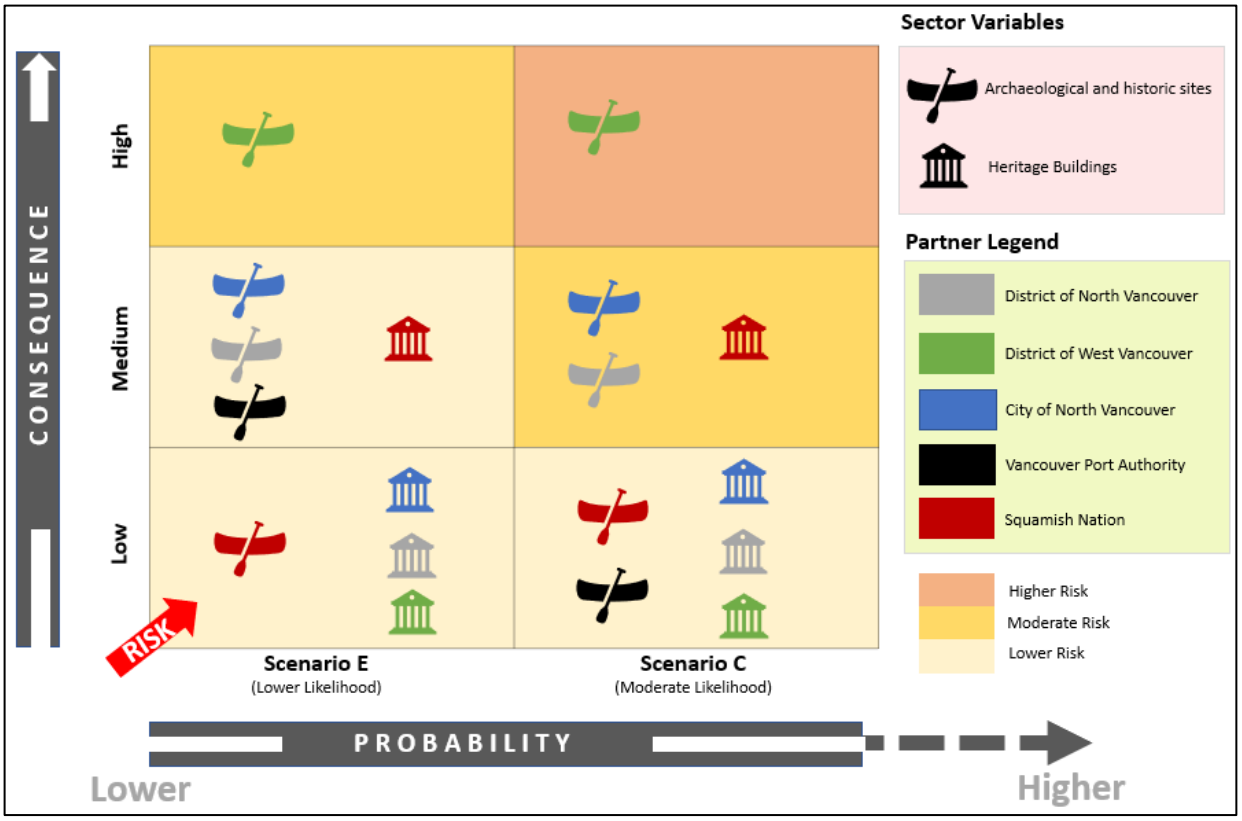


Figure 2-7: Clustered Risk Matrix - Culture and Heritage Sector

As with environmental sector variables, the individual risk scores present a more varied picture than the average ratings. While archaeological and historic sites were found as a medium risk on average, the DWV considered impacts to be a higher risk in their jurisdiction, while the SN considered impacts as a lower risk.

Consequence ratings for heritage buildings were more consistent, with almost all Technical Steering Committee members (DWV, CNV, DNV) considering impacts as low consequence and lower risk under both Scenarios. Only the SN identified impacts to heritage buildings as a medium consequence under both scenarios, and ultimately a moderate risk.

Culture and heritage sites noted in questionnaire and workshop comments as being of particular concern include shell middens, heritage buildings (e.g. Ferry Building in the DWV), and the Lower Caulfeild Heritage Conservation Area (DWV). The DNV expressed concern about potential inundation of archaeological sites within waterfront parks.

2.4 Buildings and Infrastructure

Building and infrastructure variables were considered by Technical Steering Committee members as the most at risk sector from coastal flooding overall.

The simplified risk matrix for environmental consequences across the region, on average, is shown in Figure 2-8, while individual results for each partner are shown in Figure 2-9 and Figure 2-10.

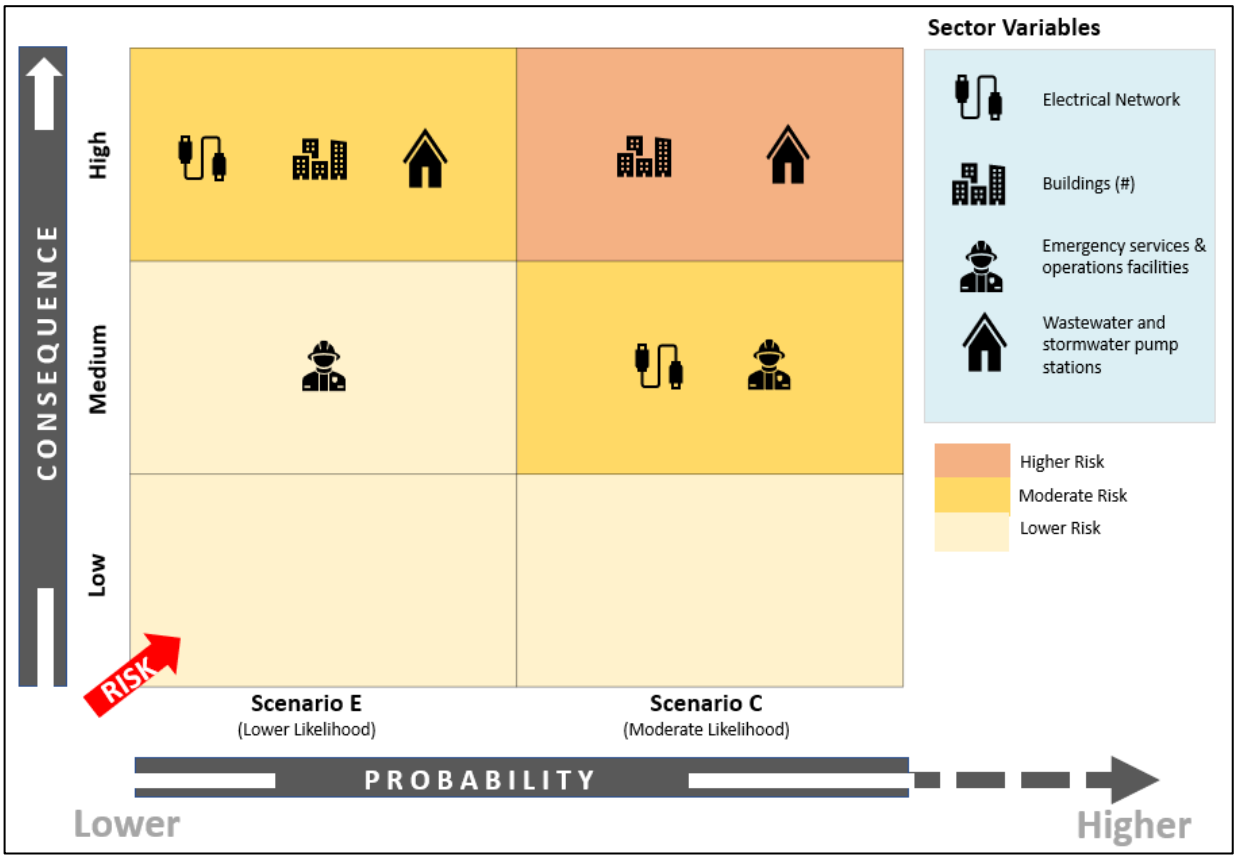


Figure 2-8: Simplified (Average) Risk Matrix - Buildings and Infrastructure Sector

On average, Technical Steering Committee members rated the number of buildings exposed to inundation, and the number of pump stations exposed to inundation, as higher risk. The extent of power outages across the North Shore and impacts to emergency services and operations facilities were both rated as moderate risk.

Figures 2-9 and 2-10 show risk ratings for each buildings and infrastructure sector variable by each project partner.

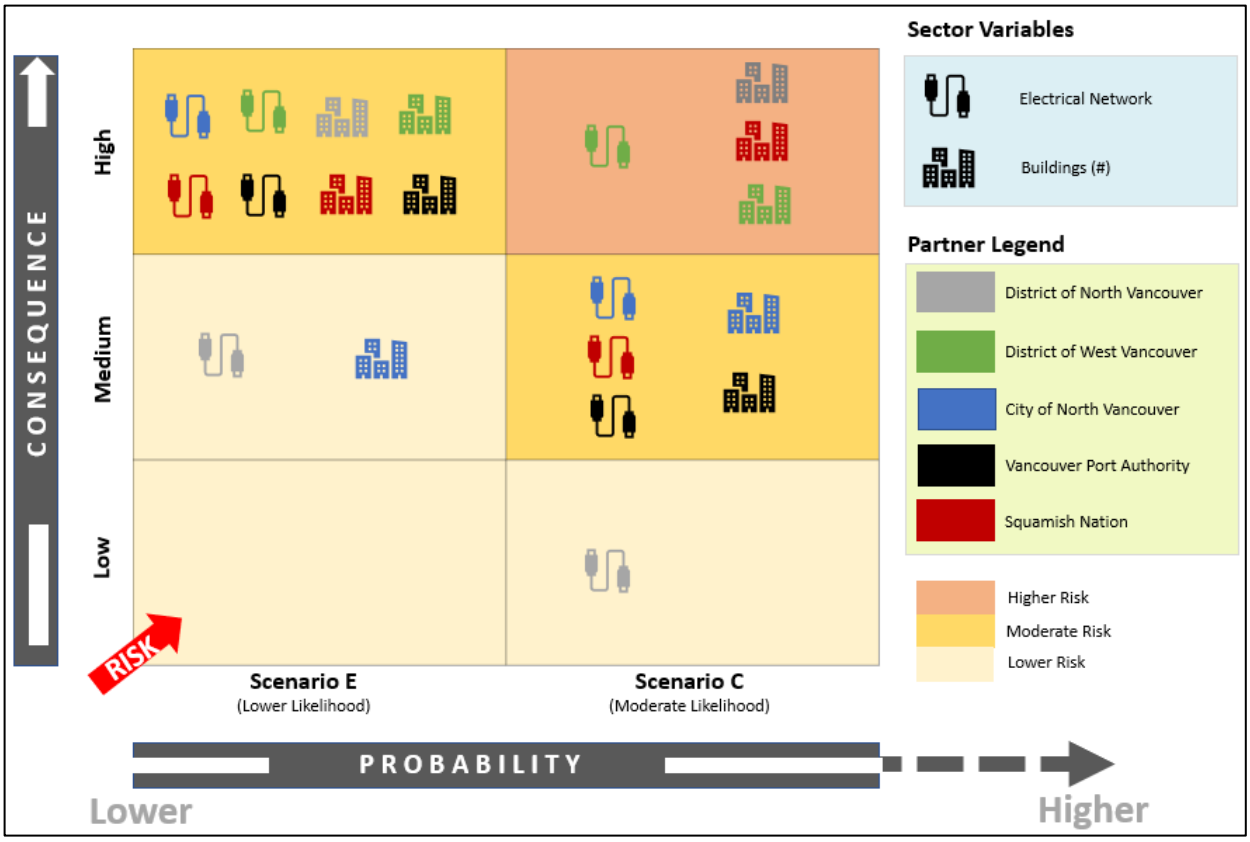


Figure 2-9: Clustered Risk Matrix - Buildings and Infrastructure Sector (1)

The majority of Technical Steering Committee members (DWV, SN, DNV) considered the number of buildings inundated to be a higher risk, while CNV and the Port both considered these impacts to be moderate risk. Compared with all other partners, the SN had the highest proportion of their buildings inundated under Scenario C (8%). The Port had the highest proportion inundated under Scenario E (37%), marking a large increase from the number of buildings inundated under Scenario C (6%). Consequence results estimate that the CNV will have the lowest proportion of buildings inundated under both scenarios, which is reflected in the relatively lower consequence and risk ratings for this variable.

DWV noted that buildings in Ambleside, Park Royal, and along the waterfront below Marine Drive are highest risk within their jurisdiction. The Port expressed concern about inundation of office spaces, maintenance workshops, materials and goods storage buildings on Port lands.

The DWV was the only partner identifying power outages as a higher risk as the DWV is the second most impacted partner, with 0.4% of the population impacted under Scenario C and 49% under Scenario E. The CNV, SN, and Port identified this variable as a moderate risk, while the DNV considered this as a lower risk reflecting the extent of impact. This variation in risk ratings is consistent with the varying extent of outages, which will post the most significant impacts to DWV and SN.

Consequence results indicate that the SN will be the partner most affected by power outages, with 2.1% of their North Shore population experiencing outages under Scenario C increasing to a significant 82% under Scenario E. The Port noted that power loss causes significant disruption to port operations,

though operators are now taking steps to build their resilience (e.g. placing transformers and switching units on pedestals or higher ground).

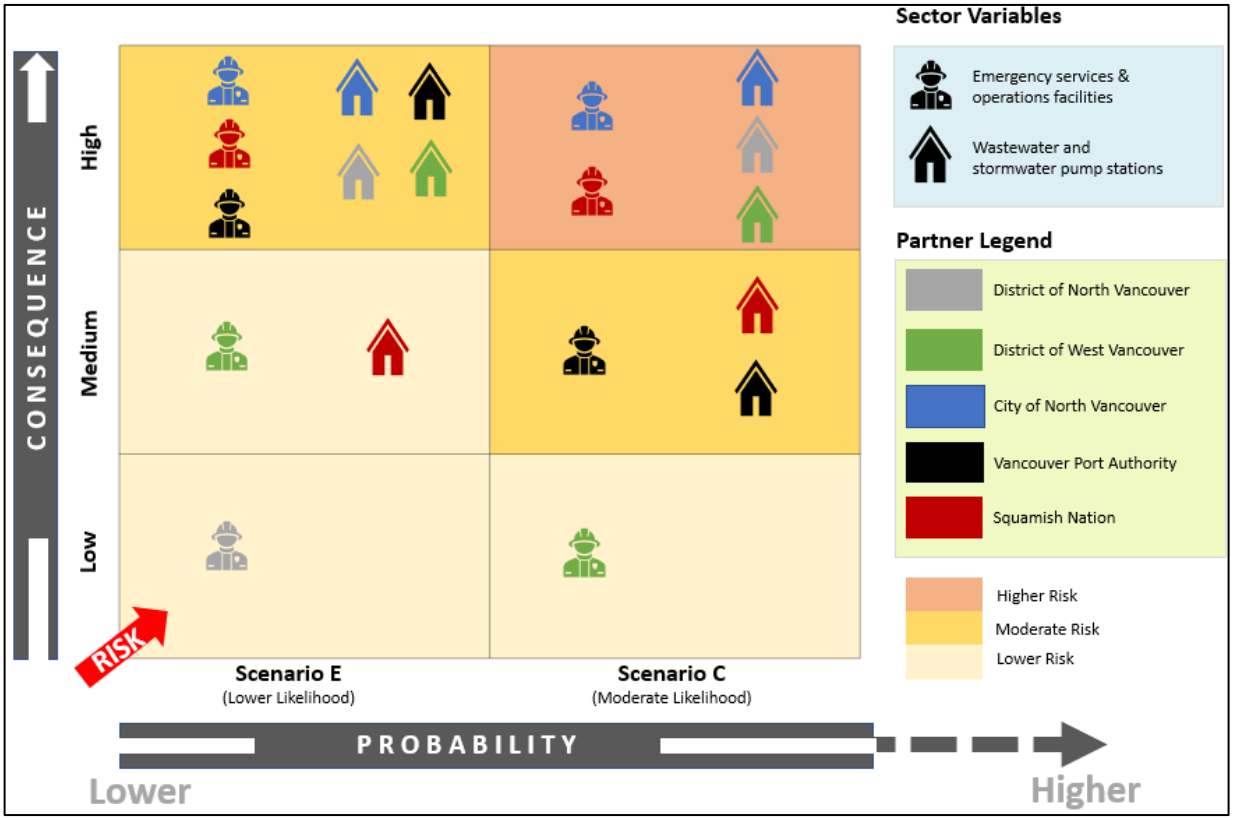


Figure 2-10: Clustered Risk Matrix - Buildings and Infrastructure Sector (2)

Technical Steering Committee members from the CNV, DNV, and DWV considered coastal flood impacts on wastewater pump stations as a higher risk overall. The Port and SN both defined these impacts as moderate risk.

Consequence results suggest that impacts will be particularly significant for wastewater pump stations, with an estimated 35 wastewater pump stations (46%) affected under Scenario C, including the only pump station in Squamish Nation. Effects are expected to increase to 50 wastewater pump stations (65%) under Scenario E, including 7 stations in CNV (70%), and 24 stations in DWV (80%). Pump station inundation poses a risk of damage, cross-contamination, and backflow.

While relatively few emergency facilities and operations centres are impacted under both scenarios, the CNV and SN identified these impacts as higher risk, while the DWV and DNV identified consequences as lower risk. In the DWV under Scenario E, West Vancouver Fire and Rescue Services Station 1 (760 16th St; 25% of all fire stations within DWV), as well as the DWV's only police station (West Vancouver Police Department, 755 16th St) and BC Ambulance Cervice (Station 255, 1542 Fulton Ave) would be inundated. The DNV assessed impacts as lower risk under Scenario E and did not assign a risk rating for Scenario C due to the absence of impacts in their jurisdiction.

2.5 Economy

Coastal flooding is expected to pose a moderate to higher risk to the North Shore economy, including impacts to local businesses and port operators.

The simplified risk matrix for environmental consequences across the region, on average, is shown in Figure 2-11, while individual results for each partner are shown in Figure 2-12.

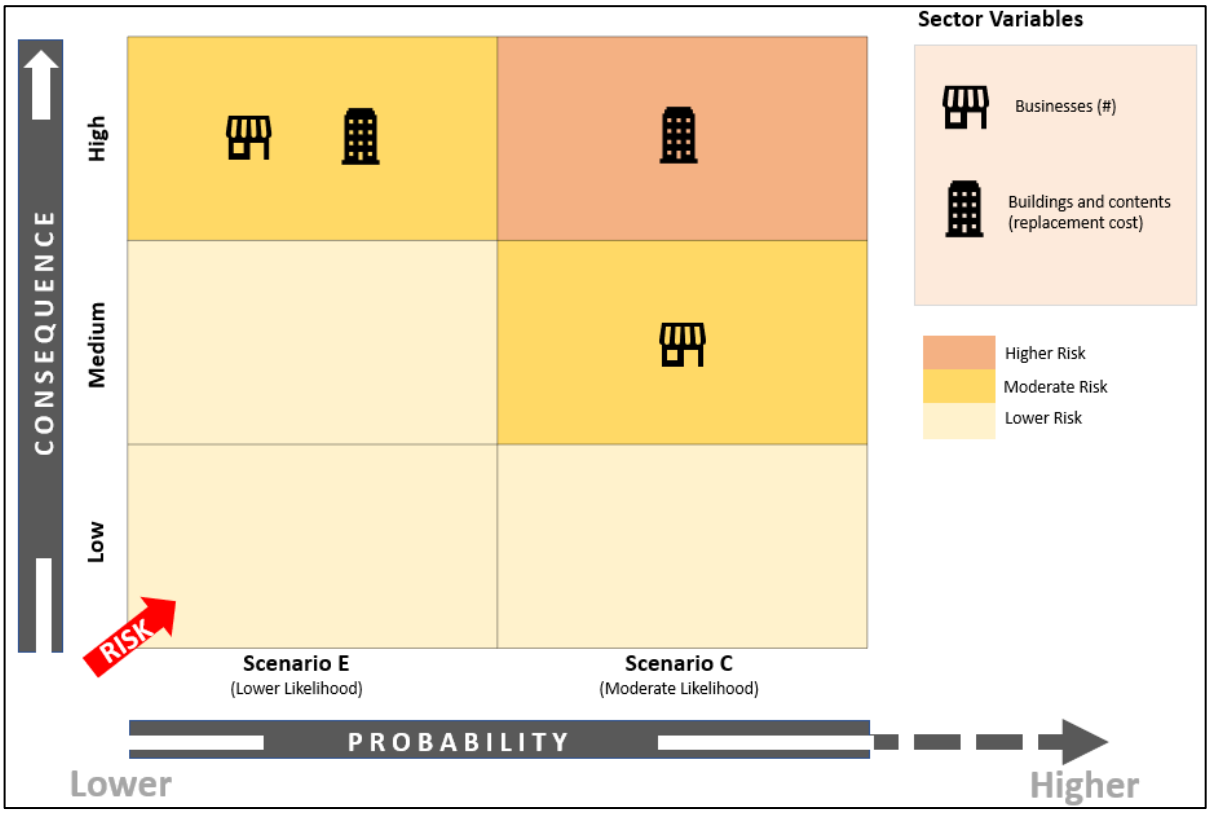


Figure 2-11: Simplified (Average) Risk Matrix - Economy Sector

On average, Technical Steering Committee members interpreted building damage costs as a higher risk, while the number of businesses impacted by inundation and/or power outage was considered a moderate risk.

Figure 2-12 shows risk ratings for each economy sector variable by each project partner.

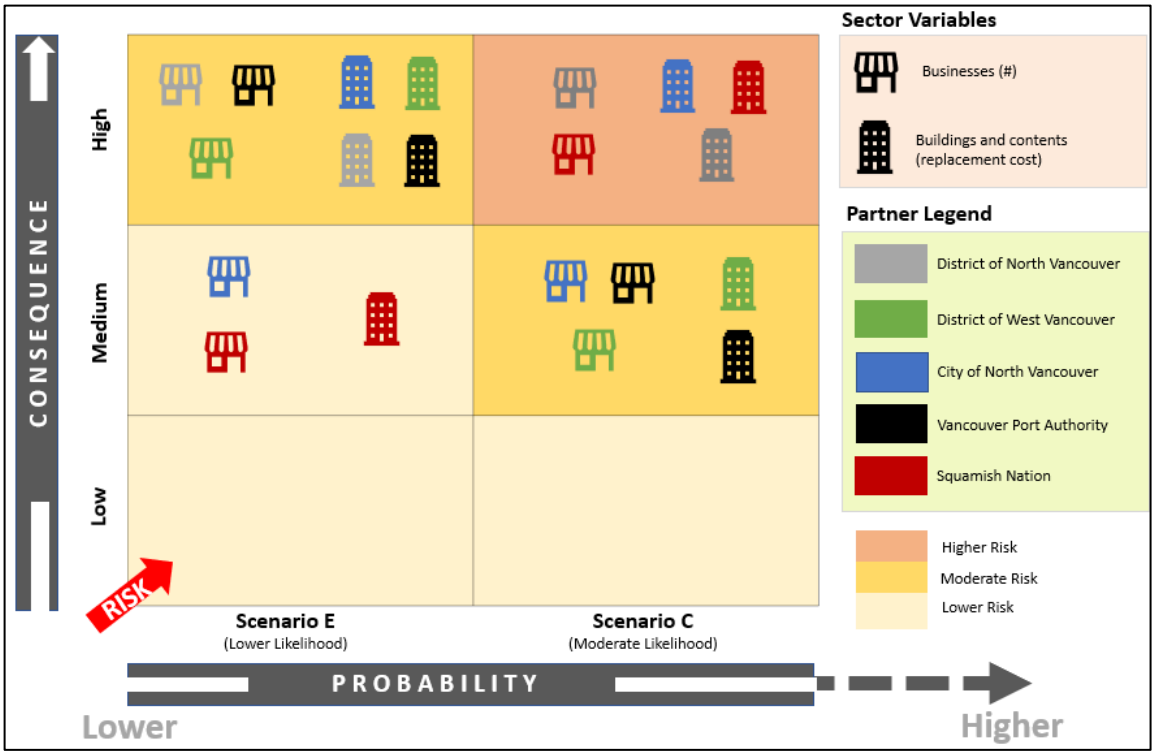


Figure 2-12: Clustered Risk Matrix - Economy Sector

Consist of average results, most project partners (SNV, SN, DNV) considered building damage as a higher risk, while the Port and DWV considered these impacts to be moderate risks. The DNV stated concerns about the impact increasing flood risk might have on businesses and raised the equity issue of who should pay for damages.

The DNV and SN also considered business disruption to be a higher risk, while the Port, DWV, and CNV considered this to be a moderate risk. In written comments, the DWV highlighted business disruption as a top concern, noting that approximately 20% of businesses within their jurisdiction face temporary closure in Scenario E. The DWV also noted that, in their jurisdiction, flooding under Scenario E opens up risk to a significant number of multi-family buildings and additional impacts on high-value residential properties. The SN highlighted impacts to retail tenants at Park Royal Village Shopping Centre as a particular concern.

The Port noted that many port operators practice finely tuned “just-in-time” operations that would be significantly impacted by disruption from inundation or power outage. As a result, any interruption, even minor, could have serious consequences for port operations, related rail and supply networks, and export industries nation-wide (e.g. farming, mining, lumber). The Port also noted that certain operators are more vulnerable to flood damage than others, including operators with primary access points in inundated areas and bulk material handling facilities with below-grade dumper pits and conveyor systems (e.g. Neptune Potash Facility). The Port expressed concern about impacted job productivity due to interruptions, noting that Seaspan Shipyards is currently the largest employer on Port lands, with up to 1,500 employees at two major sites at any time. It should be noted that a separate economic impact assessment was conducted for port terminal operations which included interviews with port terminal operation staff – refer to Appendix E (Port Economic Flood Consequence Assessment).

2.6 Transportation

Important transportation corridors and routes across the North Shore will be impacted by coastal flooding. On average, Technical Steering Committee members found inundation of emergency routes to be higher risk, and impacts to major routes, bus networks, and gas stations as a lower risk.

The simplified risk matrix for transportation variables across the region, on average, is shown in Figure 2-13, while individual results for each project partner are shown in Figures 2-14 and 2-15.

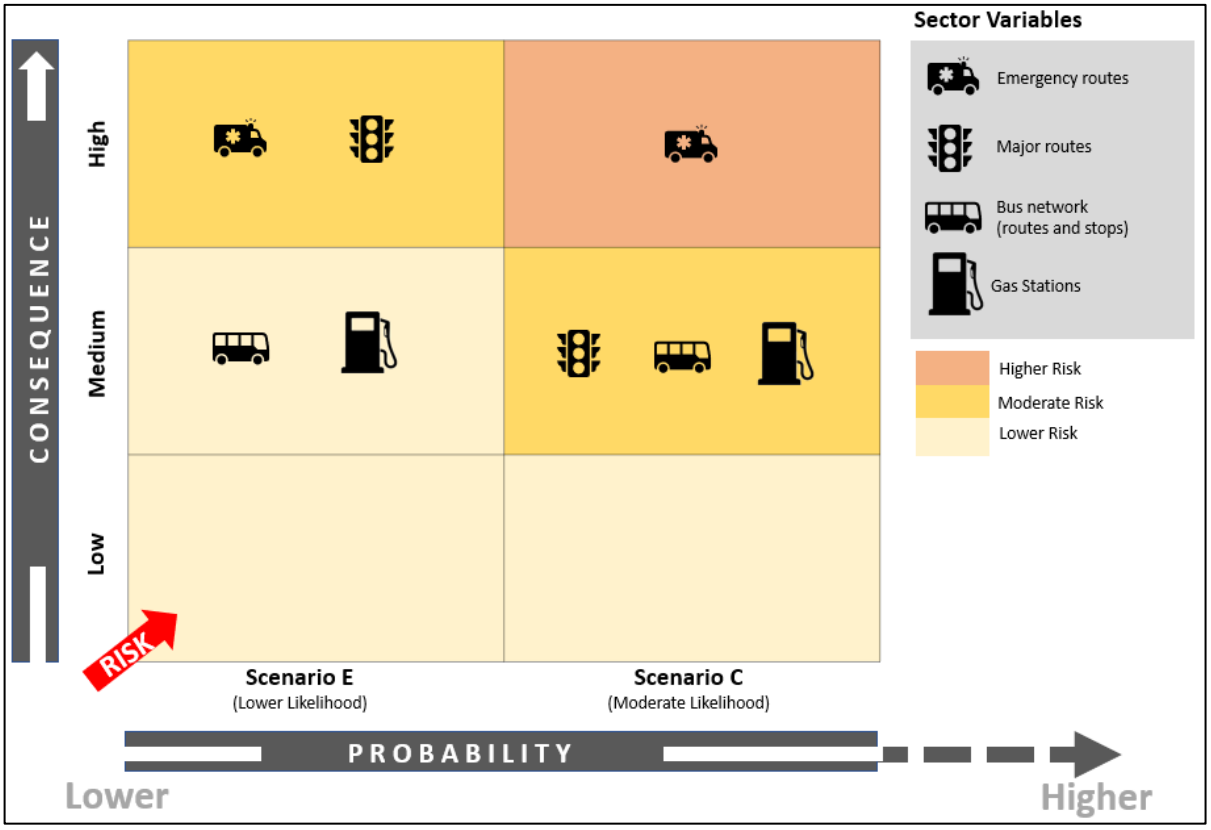


Figure 2-13: Simplified (Average) Risk Matrix - Transportation Sector

Figures 2-14 and 2-15 show risk ratings for each transportation sector variable by each project partner.

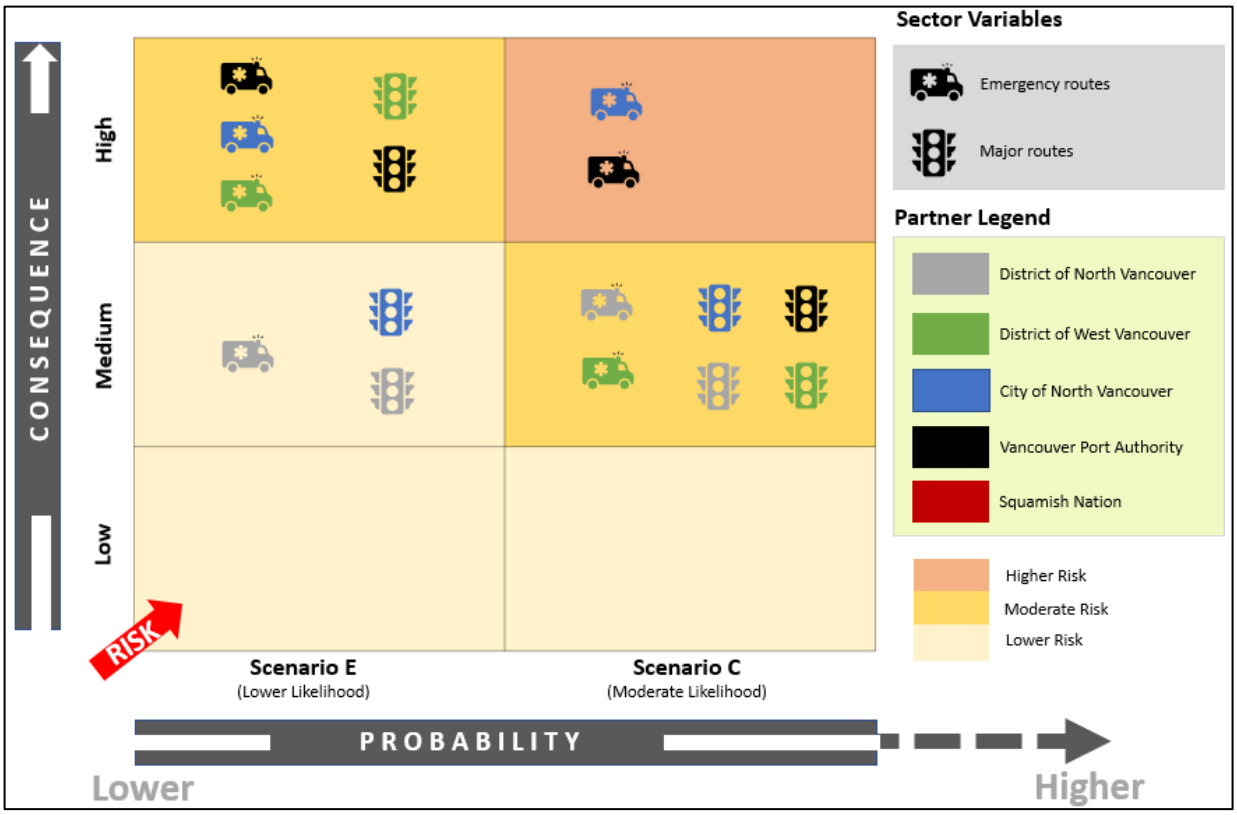


Figure 2-14: Clustered Risk Matrix - Infrastructure Sector (1)

While emergency routes were considered to be the highest risk transportation variable on average, individual results show that on the CNV and Port considered this a higher risk, with all other partners defining this a moderate risk. All partners considered inundation of major routes to be a moderate risk, with the exception of SN who declined to comment as transportation right-of-ways out not within their jurisdiction.

The DWV raised particular concern about the inundation and disruption of Marine Drive, a major arterial and commercial area. While the DNV noted that many major arterial roads on the North Shore were above inundation areas, they highlighted potential impacts to Cotton Rd (arterial access point from CNV to DNV), Dollarton Bridge and Highway, Main St. at the Highway 1 overpass (Lower Lynn Exchange), and West 1st Ave as concerns.

The Port discussed the impact that blocked road and rail access would have in disrupting port operations. In particular, a low area near the Philip Ave rail overpass falls within the inundation area, threatening both rail and road connectivity to operators. Overland flooding in the low-lying area near Lynnterm Marina could also cut off access to Lynnterm via Mountain Hwy at the railway underpass.

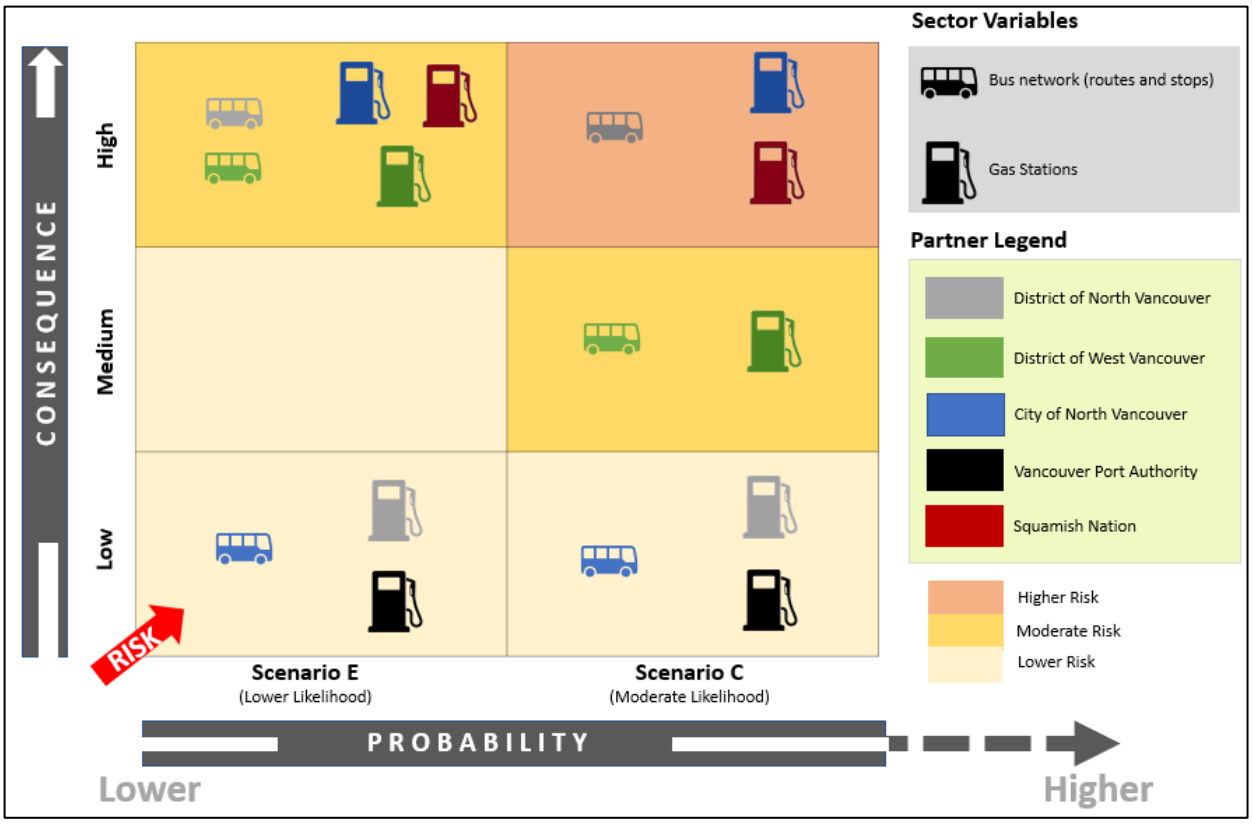


Figure 2-15: Clustered Risk Matrix - Transportation Sector (2)

While both bus and gas station variables were considered moderate consequence under both scenarios on average, individual results show a much more varied picture. The CNV and SN considered impacts on gas stations as a higher risk, while the DWV considers impacts as moderate risk, and the DNV and Port assessing impacts as lower risk. However, despite identifying gas station impacts as lower risk, the DNV noted concerns about contamination risks associated with gas station inundation, threatening public and ecological health.

While the DNV considered impacts to gas stations to be a lower risk, they found impacts to bus routes and stops to be higher risk. The DWV considered but route impacts as moderate risk, while CNV considered this as lower risk. The Port and SN declined to comment on bus routes as they are out of their jurisdiction.

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Revision History

Revision #	Date	Status	Revision	Author
0	July 16, 2020	Final	Revised based on client review	RNH / ATAL

KERR WOOD LEIDAL
consulting engineers

Appendix E

Port Economic Flood Consequence Assessment

North Shore Sea Level Rise Port Impact Analysis

July 7, 2020



Davies Transportation Consulting Inc.

North Shore Sea Level Rise Port Impact Analysis

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1 Introduction

The North Shore municipalities (including the District of North Vancouver, City of North Vancouver and District of West Vancouver) and the Vancouver Fraser Port Authority and Squamish First Nation are collaborating on a coordinated risk assessment and climate adaptation planning process. The objective is to assess the vulnerability of the North Shore to sea-level rise and to identify priority areas for mitigation, adaptation and risk management. The District of North Vancouver is the lead agency.

The project is designed to delineate the sea level rise hazard boundary for the North Shore; quantify and build a collective understanding of the coastal hazard exposure, vulnerability and risk; explore what's important to the community; and identify key action areas to minimize North Shore risk and promote community adaptability and resiliency to coastal flooding and sea level rise impacts.

The project is being carried out by Kerr Wood Leidal Associates Ltd., a consulting firm specializing in water infrastructure engineering services for municipal development based in Burnaby. Davies Transportation Consulting Inc. (DTCI) has been engaged as a subconsultant to address vulnerability and risk relating to port terminals and other industrial facilities (including Vancouver Fraser Port Authority properties) on the North Shore, and to estimate potential economic impacts of disruptions to the goods movement system. All of the terminals and other industrial facilities surveyed are located on the North Shore of Burrard Inlet, and are located in either the City of North Vancouver or District of North Vancouver.

This study complements a broader study on adaptation to climate change encompassing all Port properties which is being undertaken by Vancouver Fraser Port Authority (VFPA). VFPA is responsible for federally-owned lands and waters defined in the Port's Letters Patent under the Canada Marine Act. The Port's jurisdiction is a mix of navigational authority throughout this area and jurisdiction over certain real property in Burrard Inlet, Indian Arm, lands and waters east of the provincial bed of the Fraser River, and various federal holdings in the North, South and Middle Arms of the Fraser River. Port stakeholders were surveyed through a collaborative effort between DTCI and VFPA; details are provided in Appendix A. VFPA provided detailed mapping of potential flooding scenarios to facilitate discussions with the terminal operators and more detailed analysis of potential impacts.

2 Previous Port Studies on Sea Level Rise Impacts

The material in this section of the report includes a summary of previous North American studies on the impacts of sea level rise on major ports. No relevant Canadian studies were found. U.S. studies reviewed include the Port of Los Angeles, California; San Francisco Bay, California; the Ports of Seattle and Tacoma, Washington State; and the Port of New York/New Jersey. Additional details are provided in Appendix B.

2.1 U.S. Sea Level Rise Jurisdiction and Policy

Responsibility and authority for planning and implementing coastal programs in the United States is shared amongst federal, state and local agencies:

- The U.S. *Coastal Zone Management Act* (CZMA) of 1972 establishes the primacy of State governments in coastal management. Federal grants are provided to the States for coastal management program development and implementation subject to compliance with national requirements.

- The U.S. Federal Emergency Management Agency plays a major role in flood hazard mapping and insurance which in turn influences local building codes.

- All of the States examined in this review have established Coastal Management Programs administered by government agencies (California Coastal Commission, San Francisco Bay Conservation and Development Commission) or departments (Washington State Department of Ecology; New Jersey Department of Environmental Protection; New York Department of State).

- State agencies typically delegate regulatory powers to county or local governments subject to compliance with State legislation and regulations.

- Port authorities on the West Coast are primarily under municipal government control. The Southern California Ports of Los Angeles and Long Beach are departments of the respective City governments. The Ports of Tacoma and Seattle are quasi-governmental agencies overseen by commissioners elected directly by county voters.

- The Port Authority of New York/New Jersey is a bistate agency established in 1921 through an interstate compact authorized by the United States Congress.

- Authority to grant development permits on Port property is typically delegated to the local Port Authorities, subject to compliance with federal and state environmental regulations. In the absence of federal or state regulations requiring consideration of sea level rise in planning of seaport facilities, policies are set by the respective local port authorities.

2.2 Vulnerability of Port Assets

Vulnerabilities identified in the research include:

- Marine Terminals: Port terminals are subject to flooding and inundation, with potential damage to cargo handling equipment and economic impacts related to interruption in port operations. Inundation from rising sea levels could challenge the capacity of storm drains and treatment facilities at the terminal. Rising sea levels could also inundate or disrupt numerous nearshore facilities due to flooding caused by the increased elevation of receiving water bodies. To address potential problems in some instances drainage facilities may need to be enlarged to provide storage for additional storm water volumes that could result from water backing up due to sea level rise. Sea level rise could also affect the efficiency of cargo handling operations due to reduction of air draft under bridges and terminal handling equipment.

- Electrical infrastructure: Low-lying electrical infrastructure is at risk of damage due to flooding. The electrical infrastructure may be located on property occupied by the marine terminal, on port owned lands or may part of the general civil infrastructure that service port facilities.

- Transportation Infrastructure: Road and rail links to port facilities may be vulnerable to flood damage and interruption of operations. Transportation infrastructure such as railway lines are most often privately owned whereas road infrastructure is usually publicly owned. In some instances, there may be private industrial roads.

The impact of Hurricane Sandy on the Port of New York/New Jersey provides a practical example of impacts of flooding on a major port complex. During Hurricane Sandy storm tides reached a record 14.58 feet (4.5 m) at Bergen Point, a critical area between New York and New Jersey along the Kill Van Kull and Arthur Kill waterways that hosts a concentration of oil refineries and petroleum-chemical holding facilities. Flood inundation levels (water height above ground level) on normally dry land were 2 to 9 feet (.6 m to 2.7 m) in areas of New Jersey containing port

infrastructure.[1] Impacts included damage to electrical equipment, such as electric motors used to power cranes used for offloading cargo; damage to equipment such as truck chassis used for transporting cargo beyond the Port; damage to docks and piers that support responder, passenger ferry, and other vital operations; and damage to scientific equipment used for conducting harbor surveys which were required to enable reopening of the Port. The Port was closed to all traffic on October 28, 2012 and not fully reopened until November 4, 2012.[2]

2.3 Mitigation and Adaptation Strategies

Planning studies on sea level rise have been conducted in all of the United States jurisdictions examined. Significant findings relevant to the current study include:

- Forecasts of local sea level rise based on Greenhouse Gas emission forecasts (all ports) and local storm and tidal conditions (all ports); geological conditions were also considered in the Washington State study.

- Flood mapping incorporating sea level rise estimates were used to identify vulnerable assets on port property.

Efforts on mitigation and adaptation strategies vary widely among ports due to the absence of federal or state regulations requiring consideration of sea level rise in planning of seaport facilities. For example:

- Major California ports do not appear to have required planning for sea level rise in planning new facilities.

- The Port of Seattle is developing a draft climate change adaptation plan to address projected rates of sea level rise at Port facilities. An assessment of potential impacts of sea level rise was included in the Final Environmental Impact Statement for the Terminal 5 Cargo Wharf Rehabilitation, Berth Deepening and Improvements project in 2016.

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[1] Tropical Cyclone Report: Hurricane Sandy (AL182012), 22 – 29 October 2012 Blake, E.S. T.B. Kimberlain, R.J. Berg, J.P. Cangialosi, and J.L. Beven II National Hurricane Center 2013. https://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf

[2] Assessing the Impacts of Hurricane Sandy on the Port of New York and New Jersey's Maritime Responders and Response Infrastructure Tiffany C. Smythe, Ph.D. Post-Doctoral Fellow in Maritime Policy Center for Maritime Policy & Strategy, U.S. Coast Guard Academy p. 7 https://hazards.colorado.edu/uploads/quick_report/smythe_2013.pdf

- The first edition of the Port Authority New York New Jersey Climate Resilience Design Guidelines was issued in 2015; the most recent version was released in June 2018. Objectives of the Guidelines include supporting the incorporation of climate change projections—particularly sea level rise— into the full range of Port Authority engineering and architectural design standards, as a supplement to applicable building code requirements; and providing a clear methodology for factoring projected future sea level rise into project design criteria, while maintaining the flexibility of project teams to develop cost-effective design solutions.

- Due to the long-term nature of sea level rise, approaches to mitigation and adaptation strategies have focused on the service life of port facilities. For example, in the Port of Seattle's draft climate change adaptation plan (unpublished) the longest design life that the Port of Seattle assigns to an asset is 50 years; and the most likely amount of sea level rise that an asset will experience over the next 50 years was estimated at approximately nine inches (.23 m). Due to the high cost of mitigating impacts at existing facilities, attention has been focused primarily on design recommendations for major new facilities to be constructed in future years.

- There appear to have been no detailed studies of the potential economic impacts of sea level rise for the ports surveyed.

3 Port of Vancouver North Shore Trade Area

The Port of Vancouver's North Shore Trade Area is a critical export gateway to the Asia-Pacific region. It consists of port terminals and other industrial facilities along the North Shore of Burrard Inlet located on Port and privately-owned properties. VFPA operates as a landlord port, leasing property to private sector firms who construct and operate port terminals and other industrial facilities. In 2017, the North Shore Trade Area handled almost 34 million tonnes of cargo with a value of almost $15 billion. The area is a significant economic generator of employment in the marine, rail and trucking industries. It also supports employment in various export-based industries, including agriculture, forestry, mining and manufacturing in B.C., throughout western Canada, and across Canada as a whole.

3.1 Major Industrial Facilities

The locations of port terminals and industrial facilities in the North Shore Trade Area are shown below. These include facilities on Port property and those located on privately owned land.

Figure 3-1 North Shore Trade Area Industrial Facilities

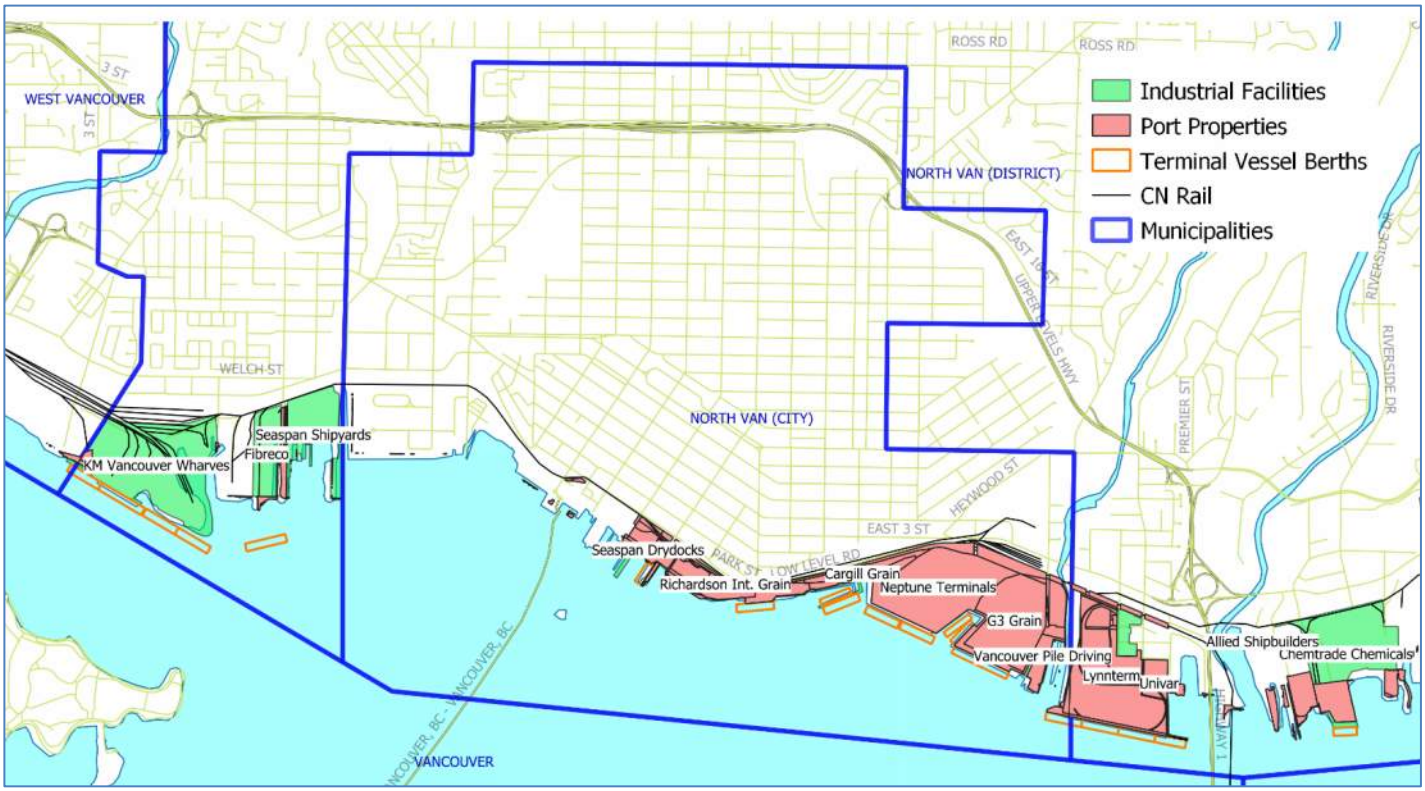


Figure 3-2 North Shore Trade Area Major Industrial Facilities Description

North Shore Major Industrial Facilities			
Facility	**Type**	**Primary Commodities**	**Municipality**
Kinder Morgan Vancouver Wharves	Port Terminal	Metal concentrates, grain, diesel fuel	DNV
Fibreco	Port Terminal	Wood chips, wood pellets, grain	DNV
Seaspan Shipyards	Shipbuilding and Ship Repair	n/a	DNV
Seaspan Drydock	Ship Repair	n/a	CNV
Richardson International Grain	Port Terminal	Grain	CNV
Cargill	Port Terminal	Grain	CNV
Neptune Bulk Terminals	Port Terminal	Coal, potash	CNV
G3 Canada (under construction)	Port Terminal	Grain	CNV
Vancouver Pile Driving	Marine Structures	n/a	CNV
Lynnterm	Port Terminal	Forest products, steel	DNV
Univar Canada	Port Terminal	Caustic soda, glycol, ethanol	DNV
Allied Shipbuilders	Shipbuilding and Ship Repair	n/a	DNV
Chemtrade Chemicals	Manufacturing/Terminal	Caustic soda, chlorine, hydrochloric acid	DNV

3.2 Commodity Traffic

The volume of commodities moving through the Port of Vancouver North Shore Trade Area is shown below for 2017, the most recent year for which data was available when the analysis was conducted. Exports accounted for 92% of the traffic and imports 8% of the total volume. Dry bulk cargo accounts for the predominant share, and this volume is anticipated to grow substantially in the coming years as the Neptune Terminals, Fibreco and the G3 Canada major capital investments come on stream.

Figure 3-3 North Shore Trade Area Commodity Traffic

North Shore Trade Area Commodity Traffic 2017 (000 Tonnes)			
Commodity Group	**Imports**	**Exports**	**Total**
Animal Products, Dairy & Produce	0	0	0
Chemicals, Basic Metals and Minerals	2651	1537	4188
Coal	0	7618	7618
Consumer & Related Goods	0	0	0
Fertilizers	0	8298	8298
Forest Products	0	2283	2283
Grain, Specialty Crops & Feed	0	11186	11186
Machinery, Vehicles, Construction & Materials	112	3	115
Petroleum Products	46	126	172
Grand Total	2810	31052	33861

3.3 Trade Value

The value of trade moving through the Port of Vancouver's North Shore Trade Area reached approximately $15 billion in 2017.

Figure 3-4 North Shore Trade Area Trade Value 2017

North Shore Trade Area Commodity Tonnes and Value 2017					
Commodity	**Import (Tonnes)**	**Export (Tonnes)**	**Total (Tonnes)**	**Average Value ($/tonne)**	**Total Value $ Millions**
Animal Feed	0	562,590	562,590	$350	$196.9
Barley (not including feed)	0	452,441	452,441	$350	$158.4
Basic Metals	145,402	93	145,495	$2,062	$300.0
Canola	0	4,206,455	4,206,455	$350	$1,472.5
Construction & Materials	96,069	13	96,082	$2,224	$213.7
Diesel & Fuel Oils	46,302	125,523	171,825	$634	$109.0
Health & Medical	0	60	60	$14,373	$0.9
Household Goods	79	338	417	$14,373	$6.0
Industrial, Auto and Vehicle Parts	8,188	150	8,339	$9,685	$80.8
Inorganic Chemicals	387,884	131,812	519,696	$1,974	$1,025.7
Lumber	0	83,867	83,867	$419	$35.2
Machinery	7,424	747	8,171	$11,462	$93.7
Meat, Fish & Poultry	0	67	67	$2,044	$0.1
Metallurgical Coal	0	7,618,164	7,618,164	$205	$1,563.6
Minerals	1,522,053	86,770	1,608,823	$199	$320.4
Miscellaneous Goods	256	23	279	$511	$0.1
Nitrogen-Based Fertilizers	0	26	26	$301	$0.0
Ores & Concentrates	595,900	1,076,329	1,672,230	$1,713	$2,865.3
Organic Chemicals	0	242,112	242,112	$1,974	$477.9
Other Cereals	0	134,880	134,880	$350	$47.2
Other Fertilizers	80	0	80	$301	$0.0
Other Products of Chemical Industries	0	8	8	$1,974	$0.0
Paper & Paperboard	0	1,107	1,107	$501	$0.6
Potash & Potassium-Based Fertilizers	0	7,041,264	7,041,264	$310	$2,185.4
Specialty Crops	96	1,803,696	1,803,792	$350	$631.4
Sulphur	0	1,257,079	1,257,079	$167	$209.8
Vehicles	69	1,912	1,981	$9,685	$19.2
Wheat	0	4,026,334	4,026,334	$350	$1,409.4
Woodchips	0	1,029,819	1,029,819	$200	$206.3
Woodpulp	0	1,168,224	1,168,224	$1,151	$1,344.1
Grand Total	2,809,804	31,051,903	33,861,707		$14,973.6

3.4 Vessel Calls

A review of the number of vessels calls to the facilities located in the Port of Vancouver North Shore Trade Area in 2017 was 956. Annual vessel traffic is anticipated to grow in the coming years as the Neptune Terminals, Fibreco, and the G3 Canada major capital investments fully come on stream. The G3 Canada terminal is expected to handle approximately 50 vessels per year after it comes on stream in 2020.

Figure 3-5 Port of Vancouver North Shore Vessel Calls 2017

Port of Vancouver North Shore Vessel Calls 2017	
North Shore Terminal	**# of Vessel Calls**
Canexus Chemicals	15
Cargill	105
Fibreco Terminal	55
Kinder Morgan Vancouver Wharves	187
Lynnterm	130
Neptune Bulk Terminals	266
Richardson International	140
Univar Canada Terminal	58

Port terminals are subject to flooding and inundation, with potential damage to cargo handling equipment and economic impacts related to interruption in port operations. Sea level rise could also affect the efficiency of cargo handling operations due to reduction of air draft under bridges and terminal handling equipment.

The frequency of vessel calls is a factor in risk exposure to coastal flooding. For example, Cargill, Kinder Morgan Vancouver Wharves, Lynnterm, Neptune Bulk Terminals, and Richardson International all experience vessels alongside their berths on a daily basis, so there is a higher probability that cargo handling operations will be interrupted when a flooding event occurs.

4 Economic Impacts of Sea Level Rise on North Shore Port Facilities

4.1 Economic Impact Methodology

The assessment of the potential economic impacts of coastal flooding for North Shore port-related industries is based on a methodology developed for the U.S. Transportation Research Board (TRB). The TRB study developed a robust methodology for estimating the impacts of disruptions and delays to the goods movement system which takes into account the specific characteristics of each case including spatial scale, duration, supply chain resiliency and interdependencies among businesses.[3]

The TRB methodology consists of a sequential five-step process:

1. The initial step **identifies the direct and immediate physical effects of a network disruption,** including the identification of the specific transportation facilities affected and the associated modes of transport within, into, and out of the region impacted. For this study, the effects were identified based on the detailed LIDAR mapping analysis by VFPA (based on the KWL analysis) for the three scenarios analyzed, and information obtained through discussions with terminal operators and other industrial businesses.

2. The second step **identifies current and future affected network flows by facility and link.** These have been identified based on VFPA data and data obtained from terminal operators.

3. The third step **identifies supply chain characteristics and parameters.**

4. The fourth step **models the response of the supply chain to disruptions and delays.** This will include consideration of the potential for rerouting of affected traffic via other port facilities (within or outside the Lower Mainland), mode shifts, source-market restructuring of origin-destination flows and more permanent restructuring of origin-destination flows; and industry responses, including inventory draw-downs, reduced or suspended production levels, and shifts in the location(s) of production.

[3] Methodologies to Estimate the Economic Impacts of Disruptions to the Goods Movement System National Cooperative Highway Research Program Report 732 Georgia Tech Research Corporation; Parsons Brinckerhoff, Inc.; and A. Strauss-Wieder, Inc; Transportation Research Board, Washington DC 2012.

5. The final step **models the economic impacts of network disruptions**. For this project, the primary focus will be on direct economic impacts of the coastal flooding events modelled, including the supply chain impacts modelled using the TRB methodology, and costs related to repair and/or replacement of affected terminal equipment and infrastructure. Longer term estimates will take into account the typical lifespan of terminal facilities and potential for redevelopment of existing terminal operations as port traffic evolves; for example, the Fibreco terminal is currently planning to shift from handling wood chips and pellets to grain as a result of changing market demands.

4.2 Sea Level Rise Scenarios

For a detailed analysis of potential economic impacts of coastal flooding on port activities, three of the scenarios developed for the study were chosen. The scenarios are:

- Scenario B: .5 m sea level rise, 10% annual exceedance probability event (10-year return period).
- Scenario C: 1 m sea level rise, 10% annual exceedance probability event (10-year return period).
- Scenario E: 2 m sea level rise, 0.5% annual exceedance probability event (200-year return period).

These scenarios were mapped by VFPA and discussed with port stakeholders in the course of our interviews. The duration of flood events at each site depends on the level of inundation:

- Freeboard zone[4]: Possibility of getting wet – splash zone, minor flooding, but duration very brief, perhaps one hour at most.
- Less than 0.1m depth: Likely an hour at most.
- 0.1 to 0.5m depth: One to two hours, possibly 2 to 6 times or more during high tide cycle over several days.
- 0.5 to 1.0 m: 2 to 3 hours, and possibly 1 hour at any tide/weather condition almost every day.

[4] Freeboard is a vertical distance added to water surface elevations to account for scientific uncertainty. A typical value of 0.6 m is used in British Columba for flood hazard assessment. The flood maps include a 'freeboard zone' which shows the additional area that would be inundated if a 0.6 m freeboard is included.

- 1 to 2 m: 3 hours or more, most days.
- >2m: 4 hours or more. Flooded twice daily in almost any tide/weather conditions.

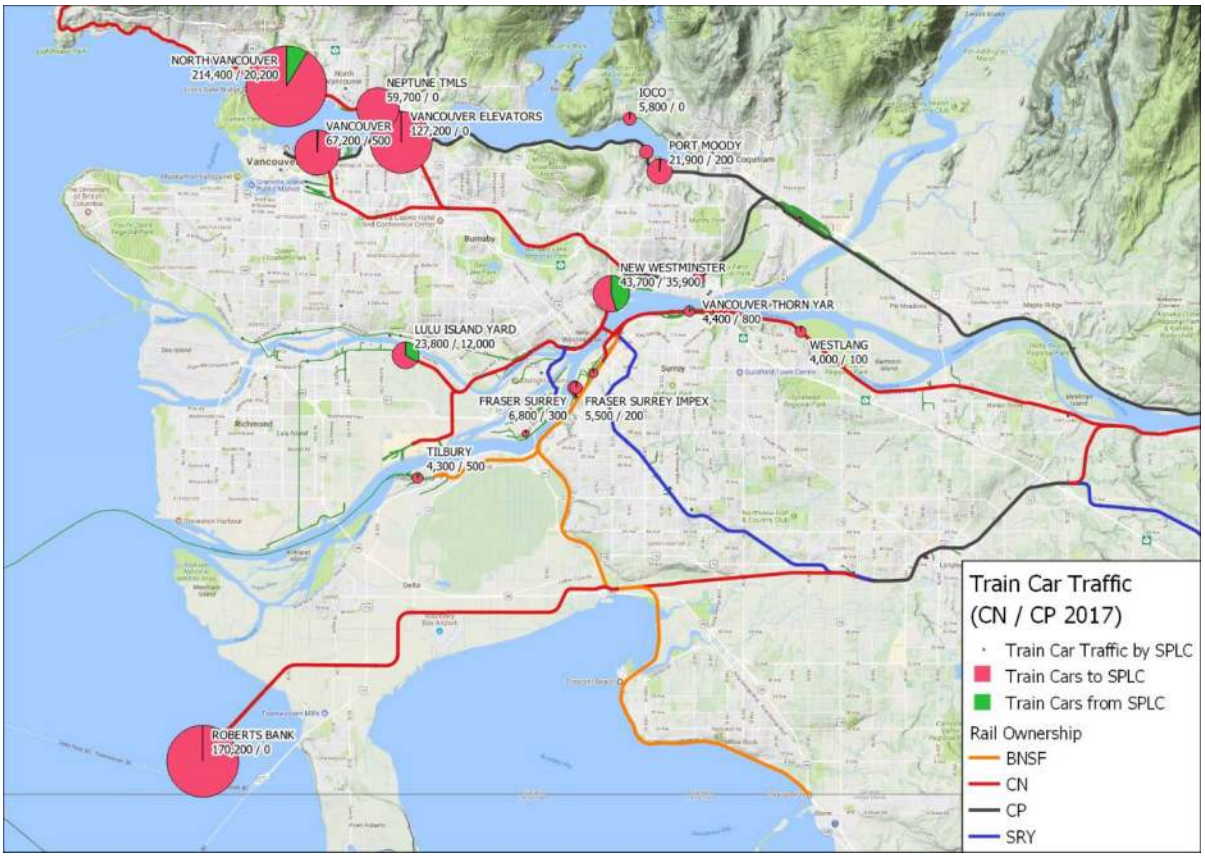
4.3 North Shore Cargo Flows and Supply Chain Characteristics

4.3.1 North Shore Rail Traffic and Infrastructure

Direct rail service is provided by CN Rail. CP Rail traffic is interchanged with CN at Sapperton in New Westminster; in the Fraser Valley at Boston Bar/North Bend; or further inland in the Kamloops area.

The distribution of CN/CP carload traffic by location is shown in the figure below.

Figure 4-1 CN/CP Carload Traffic 2017[5]



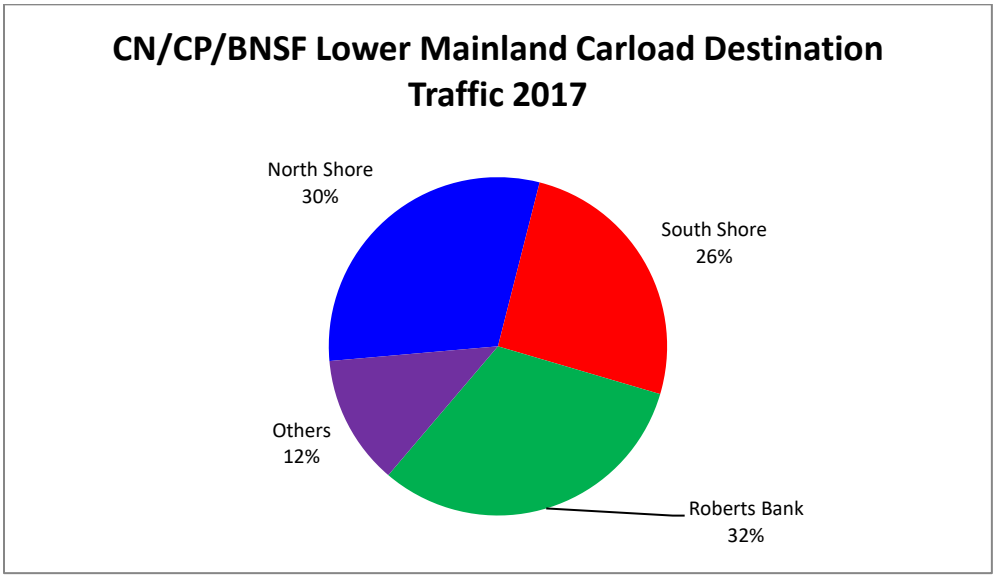
Source: Rail Activity and Capacity Issues in the Lower Mainland Area

[5] Excludes intermodal traffic. Source: Rail Activity and Capacity Issues in the Lower Mainland Area Davies Transportation Consulting Inc. for Transport Canada Economic Analysis March 31, 2018. SPLC refers to the Standard Point Location Code, a 9-digit geographic code used by North American transportation industries, especially rail.

Carload traffic includes all types of traffic except intermodal. The figure shows the number of loaded rail cars to and from rail stations in the Lower Mainland. Destination traffic predominates. In 2017, traffic destined for the Lower Mainland (exports) accounted for 93% of North Shore rail carloads. Traffic originating in the North Shore Trade Area consists primarily of metal concentrates.

The distribution of carload destination traffic for the Class 1 Railways is shown below. Except for coal traffic, detailed data on BNSF traffic is not available; the numbers below include only BNSF traffic destined to Roberts Bank.

Figure 4-2 CN/CP/BNSF Lower Mainland Carload Destination Traffic



For CN/CP, the North Shore accounts for the largest share of traffic, followed by the South Shore and Roberts Bank. When BNSF's coal traffic to Roberts Bank is included, the North Shore traffic accounts for 30% of total traffic.

The primary route for traffic to the NSTA is the North Shore Rail Corridor which includes the following track segments:

- CN Yale subdivision from Hydro to the New Westminster Rail Bridge,
- The New Westminster Rail Bridge,

- The BNSF main line from the New Westminster Rail Bridge to Willingdon Junction,
- The CN tunnel and Second Narrows Rail Bridge, and CN line between the Second Narrows and Lions Gate Bridges connecting to the former BC Rail line from the west.

Rail service to the North Shore is heavily dependent on the Second Narrows Rail Bridge. In 2017, rail traffic on the Second Narrows Rail Bridge totalled approximately 15 trains per day, compared to 2 trains per day on the ex-BCR Squamish subdivision, the alternate access to the North Shore from the west. The bridge is owned by CN Rail and links the North Shore to the rest of the Lower Mainland rail network. All rail switching, and train movement activity is carried out by CNR, although CPR and BNSF have market access via joint section and co-production arrangements to service the North Shore port terminals. CP Rail North Shore rail traffic is interchanged with CN at Sapperton in New Westminster or in the Fraser Valley at Boston Bar/North Bend or further inland in the Kamloops area.

The CN mainline is at a relatively high elevation coming across bridge at 2nd Narrows; access lines to rail yards are slightly lower. There is a low area east of the former BC Rail yard between Kinder Morgan Vancouver Wharves and Fibreco. There is no history of serious flooding events affecting rail operations, though in the past flooding has occurred close to the tracks at this point due to a combination of high tides and weather conditions (i.e. strong winds from the south).

CN has no operational concerns at this time with respect to flooding, and no contingency plans exist for this reason. As per operating protocols on network, if a problem occurs then actions to “move around” the problem are implemented. As the North Shore is the “end of the line” this will result in delays.

CN’s network is more vulnerable to rapid events that can cause wash-outs to rail tracks such as stream and debris flow events, landslides, etc. Climate change across Western Canada (forest fires, rainier winters, dryer summers, etc.) that affect geotechnical stability of slopes and streamflow conditions is more of a threat than sea level rise.

4.4 Port Terminal Operations

Efficient port terminal operations require close coordination between vessel operations, inland transport networks and originating production facilities. The majority of export cargo shipped from the North Shore marine terminals consists of dry bulk commodities.

Coal, potash and sulphur: Coal, potash and sulphur are shipped in unit trains to the specialized dry bulk marine terminals on the North Shore. A unit train is a train in which all cars carry the same commodity and are shipped from the same origin to the same destination. The railways supply locomotives and crews for unit train operations, which typically remain with the train during loading and unloading. The unit trains used to haul Teck coal to port typically have 154 cars for a train length of 8,500 feet and a capacity of 16,170 tonnes.

Unit trains typically consist of dedicated trainsets of railcars provided by the shipper. In order to justify the cost of owning or leasing the railcars, movements must be frequent enough to justify the fixed costs of car supply; and low cycle times between origin and destination are required to minimize costs. The origin and destination terminals must have sufficient handling capacity to load and unload trains promptly to avoid additional railway charges for detention of crews and locomotives. Onsite storage is required as a buffer to accumulate sufficient quantities of product to load large vessels without delay, and to avoid disruptions in vessel loading due to any interruptions in rail service.

The primary source of coal handled at Neptune Terminals on the North Shore is Teck's mines in southeastern BC. The unit trains used to haul Teck coal to port typically have 154 cars for a train length of 8,500 feet and a capacity of 16,170 tonnes. Teck is a co-owner of Neptune Bulk Terminals; in addition to their Neptune tonnage a portion of Teck's coal is exported via Westshore Terminals at Roberts Bank.

Potash is sourced from mines in Saskatchewan and shipped by Canpotex in 170 car unit trains for a train length of 8500 feet and a payload capacity of 17,680 tonnes. Canpotex is a co-owner of Neptune Bulk Terminals and does not currently export from any other terminals at the Port of Vancouver. Canpotex owns another terminal in Portland, Oregon.

Sulphur is produced as a by-product of oil and gas production. It is shipped from multiple origins in Western Canada in 115 car unit trains for a train length of 8500 feet and a payload capacity of

12,000 tonnes. The primary shipper is Sultran. In addition to shipments through Kinder Morgan Vancouver Wharves, Sultran exports sulphur through their wholly owned subsidiary Pacific Coast Terminals in Port Moody.

Grain: Grain trains are typically tendered to the railways in large car blocks, but not necessarily handled as unit trains. For example, CN and CP provide rate incentives for car blocks of 100 cars or more for grain shipments. From August to November 2017, over 80% of grain cars were supplied in lots of 100 or more by both CN and CP. However, these car blocks are not necessarily handled as unit trains by the railways. In order to maximize train lengths for line haul operations, these 100 car blocks may be disassembled and recombined into trains of up to 160 cars.

Because of the multiple grades and types of products handled at the grain terminals, holding inventory in longer term storage at port terminals is not practical. The grain companies assemble shipments to order at their inland terminals and dispatch to the port to arrive for loading to vessel on a just-in-time basis. Any disruptions in the schedule of country elevator loading, rail transport, vessel arrival or terminal operations results in additional costs. These may include:

- If the cargo does not arrive at the terminal in time to load the vessel on schedule, the vessel owner will charge demurrage for each day in excess of the contracted laytime. The amount typically varies depending on current shipping market conditions.

- If a portion of the shipment is delayed in transit the vessel may have to berth at the terminal multiple times to complete loading. This may result in additional costs for pilotage and tug services. For grain vessels, these are estimated to range from CDN $22,000 to $26,000.[6]

- Under the collective agreements between the International Longshore Workers Union (ILWU) and the British Columbia Maritime Employers Association (BCMEA), longshore workers are ordered in advance for each shift. The contract defines three standard shifts: day shift (8 am to 5 pm); night shift (5 pm to 1 am) and graveyard shift (1 am to 8 am). Substantial shift premiums apply for night and graveyard shifts and for weekends. Once dispatched, workers must be paid for a complete shift whether or not operations proceed as planned. Terminals can incur significant

[6] Vancouver port cost estimates for grain vessels Colley West Shipping
https://www.colleywest.bc.ca/vancouver-grain/

additional labour charges if operations are disrupted by weather (high winds, rain, etc.) or delays in receipt of rail cars, etc.

- In some cases, contracts can be cancelled for non-delivery.

These additional costs are normal occurrences in day-to-day terminal operations.

Ores and Concentrates

The dry bulk cargo includes imports of lead-zinc concentrates and exports of copper concentrates through Kinder Morgan Vancouver Wharves (KMVW). Lead-zinc concentrates are imported by Teck for processing in their Trail smelter operations, which is one of the world's largest fully integrated zinc and lead smelting and refining complexes. Concentrates are imported through KMVW and then interchanged by CN Rail with BNSF for shipment via the Kettle Falls International Railway (KFR) to a bulk reload centre at Waneta, BC. The concentrate is then trucked approximately 9 km to the refinery (8 km on the section of Highway 3 between Waneta Junction and Trail). On occasions when rail capacity is insufficient to supply the refinery's requirements concentrates may be trucked from KMVW to Trail.

Copper concentrates are shipped to KMVW for export from multiple origins by rail and/or truck. The concentrates shipped from and to KMVW by rail are handled in manifest trains. A manifest train is comprised of small blocks of mixed car types and multiple commodities, origins and destinations. These car blocks must be marshalled from multiple origins into trains for transit, and the trains split into car blocks for delivery to specific terminals at destination. In the Lower Mainland manifest train operations are typically used for breakbulk cargo (lumber, pulp, etc.) and all dry and liquid bulk commodities except coal, grain, potash and sulphur handled as unit trains.

Breakbulk cargo

This category encompasses a variety of goods that must be loaded individually, and not in intermodal containers nor in bulk as with oil or grain. The only terminal handling breakbulk cargo on the North Shore is Lynnterm. Traffic consists primarily of outbound forest products (pulp, lumber) and inbound steel. The largest portion of outbound forest products is delivered to the terminal by rail. Imported steel is delivered from the terminal by truck and rail.

4.5 Manufacturing and Distribution Facilities

The major manufacturing and distribution facilities at tidewater along the North Shore include chemical facilities and shipyards. Univar and Chemtrade primarily handle products related to the manufacturing and/or distribution of chemicals. These facilities are heavily dependent on rail service, but rely on other modes as well. For example, Chemtrade is dependent on the receipt of bulk salt by vessel, and delivery of chemical products by vessel, barge, rail, and truck.

Seaspan Shipyards, Vancouver Drydock, and Allied Shipbuilders are dependent on the access of the workforce to the site, and reliable delivery of raw materials. Supply chains for the shipyards are more reliant on the road network than the marine terminals.

The shipbuilding supply chain is a very complex process, primarily due to the length of time it takes to complete a single project. In a shipyard, material and equipment are most often received from vendors at the truck gate. Supplies then move into a receiving area where they are checked and inspected. Based on the type of supplies and the nature of the work, they may be stored onsite, moved directly to shop facilities or even directly to a vessel.

The size of the shipbuilding workforce varies depending on the volume of business. The amount of activity on site will significantly influence the magnitude of the direct economic impact of any delays in accessing the site due to flooding.

5 Effects of Coastal Flooding from Sea Level Rise on North Shore Industry

Port stakeholders were surveyed through a collaborative effort between DTCI and VFPA; details are provided in Appendix A. VFPA provided detailed mapping of flooding scenarios to facilitate discussions with the terminal operators and more detailed analysis of potential impacts.

None of the facility operators interviewed reported any history of serious operational disruptions resulting from coastal flooding.

5.1 Scenario B: .5 m Sea Level Rise

Scenario B assumes a .5 m sea level rise, with a 10% annual exceedance probability event (10-year return period). Duration of the flooding i.e. (total number of hours when stillwater level without freeboard exceeds extreme high tide) is expected to be 6 hours.

Based on the LIDAR mapping and information gathered in meetings with the facility operators, the economic impacts of a flooding event similar to that which might be experienced with this level of sea level rise would be relatively insignificant i.e. any disruption to ongoing operations would be within the bounds of current variability due to weather and/or variations in rail shipments, vessel arrivals, etc.

5.2 Scenario C: 1 m Sea Level Rise

Scenario C assumes a 1 m sea level rise, with a 10% annual exceedance probability event (10-year return period). Duration of the flooding i.e. (total number of hours when stillwater level without freeboard exceeds extreme high tide) is expected to be 6 hours.

Based on the LIDAR mapping and information gathered in meetings with the facility operators, overall the economic impacts of a flooding event similar to that which might be experienced with this level of sea level rise would be relatively insignificant i.e. any disruption to ongoing operations would be within the bounds of current variability due to weather and/or variations in rail shipments, vessel arrivals, etc.

However, there are several points of vulnerability where disruptions in operations could occur due to site access flooding. These include:

- Rail and road access to Kinder Morgan Vancouver Wharves, Fibreco and employee access and parking at Seaspan Shipyards would be disrupted as a result of flooding at the eastern edge of the KMVW site along McKeen Avenue.

- Road access to Lynnterm and Univar would be interrupted as a result of flooding overland from the Lynnterm marina site onto local streets and/or the Mountain Highway underpass.

There are also facilities which are vulnerable to extended disruptions of operations at this level of sea level rise, including:

- Allied Shipbuilders could experience major damage to the upland works yard and building shops, and there could be major damage to the machine shop and fabrication shops, with loss of heavy equipment at ground level that would render the shipyard inoperable for a long period.

- Vancouver Pile Driving is located on a relatively low-lying site. With a 1 m sea level rise there would be extensive flooding.

5.3 Scenario E: 2 m Sea Level Rise

Scenario E assumes a 2 m sea level rise, with a .5% annual exceedance probability event (200-year return period). Duration of the flooding i.e. (total number of hours when stillwater level without freeboard exceeds extreme high tide) is expected to be 14 hours.

Based on the LIDAR mapping and information gathered in meetings with the facility operators, a flooding event similar to that which might be experienced with this level of sea level rise would disrupt operations at all facilities for an extended period.

5.4 Detailed Summary

The potential impacts of coastal flooding due to sea level rise for North Shore port-related industrial sites are summarized below, based on the LIDAR mapping and information gathered from terminal operators and other facility operators.

Figure 5-1 Impacts of Flood Scenarios

Impacts of Flood Scenarios			
Site	**Scenario B: 0.5 m sea level rise.**	**Scenario C: 1 m sea level rise.**	**Scenario E: 2 m sea level rise.**
CN Rail	Minimal impacts. Potential short term disruption to operations in area of ex-BCR rail yard at McKeen Avenue (KMVW and Fibreco).	Minimal impacts. Potential short term disruption to operations in area of ex-BCR rail yard at McKeen Avenue (KMVW and Fibreco).	Flooding of mainline at several points on North Shore. Infrastructure resilient to short term inundation.
Kinder Morgan Vancouver Wharves	Minimal impacts to terminal operations.	Significant flooding on McKeen Avenue, eastern parcel presently used for parking, road/rail overpass. Significant potential impacts to stormwater discharge systems.	Major impacts - flooded access roads and the CN mainline adjacent to terminal.
Fibreco	Minimal impacts.	Potential flooding expected on access roads and rail. Existing new infrastructure well above flood levels.	Major impacts - flooded access roads and the CN mainline adjacent to terminal.
Seaspan Shipyards	Minimal impacts. Potential flooding in employee parking lots; potential basement flooding in older buildings.	Minimal impacts. Potential flooding in employee parking lots; potential basement flooding in older buildings.	Almost all areas of site experiencing flood risk. Site not viable in present elevations/condition for this flood level
Vancouver Drydock	Minimal impacts.	Property remains above flood levels. Infrastructure and services (utilities) on pier likely vulnerable.	Significant flooding around the shoreline, and main pier. Entire site affected at present elevations.
Richardson Grain	Minimal impacts. Most of the site is dry, with some potential wave runup and splash in the very western edge of the property where the roadway access is.	Minimal impacts. Increased flood hazard along the shoreline. Most major buildings remain dry.	Potential flooding of grain silos (annexes) and terminal operations buildings. More than .5 m flooding at shiploader and berth faces. Impacts to electrical systems and potential flooding into conveyor systems below annexes.
Cargill	Minimal Impacts. Site appears to be mostly dry. Minor freeboard-zone vulnerability along shoreline.	Most of the site is in the freeboard zone. Possibly some backflooding issues at parking lot drains. Several low level ventilation windows/vents on east annex may be vulnerable. Rail storage still dry.	Almost all areas of site experiencing flooding or flood hazard. Flooding at this level would flood access roads, and site.

Impacts of Flood Scenarios (continued)			
Site	**Scenario B: 0.5 m sea level rise.**	**Scenario C: 1 m sea level rise.**	**Scenario E: 2 m sea level rise.**
Neptune Bulk Terminals	Minimal impacts. Most of the project site is dry, with some potential wave runup and splash in the berth face – flooding occurring in SW corner. No concern of coastal flooding reaching rail loops or potash sheds	Potash sheds and rail loops in freeboard zone; risk of flood water reaching the potash sheds and contaminating product inventory.	Operations not viable. Almost all areas of site experiencing standing water above grade. Damage to potash inventory. Rail loops under standing water. Flooding into all rail car dumpers and major impacts on material handling equipment. Flooding of the CN mainline adjacent to terminal.
G3 Grain Terminal	All of site remains dry and outside of flood hazard zone.	The shared access with Van Pile to the berth is subject to flood risk.	Rail loops dry with 2m of SLR. The neighbouring Van Pile site and shared access road significantly flooded. Berth face may experience flooding.
Lynnterm	Minimal impact. Risk of flooding of only site access via the CN rail underpass at Mountain Highway.	Minimal impact. Risk of flooding of only site access via the CN rail underpass at Mountain Highway. Overland flooding in nearby Lynnterm Marina will flood Orwell Street and parts of Bay Street/Mountain Highway.	Almost all areas of site experiencing flooding or flood hazard. Flooding at this level would flood access roads and the site.
Univar	Minimal impact. Risk of flooding of only site access via the CN rail underpass at Mountain Highway.	Minimal impact. Risk of flooding of only site access via the CN rail underpass at Mountain Highway. Overland flooding in nearby Lynnterm Marina, will flood Orwell Street and parts of Bay Street/Mountain Highway.	Operations would need to be completely shut down due to safety concerns. Impacts to many electrical systems, potential flooding into sumps, railyard, offices, maintenance, etc. Resumption dependent rail service and road access.
Chemtrade	Most of the site is dry, with some areas at the south in the freeboard zone.	Most of the site, except for a largely unused area to the north, is in the freeboard zone, with some marginal flooding possible in the southern area.	The entire site, and surrounding area, is under water, except for a largely unused area to the north which would become an island.
Allied Shipbuilders	High tides may cause worsening problems with the seawater cooling system.	Potential damage to the machine shop and fabrication shops, with loss of heavy equipment at ground level that would render the shipyard inoperable for a long period of time following the flood.	Entire property and roadway access under deep water. Daily flooding of the property likely from regular tides.
Vancouver Pile Driving	Low-lying portions of the site along the barge basin marginal wharf, and the laydown area at the north end of the barge basin would be flooded by about 0.5m of water. The rest of the site lies within the freeboard zone.	Extensive flooding of the site would occur.	Extensive flooding of the site would occur.

6 Potential Economic Impacts on Current Operations

The risk of coastal flooding due to sea level rise is expected to increase gradually over a very long period. However, for purposes of this study it may be instructive to assess the potential impacts of an instantaneous event which mimics the anticipated effects of sea level rise; for example, a storm surge similar to that experienced at the Port of New York/New Jersey as a result of Hurricane Sandy. The Port was closed to all traffic on October 28, 2012 and not fully reopened until November 4, 2012.[7]

6.1 Flooding Economic Impacts Example – Hurricane Sandy and the Port of New York/New Jersey

The impact of Hurricane Sandy on the Port of New York/New Jersey in October and November of 2012 is instructive in assessing potential impacts of a major coastal flooding event. Hurricane Sandy made landfall in the northeastern U.S. near Brigantine, NJ on October 29, 2012 as a post-tropical cyclone with sustained winds of 70 knots. The chronology of events is highlighted below.

Figure 6-1 Hurricane Sandy Impacts on the Port of New York/New Jersey – Chronology

Hurricane Sandy Impacts on the Port of New York/New Jersey - Chronology		
Day 1	October 28, 2012	The US Coast Guard closed the Port of New York/New Jersey in anticipation of the arrival of the storm.
Day 2	October 29, 2012	Hurricane Sandy made landfall in the northeastern U.S. near Brigantine, NJ on October 29, 2012 as a post-tropical cyclone with sustained winds of 70 knots. Record storm tides (combination of storm surge and astronomical tide) reached 14.06 ft (4.3 m) above Mean Lower Low Water at the Battery (the southern tip of Manhattan). Inundations (water height above ground level) on normally dry land were 2 to 9 feet (.6 to 2.7 m) in areas of New Jersey containing port infrastructure.
Day 5	November 1, 2012	The port remained closed as the port was without power and the channel remained closed to navigation
Day 8	November 4, 2012	Navigation channels were reopened and the first cargo ship docked at the Port following completion by the Coast Guard of surveys to identify and clear any obstructions.
Day 9	November 8, 2012	Partial operations (truck gates) began at major container terminals.
Day 10	November 9, 2012	Vessel operations began at major container terminals.
Day 14	November 11, 2012	All of the marine terminals in the Port of New York and New Jersey had reopened including all six container terminals, the three cruise terminals and the four auto-processing terminals

[7] Assessing the Impacts of Hurricane Sandy on the Port of New York and New Jersey's Maritime Responders and Response Infrastructure Tiffany C. Smythe, Ph.D. Post-Doctoral Fellow in Maritime Policy Center for Maritime Policy & Strategy, U.S. Coast Guard Academy p. 7 https://hazards.colorado.edu/uploads/quick_report/smythe_2013.pdf

Record storm tides (combination of storm surge and astronomical tide) reached 14.06 ft (4.3 m) above Mean Lower Low Water at the Battery (the southern tip of Manhattan). Inundations (water height above ground level) on normally dry land were 2 to 9 feet (.6 to 2.7 m) in areas of New Jersey containing port infrastructure. The storm resulted in substantial damage to port facilities and disruptions in port operations for an extended period.

Reopening of the port terminals was delayed due to the slow pace of restoration of electricity. In New York and New Jersey, the storm resulted in damage to 89 substations, 3500 transformers, and 25 transmission lines.[8] In New York and New Jersey, restoration of power to approximately 85% of affected locations took nine days.[9]

Costs due to the storm included:

Cargo Losses: The largest share was due to flood damage to approximately 16,000 new automobiles at the auto terminals; at an average $30,000 per vehicle this would amount to US$480 million. At the container terminal, approximately 15,000 containers were damaged; costs would vary depending on the contents and on the level of damage.

Equipment Losses: Flooding destroyed approximately 2,500 trucks serving the port. At a replacement value of $100,000 for new trucks, this would amount to US$250 million. Some electrically powered cargo handling equipment was damaged by exposure to salt water. The tidal surge at all the terminals brought water levels above the motors on the wheels of some of the ship-to-shore cranes, and salt water got into them. There was no structural damage to the ship-to-shore cranes. At Global Terminal, which uses rubber-tire gantry cranes, the motors were high enough off the ground and sealed, so they were not affected by the storm-driven seawater. Equipment was restored flushing the motors with fresh water;[10] removal, “baking”, cleaning and reinstallation;[11] or replacement. Repair costs for container cranes were estimated at approximately US$160,000 per unit.[12]

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[8] Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure Office of Electricity Delivery and Energy Reliability U.S. Department of Energy April 2013 p. 9.

[9] Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure p. 12.

[10] “Sandys Tidal Surge Caused Major Damage to NY NJ Terminals” Journal of Commerce October 31, 2012.

[11] “NY NJ Port Assesses Damage from Sandy” Journal of Commerce November 9, 2012.

[12] Lessons from Hurricane Sandy for Port Resilience UTRC-RF Project No: 49997-56-24 Stevens Institute of Technology December 2013 p. 12.

Supply Chain Costs: Shippers incurred additional costs due to cargo damage and delays. These losses may potentially be covered by business interruption insurance or cargo/marine coverages.[13] The application of coverage could depend on whether the damage was caused by wind (which is not generally covered in the policies) or flooding (which is typically covered). In 2015 a judge ruled on a suit by a retailer against the shipping line ZIM and New York Container Terminal that damage to containerized cargo sustained during Hurricane Sandy was due to an "Act of God" and therefore neither the shipping line nor the terminal operator was liable for the losses. In general, it appears that the costs of damage and delays primarily fell to the cargo owners.

Traffic Diversion: Approximately 25,000 containers were diverted to other ports. This is equivalent to a decline of approximately 1.5% in the Port's annual traffic for 2012.

6.2 Potential Impacts of Flooding on North Shore Port Operations

Potential economic impacts of a major coastal flooding event are estimated below, based on the assumption that coastal flooding results in the complete interruption of rail and vessel activity at all port terminals for a period of seven days. These costs are likely to be borne primarily by cargo owners. The largest portion of North Shore cargo consists of bulk commodity exports which are sold either Free on Board (loaded onto the vessel) or Cost, Insurance and Freight (delivered to destination port). Under either of these arrangements ownership of the cargo is not transferred prior to loading onto the vessel, so the impact of costs due to a disruption in port operations would fall primarily on the Canadian exporters.

Cargo Losses: Many of the major bulk commodities (coal, sulphur, concentrates) handled at North Shore terminals are not seriously affected by short term immersion. The primary vulnerability of cargo stored onsite at the terminals appears to be the potash inventory at Neptune Bulk Terminals. Potash contaminated by seawater would be a total loss and would have to be transported to a landfill for disposal. At the 2017 average price for potash, the cargo loss would be CDN $310 per tonne plus the disposal cost.

Project's Website: http://www.utrc2.org/researc h/pro jects/hurricanesandy- port-resilience

[13] Exposures at East Coast Ports and Terminals Could Rack Up Record Post-Sandy Supply Chain Losses Best's News Service January 30, 2013.

Equipment Losses: Due to the focus on bulk commodity cargoes on the North Shore, the primary onsite equipment includes shiploaders and conveyors. Low-lying electrical substations and other equipment may also be at risk of flooding. Based on the LIDAR mapping and information gathered in meetings with the facility operators, equipment likely to be affected by a flooding event of similar magnitude to Scenario E include:

- Subsurface dumping pits and underground conveyors at multiple bulk terminals.
- Low-lying electrical substations and other infrastructure.

Supply Chain Costs

The estimates represent the upper bound of potential losses i.e., they assume that the disruption in deliveries results in the loss of sales of these commodities. In reality, the impact is more likely to be a delay in deliveries which may result in additional costs for vessel demurrage, inventory costs, etc., and where facilities are not operating at maximum capacity the more likely impact would be operational delays rather than lost sales.

Assumptions used to generate these estimates include:

- Coastal flooding results in the complete interruption of rail and vessel activity at all port terminals for a period of 7 days.

- Shippers with the ability to divert a portion of their traffic mitigate their losses by diverting 50% of normal North Shore traffic to available alternatives. For coal, the alternative is Westshore Terminals at Roberts Bank; for potash, the alternative is Canpotex's terminal in Portland, Oregon. Both of these alternatives are likely to result in additional transportation and handling costs, which are not included in these estimates.

- The volume of cargo affected is based on typical weekly rail volumes for the various commodities.

- The unit values of commodities are based on values reported in VFPA statistics for 2017.

Figure 6-2 North Shore Terminals Potential Supply Chain Losses Due to 7 Day Disruption

North Shore Port Terminals - Impact of 7 Day Disruption in Operations										
	Train Capacity	2017 Tonnage	Annual Trains	Daily Frequency	Disruption Impacts - Trains	Disruption Impacts - Tonnes	Unit Price	Total Traffic Loss ($ millions)	% Diverted	Mitigated Loss ($ millions)
Coal	16,170	7,618,000	471	1.3	9.0	146,099	$205.00	$30.0	50%	$15.0
Potash	17,680	7,041,264	398	1.1	7.6	135,038	$310.00	$41.9	50%	$20.9
Sulphur	12,000	1,257,079	105	0.3	2.0	24,108	$167.00	$4.0	0%	$4.0
Grain	10,080	11,186,000	1,110	3.0	21.3	214,526	$350.00	$75.1	0%	$75.1
Other Commodities	8,000	5,206,000	651	1.8	12.5	99,841	$1,050.00	$104.8	0%	$104.8
Total				7.5		619,612		$255.8		$219.8

Traffic Loss and Diversion: Based on the assumptions above, the total cargo loss would be approximately 480,000 tonnes or 1.5% of the total 2017 North Shore tonnage. Cargo diversion would total approximately 140,000 tonnes, approximately .4% of total 2017 tonnage.

Labour Income: The primary impact on labour income would be due to reduced hours for longshore workers over the course of the disruption. Based on the Vancouver Fraser Port Authority 's 2016 Economic Impact Study, International Longshore and Warehouse Union (ILWU)Stevedores is the most common job category at the port, with more than 5,810 jobs.[14] Assuming that the North Shore share of this total is proportional to the share of cargo handled would imply 1394 longshore jobs on the on North Shore. Based on BC Stats data, the average annual salary of a longshore worker in BC is $83,200.[15] This would imply a total annual longshore payroll of approximately $116 million for North Shore terminals; a loss of 7 days of work would amount to $2.2 million.

Figure 6-3 North Shore Longshore Income Potential Loss Due to a 7 Day Disruption in Port Operations

North Shore Longshore Income - Potential Cost of a 7 Day Disruption in Port Operations	
Total Port of Vancouver ILWU Jobs	5810
North Shore share	24%
North Shore Jobs	1394
Median Salary	$83,200
Total payroll ($ millions)	$116
Lost Income 7 Day Disruption ($ millions)	$2.2

[14] Port of Vancouver 2016 Economic Impact Study InterVISTAS Consulting Inc. May 26, 2017 p. 24.
[15] Longshore workers (NOC 7451) BC Stats https://www.workbc.ca/careers/7451#earnings-and-outlook

7 Adaptation Strategies and the Lifespan of Port Assets

Sea level rise adaptation strategies for ports are fundamentally influenced by the relatively limited lifespan of capital assets (terminal infrastructure and equipment). Port terminals require periodic capital expenditures ranging from rehabilitation or replacement of existing equipment up to complete terminal redevelopment as a result of functional obsolescence or changes in markets. As examples, two North Shore terminals are currently being redeveloped from their original purposes due to market changes: both the former Seaboard Terminal (now G3) and Fibreco are being redeveloped to handle grain products due to the decline in cargo volumes of forest products. These examples provide some indication of the potential lifespan of marine terminals. Seaboard was built in 1971, and Fibreco was built in 1979. Given the long-term nature of the problem, current port-related assets may be obsolete and subsequently replaced prior to any anticipated disruption to operations due to sea level increases.

From an investment perspective, the amount of capital a firm will be willing to invest now to avoid a loss in the future is a function of the number of years until the loss will be incurred, and the discount rate which reflects the time value of money – in this case the potential returns from investing the capital in the most profitable alternative. The table below shows a simple calculation reflecting the present value of an estimated total loss for a single flooding event similar to Scenario E as detailed in the previous chapter. The results show that even if a firm was sure that the event would occur at a specific time, the present value of the future cost is significantly less than the cost if the event occurred now, and the amount of capital a firm would be willing to invest to avoid the loss is substantially reduced.

Figure 7-1 Present Value of Estimated Supply Chain Losses for Future Years

Present Value of Estimated Supply Chain Losses for Future Years (CDN $ millions)					
	Discount Rate	2019	2050	2100	2150
Present Value	2.5%	$219.8	$102.3	$29.8	$8.7

However, the actual pace of sea level rise is uncertain, and Scenario E assumes a sea level rise of 2 metres and a once in 200-year storm surge, which makes it a very low probability event. Where the probability of a major disruption during the life cycle of port assets is very small, there is little incentive to invest additional capital to mitigate potential losses. However, as port assets are replaced it would be prudent to consider the potential levels and pace of sea level rise in design and construction.

8 Appendix A: Port Stakeholder Consultations

8.1 Port Stakeholders Consulted

Port stakeholders were surveyed through a collaborative effort between DTCI and VFPA. VFPA provided detailed mapping of potential flooding scenarios to facilitate discussions with the terminal operators. Consultations included:

- Review of terminal/facility operations.
- Detailed review of existing infrastructure including cargo-handling equipment, rail infrastructure, electrical, sewer and drainage.
- Discussion of potential impacts for three flood scenarios depicted in VFPA maps.

Companies interviewed are listed below.

North Shore Trade Area Stakeholder Consultations	
Company	**Date**
Allied Shipyard	June 26, 2019
Cargill Limited	April 26, 2019
Chemtrade Chemicals	April 26, 2019
CN Rail	April 16, 2019
Fibreco Export Inc.	April 15, 2019
G3	April 17, 2019
Kinder Morgan Vancouver Wharves	April 15 2019
Neptune Bulk Terminals (Canada) Ltd.	April 12, 2019
Richardson International	March 27, 2019
Seaspan Vancouver Shipyards and Drydock	April 10, 2019
Univar Canada Ltd.	April 4, 2019
Vancouver Pile Driving	January 30, 2020
Western Stevedoring Company Limited	April 16, 2019

8.2 Port of Vancouver Flood Risks Questionnaire

The following questionnaire was used as a guide for discussions with terminal operators and other industrial facility operators.

Name of site and/or operator:
Primary commodities or activities:
Interview conducted by, and date:
Person(s) interviewed, and roles:

Part 1 – Current Experience

Has there been any history of flooding events at this site? *(to the extent possible, include dates, location on site, general description).* A "best guess" is helpful if specific details are uncertain.
If yes: 1. What was the average duration? 2. Approximate depth? 3. What structures on site would the flooding reach?

4. To the best of your knowledge, what impact would flooding cause to these structures? (e.g., just minor damage easily cleaned up, impact to electrical and mechanical systems, damage to structure and contents,...)

5. Was there any impact on operations?

6. Was there a threat to any infrastructure, operations, or safety?

7. Did flooding occur in non-critical areas (e.g., a parking lot) as compared to operation critical areas for the terminal facility?

8. Does it seem likely that this type of event may happen again?

Does this site include flood hazards in its emergency management plan?

Are there any plans for mitigating current (or near-term) flood hazards?

Part 2 – Future Possibilities

Review the flood risk scenario maps of the site, and understand the approximate time-frames, duration, and likelihood of occurrence. Think about all types of infrastructures and facilities on the site, stored goods and materials, operations and safety, and especially anything that may be low-lying, below ground, or particularly exposed.

If multiple scenarios are assessed, use more than one questionnaire form.

Describe the flood scenario assessed. What would the duration be, approximate depth(s) on site, areas of the site affected, and how often this scenario may recur.

Would there be a safety hazard to personnel on site?
Would operations be impacted? For how long?
Would there be any kind of release of contaminants? (fuel, waste water treatment, bulk commodities on site, etc.)
Would there be damage to structures? (offices, storage facilities, workshops, docks and berthing structures, etc.)
Would there be damage to mobile equipment? (vehicles, railcars and engines, forklifts, cranes, etc.)
Would there be damage to fixed equipment? (conveyors, gangways, refrigeration units, other cargo handling equipment, etc.)
Would there be damage to goods and commodities stored on site?
Would electrical power and communications be affected? How would interruptions affect the rest of your operations?

Are there any particularly vulnerable features on the site? Think of low-lying areas, pumps and electrical equipment in below-grade vaults, cargo dumper pits, or other such features. How would these be affected?
Would access to the site be affected? (roadways, rail lines). How will this affect the ability of staff to get to work? Movement of goods? Emergency service access?
As best as possible, describe the possible economic costs to the business, in terms of repair costs, losses from damaged goods, length of time to restore regular operations, or lost wages.

9 Appendix B: Review of U.S. Sea Level Rise Studies

9.1 Regulatory Authority for Coastal Management in the U.S.

9.1.1 Federal Jurisdiction

Office of Ocean and Coastal Resource Management

The *Coastal Zone Management Act* (CZMA) of 1972 delineated a relationship between federal and state governments for environmental management of coastal areas of the United States. The CZMA emphasizes the primacy of state decision-making regarding the coastal zone. The federal Office of Ocean and Coastal Resource Management (OCRM), within the National Oceanic and Atmospheric Administration's (NOAA's) National Ocean Service (NOS) is included in the portfolio of responsibilities of the United States Department of Commerce. The organization approves state Coastal Management Plans and oversees individual applications for federal consistency. OCRM provides management and legal assistance to coastal states, federal agencies, tribes and others; and mediates CZMA related disputes. Approval of Coastal Management Plans requires *a National Environmental Policy Act* (NEPA) review. The CZMA contains a major governance principal called "federal consistency". The provision requires the federal government to comply with a state's Coastal Management Program when taking actions that are likely to affect coastal resources. More specifically, the activities of federal agencies with impacts on the coastal zone "to the maximum extent practicable" are to be consistent "with the enforceable policies of a coastal state's federally approved coastal management program."

The CZMA was substantively amended on July 16, 1976 (P.L. 94-370) and on October 1, 1980 (P.L. 96-464). The Act and its amendments affirm a national interest in the effective protection and careful development of the coastal zone, by providing assistance and encouragement to coastal states (and U.S. territories) to voluntarily develop and implement management programs for their coastal areas. Financial assistance grants under Sections 305 for program development and 306 for program implementation were authorized by the CZMA to provide coastal states and territories with the means for achieving these objectives.[16]

Federal Emergency Management Agency

[16] New York State Coastal Management Program And Final Environmental Impact Statement Prepared by: Office of Coastal Zone Management National Oceanic and Atmospheric Administration Department Of Commerce and New York Department of State 1982 p. 3.

The U.S. Federal Emergency Management Agency (FEMA) is an agency of the United States Department of Homeland Security. FEMA plays a major role in planning for mitigation measures related to flooding. Through FEMA's flood hazard mapping program, Risk Mapping, Assessment and Planning (MAP), FEMA identifies flood hazards, assesses flood risks and partners with states and communities to provide accurate flood hazard and risk data to guide them to mitigation actions. Flood hazard mapping is an important part of the National Flood Insurance Program (NFIP), as it is the basis of the NFIP regulations and flood insurance requirements. FEMA maintains and updates data through Flood Insurance Rate Maps (FIRMs) and risk assessments. FIRMs include statistical information such as data for river flow, storm tides, hydrologic/hydraulic analyses and rainfall and topographic surveys. Local building codes often reference FEMA FIRMs in setting design requirements.

FEMA maps coastal flood hazards based on existing shoreline characteristics, and wave and storm climatology at the time of the flood study. In accordance with the current Code of Federal Regulations, FEMA does not map flood hazards based on anticipated future sea levels or climate change. FEMA notes that "Over the lifespan of a study, changes in flood hazards from sea level rise and climate change are typically not large enough to affect the validity of the study results."[17]

FEMA's Strategic Plan for 2018-2022 was published on March 15, 2018. It replaces a version issued by the former Administration that repeatedly cited the challenges caused by a changing climate, and the need for FEMA to incorporate those risks into its long-term plans. By contrast, the new document doesn't mention climate, global warming, sea-level rise, extreme weather, or any other terminology associated with scientific predictions of rising surface temperatures and their effects.[18]

9.1.2 State of California

California Coastal Commission

[17] "How is FEMA accounting for sea level rise and climate change on the FIRMs? Does sea level rise/climate change affect the FIRMs?" FEMA website https://www.fema.gov/coastal-frequently-asked-questions#How%20is%20FEMA%20accounting%20for%20sea%20level%20rise%20and%20climate%20change%20on%20the%20FIRMs?%20Does%20sea%20level%20rise/climate%20change%20affect%20the%20FIRMs?

[18] "FEMA Strips Mention of Climate Change From Its Strategic Plan" Bloomberg March 15, 2018 https://www.bloomberg.com/news/articles/2018-10-17/mueller-said-ready-to-deliver-key-findings-in-his-trump-probe

In California, the California Coastal Commission, in partnership with coastal cities and counties, plans and regulates the use of land and water in the coastal zone. The Commission was established in 1970 and made permanent through the *California Coastal Act* of 1976.

Development activities in the coastal zone generally require a permit from the Commission. Chapter 8 of the *California Coastal Act* (Coastal Act) establishes specific planning and regulatory procedures for California's "commercial ports" (defined as the ports of San Diego, Los Angeles, Long Beach, and Hueneme). The *Coastal Act* requires that a coastal development permit be obtained from the Coastal Commission for any development within these ports. However, a commercial port is granted the authority to issue its own coastal development permits once it completes a Master Plan certified by the Commission.

In 2015 the Coastal Commission issued policy guidance calling for sea level rise to be considered in local coastal programs and coastal development permits. However the document was issued for guidance only and does not carry the force of regulations.[19] The California Association of Port Authorities maintained that the Coastal Act (section 8) does not give the Commission the power to require consideration of sea level rise in port Master Plans.[20]

San Francisco Bay Conservation and Development Commission

The San Francisco Bay area (including the Port of Oakland) has its own San Francisco Bay Conservation and Development Commission (BCDC). Because San Francisco Bay does not lie within the Coastal Commission's jurisdiction, coastal management of the bay is provided by BCDC. The primary State law governing the BCDC is the *McAteer-Petris Act*. BCDC is the federally-designated state coastal management agency for the San Francisco Bay segment of the California coastal zone under CZMA. It is overseen by a 27-member Commission with members appointed by the Governor, local governments, and various Departments of the State government. Federal representation is provided by commissioners appointed by the EPA and US Army Corps of Engineers.

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[19] Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits August 12, 2015 https://documents.coastal.ca.gov/assets/slr/guidance/August2015/0_Full_Adopted_Sea_Level_Rise_Policy_Guidance.pdf

[20] "Comments on Draft Sea-Level Rise Policy Guidance" California Association of Port Authorities February 14, 2014 http://californiaports.org/wp-content/uploads/2015/08/CAPA.SLR_.LETTER.FINALpdf-1-1.pdf

9.1.3 Washington State

Washington State Department of Ecology

In Washington State, the Department of Ecology is responsible for coastal management under the CMZA. Environmental management of coastal areas is coordinated under Washington's *Shoreline Management Act* (SMA). SMA was passed by the Legislature in 1971 and adopted by the public in a 1972 referendum. The goal of the SMA is "to prevent the inherent harm in an uncoordinated and piecemeal development of the state's shorelines."

The SMA establishes a balance of authority between local and state government. Cities and counties are the primary regulators but the state (through the Department of Ecology) has authority to review local programs and permit decisions. Under the SMA, each city and county adopts a shoreline master program that is based on state guidelines but tailored to the specific needs of the community. Local shoreline master programs combine both plans and regulations. The plans are a comprehensive vision of how shoreline areas will be used and developed over time. Regulations are the standards that shoreline projects and uses must meet.

Local governments may modify master programs to reflect changing local circumstances, new information, or improved shoreline management approaches. All changes to master programs require public involvement. At a minimum, local governments must hold public hearings. The Department of Ecology provides technical assistance to all local governments undertaking master program amendments. Ecology also provides grants (approximately $425,000 per year) to local governments within the state's Coastal Zone.

Port districts have been given the legal authority to manage certain aquatic lands that are owned by the state. These aquatic properties abut uplands that are owned, leased or managed by the port. The details of this management responsibility are set forth in a Port Management Agreement (PMA). The PMA is a document signed by both the port and the Department of Natural Resources (DNR). The port manages these state-owned aquatic lands using the state's aquatic land management laws and regulations, in addition to the regular laws that govern port operations.

9.1.4 States of New York/New Jersey

Coastal management of the New York–New Jersey Harbor Estuary[21] is complex due to multiple layers of overlapping jurisdictions. Federal jurisdiction is similar to that on the West Coast.

[21] Also known as the Hudson-Raritan Estuary.

Jurisdiction is established by the *Coastal Zone Management Ac*t (CZMA) of 1972 which emphasizes the primacy of state decision-making regarding the coastal zone. Consequent amendments encourage the development of coastal management programs by state governments through the provision of grants for program development and implementation.

State Coastal Management Programs

The New York – New Jersey Estuary straddles the New York – New Jersey boundary, and both states have developed Coastal Management programs.

In 1982, the New York State Coastal Management Program was created to establish the boundaries of the Coastal Area within which the CMP applies, describe the organizational structure to implement the CMP, and provide a set of statewide policies enforceable on all State and Federal agencies which manage resources and coordinate actions along the State's coastline.

New Jersey's Coastal Management Program (NJCMP) was approved in August 1980. The program is part of the National Coastal Zone Management Program which addresses sustainable and resilient coastal community planning, climate change, ocean planning, and planning for energy facilities and development. It is a voluntary partnership between the federal government and U.S. coastal and Great Lakes states and territories authorized by the Coastal Zone Management Act (CZMA) of 1972 and administered by the National Atmospheric and Oceanic Administration (NOAA).

A separate program, the New York-New Jersey Harbor & Estuary Program (HEP) was established in 1987 as one of the Nation's 28 Estuaries of National Significance. The Program focuses on protecting and restoring healthy waterways and productive habitats, managing sediments, fostering community stewardship, educating the public, and improving safe access to our waterways. HEP was established as a partnership of federal, state, and local governments; scientists; civic and environmental advocates; the fishing community; business and labor leaders; and educators.

Port of New York and New Jersey

Oversight of regional seaports is provided by the Port Authority of New York and New Jersey (PANYNJ), a bistate agency established in 1921 through an interstate compact authorized by the

United States Congress. In addition to overseeing maritime facilities, PANYNJ is responsible for the vehicular crossings and the rapid transit system between New York and New Jersey, several of the region's airports, and other transportation and real estate development projects.

The port district encompasses the region within approximately a 25-mile (40 km) radius of the Statue of Liberty National Monument. It includes the system of navigable waterways in the New York–New Jersey Harbor Estuary, which runs along 650 miles (1,050 km) of shoreline in the vicinity of New York City and north eastern New Jersey, as well as the region's airports and supporting rail and roadway distribution networks. The port is by tonnage the third largest in the United States and the busiest on the East Coast.

Port planning and decision-making, with regard to both coastal storms and other safety and security issues, is shaped in part by two port-wide standing committees: the Harbor Safety, Navigation and Operations Committee ("Harbor Ops") and the Area Maritime Security Committee (AMSC). The Harbor Ops committee comprises broad, inclusive membership from both the public and private sectors who convene regularly to discuss a wide variety of Port and MTS safety and security matters. It is sponsored by the non-profit Maritime Association of the Port of NY and NJ; founded in 1917, it has existed in its current form since 1978.

The Port's AMSC was first established in 2004 pursuant to the Maritime Transportation Security Act of 2002 (P.L. 107-295), which called for the establishment of maritime security committees in the nation's ports to implement area maritime security plans. The Port's AMSC is led by the Coast Guard and its structure is shaped by this federal law. Membership is limited to those public and private actors with specific interest in maritime security issues.[22]

9.2 California

9.2.1 Port of Los Angeles, California

The Port of Los Angeles operates as a department of the City of Los Angeles. The Port manage State-owned lands granted to the local cities under Tideland Trust agreements. Commission members are appointed by the City Councils and/or the Mayor.

[22] Assessing the Impacts of Hurricane Sandy on the Port of New York and New Jersey's Maritime Responders and Response Infrastructure Tiffany C. Smythe, Ph.D. Post-Doctoral Fellow in Maritime Policy Center for Maritime Policy & Strategy, U.S. Coast Guard Academy pp. 4-5 https://hazards.colorado.edu/uploads/quick_report/smythe_2013.pdf

The Port of Los Angeles (POLA) is America's premier gateway for international commerce. Located in San Pedro Bay, 20 miles south of downtown Los Angeles. Major cargo and marine terminal types within the Port include container, auto, cruise, break-bulk, liquid and dry bulk. The Port occupies 7,500 acres (3,200 water, 4,300 land) and has 43 miles of waterfront. POLA is one of the largest container shipping facilities in the world. It owns many square miles of land, but its main assets are twenty container ship terminals—large steel and concrete structures that serve as docking facilitates for large container ships, the foundations for the large moving cranes that load and unload these ships, and transportation hubs for the trucks and trains that carry goods inland.

The edge of POLA's terminals currently lies about 12 feet (3.65 m) above mean sea level. Conduits carrying high-voltage electric lines run underneath the main floor and lie 9.2 feet (2.80 m) above mean sea level. A breakwater, managed by the U.S. Army Corps of Engineers, provides the main barrier to wave action and storm surge in the harbor.

The design and use of the terminals is driven by container ship technology. POLA first built these terminals in the 1960s and gave them a major overhaul in the 1980s when the size of container ships increased significantly. Several factors will drive the lifetime of POLA's current terminals, including how long they take to wear out and any impending changes in container ship technology, both of which are uncertain.

POLA's terminals are relatively high above today's mean sea level and have never been flooded in the past few decades. Given this large apparent safety margin, POLA would only consider sea level rise when planning a major upgrade of its terminals because hardening at that time would cost much less than it would at any other time.

9.2.2 California Energy Commission

Purpose

The California Energy Commission (CEC) is California's primary energy policy and planning agency. In 2012 CEC commissioned a study conducted by RAND to develop a methodology to incorporate uncertain climate change projections in their investment plans. The study addressed two questions:

(1) Under what future conditions would a Port of Los Angeles decision to harden its facilities against extreme sea level rise at the next upgrade pass a cost-benefit test, and

(2) Does current science and other available information suggest such conditions are sufficiently likely to justify such an investment?[23]

The RAND study focused on the question of whether POLA should harden its container ship terminals against future sea level rise during the next major upgrades of those terminals. Because these terminals are currently relatively high above the water, a decision to make such an investment can be thought of as purchasing relatively low-cost insurance against the potential impacts of poorly understood extreme events.

Approach

The study used a robust decision making (RDM) analysis[24]. The RDM approach consisted of the following steps:

- Considering selected parameters as deeply uncertain and evaluating over many cases, each described by some combinations of values of these deeply uncertain parameters;

- Concisely summarizing the common factors among those cases in which hardening at the next upgrade passes the cost-benefit test;

- Estimating the probability threshold that is the likelihood for these cases that would justify hardening at the next upgrade; and then

- Evaluating scientific lines of evidence to help judge whether or not these cases are sufficiently likely to justify a decision to harden at the next upgrade.

Findings

[23] Lempert, Robert, Ryan L. Sriver, and Klaus Keller (RAND). 2012. Characterizing Uncertain Sea Level Rise Projections to Support Investment Decisions California Energy Commission Publication Number: CEC-500-2012-056.
[24] https://www.rand.org/topics/robust-decision-making.html

This study conducted an RDM analysis for four POLA facilities of varying height above mean sea level: the underside of the container ship terminals, the top of those terminals, Berths 206–209, and the Alameda and Harry Bridges Crossing. Given the assumptions and decision criteria embedded in the analysis, it was found that a decision to harden at the next upgrade merits serious consideration for only one out of the four facilities considered: the Alameda and Harry Bridges Crossing. The Port of Los Angeles would need to identify hardening costs that are 5, 25, and 250 times lower than current estimates to warrant additional study for Berths 206–209, the terminal bottoms, and terminal tops, respectively.

9.2.3 Sea Level Rise Vulnerability Study for the City of Los Angeles

Purpose

Potential impacts of sea level rise on facilities at the Port of Los Angeles were examined as part of a broader study undertaken for the City of Los Angeles in 2013.[25] Sea level rise in Los Angeles is expected to match global projections over the next century with an increase of 0.1 - 0.6 meters (m), or 0.3 - 2.0 feet (ft), from 2000 - 2050 and 0.4 - 1.7 m (or 1.3 - 5.6 ft) from 2000 - 2100 (NRC 2012). Tides, wave-driven run-up, and storm surge play critical roles in coastal flooding in Southern California, especially when big wave storms occur at or near peak high tides. Sea level rise will potentially exacerbate the damage from these events.

Approach

The study assessed the vulnerability and potential replacement costs for Port of Los Angeles facilities including container terminals, electrical infrastructure, transportaiton infrastructure, the harbor breakwater and marinas.

For the vulnerability assessments, the City utilized a coastal impacts model developed by Dr. Patrick Barnard and colleagues at the United States Geological Survey (USGS). This model incorporates not only the impacts of rising sea levels, but also the impacts of waves and storm surge associated with coastal storms. The USGS model is based on a storm that occurred in the Los Angeles region during January 2010. The modelers applied two sea level rise scenarios using upper-end estimates of 0.5 meters (m) sea level rise between 2000 - 2050 and 1.4 m sea level rise between 2000 - 2100 (scenarios based on Rahmstorf 2007). The scenarios were added to

[25] Sea Level Rise Vulnerability Study for the City of Los Angeles Grifman, P.M., J.F. Hart, J. ladwig, A.G. Newton Mann, M. Schulhof USCSC-TR-05-2013.

the tide, wave and wind conditions of the January 2010 storm to project what could be expected for a similar type of storm event under conditions related to rising seas.

Findings

In general, the study found that replacement costs for Port facilities would be high but long term vulnerability is low due to the ability to adapt over time by building infrastructure at higher elevations.

Figure 9-1 Sea Level Rise Port Impacts, Los Angeles

Sea Level Rise Port Impacts - City of Los Angeles Study 2013				
Assets	**Description**	**Sensitivity**	**Adaptive Capacity**	**Replacement Cost**
Container Terminals	Marine terminals handling container shipments.	Highly sensitive to flooding and inundation.	Short term: Low. Long Term: High due to capacity to adapt by building infrastructure at higher elevation.	US$2.85 billion replacement cost; disruption costs US$1 billion per day
Electrical Infrastructure	Electrical infrastructure for container handling and lighting.	Highly sensitive to flooding and inundation.	Short term: Low. Long Term: High due to capacity to adapt by building infrastructure at higher elevation.	US$350 million
Transportation Infrastructure	Roads, rails and grade separations for moving cargo to and from the port.	Medium	High - quickly rebuildable.	US$1 billion
Breakwater	8.5 mile rock structure to prevent waves from entering the harbor.	Medium	Partially functional if damaged (i.e. low tide).	US$500 million
Marinas	Docks with moorings for small boats.	Medium	High	US$180 million

9.2.4 San Francisco Bay, California

Purpose

In 2010, the San Francisco Bay Conservation and Development Commission (BCDC) and NOAA's Office for Coastal Management (NOAA OCM) brought together local, regional, state and federal agencies and organizations, as well as non-profit and private associations for a collaborative planning project along the Alameda County shoreline – the Adjusting to Rising Tides (ART) Subregional Project – to identify how current and future flooding will affect communities, infrastructure, ecosystems and economy. [26]

Approach

[26] Adapting to Rising Tides http://www.adaptingtorisingtides.org/

Since its inception the ART Program has led and supported multi-sector, cross-jurisdictional projects that build local and regional capacity in the San Francisco Bay Area to plan for and implement adaptation responses. The ART approach was built on a traditional planning process framework – from scoping to implementation – tested and refined by ART Program staff to address the specific challenges of building climate resilience across different communities, assets and services, and jurisdictions and owners.

Experience with a variety of adaptation planning efforts that range from broad to focused scales, single to multi-sector, has led the ART Program to emphasize three factors for success in this approach.

- Collaborative by design: Climate change, similar to hazard planning, requires planning across jurisdictions, geographies, sectors, and time frames to address complex, cross-cutting issues. ART emphasizes convening and closely collaborating throughout a planning process with a stakeholder working group representing the diverse values, viewpoints and responsibilities relevant to the project, to build relationships that lead to future collaborations.

- A transparent process: To build a strong, actionable case for adaptation, the ART approach adheres to transparent decision-making throughout the planning process. ART Design Your Project guidance and supplies help maintain transparency and support clear communication to stakeholders about decisions and project outcomes, including resilience goals developed and agreed upon by the working group, and evaluation criteria that clearly reflect priorities and objectives.

- Sustainability from start to finish: A core aspect of ART is consideration of the relevance and implications of all aspects of sustainability in each step of the planning process, from who is included in the initial working group list to what evaluation criteria are selected to evaluate adaptation responses. ART uses four sustainability frames:

Figure 9-2 Sustainability Concept, San Francisco



The ART project has completed vulnerability and resilience assessments across multiple sectors, including seaports. The Bay Area's major container port is the Port of Oakland, which handles 99% of the containerized goods moving through Northern California and specializes in import of high-value consumer goods and export of agricultural products from the Central, Napa, and Salinas valleys. Minor ports in the Bay Area each have a niche role in cargo movement; the Port of Benicia has developed a specialty in, for example, cars and petrocoke, Redwood City in construction materials, Richmond in liquid bulk and cars, and San Francisco in dry bulk. The Port of San Francisco has recently included other maritime uses, such as hosting cruise ship calls.[27]

Findings

The research found that most seaports are not directly vulnerable to current or future flooding, although some have infrastructure located under wharves that could be damaged from increased tidal and wave energy as sea levels rise. However, seaports require a number of on-site and off-site facilities and services that can be disrupted or damaged by temporary flooding or permanent flooding, such as utilities, storm water, pipelines, and transportation infrastructure.

Past ART projects in Alameda and Contra Costa Counties identified railroads and highways that directly serve the ports of Oakland and Richmond as areas of vulnerability. Rail lines are often located along the shoreline and cross many tidal creeks and channels throughout the region. Damage due to flooding at any point in the rail system can result in system-wide disruptions. Loss of rail service to seaports could result in increased truck traffic, affecting congestion and air quality in surrounding neighbourhoods, local roadways, and interstates. For example, at the Port of Oakland, goods are transferred from ships to Union Pacific Railroad (UPRR) and I-880 which are both at risk of future flooding. This area of shoreline is also located on bay fill so future rising groundwater rise is an added risk. Similarly, at the Port of Richmond, some access roads and UPRR and BNSF rail lines are located within the 100-year floodplain and may be exposed to more frequent or extensive flooding with sea level rise. The Port of Redwood City (assessed by San

[27] Adapting to Rising Tides – Seaports http://www.adaptingtorisingtides.org/portfolio/seaport/

Mateo County's Sea Level Vulnerability Assessment) is also sensitive to sea level rise primarily due to flood risk at critical and connected transportation assets (Seaport Boulevard and UPRR).

While it appears that no detailed economic impact analysis has been undertaken as part of the ART program, the findings suggested that a disruption at one of the region's ports, particularly the Port of Oakland or the Port of Richmond, could have significant and negative implications for the region's economy, environment and communities access to products, and jobs. The results included a recommendation that "efforts to address seaport vulnerability must look at goods movement systems more broadly".

9.3 Washington State

9.3.1 Ports of Seattle and Tacoma, Washington State

The Ports of Tacoma and Seattle are quasi-governmental agencies overseen by commissioners elected directly by county voters. Since 2015, container terminal operations at the Ports of Seattle and Tacoma have been jointly managed by the Northwest Seaport Alliance (NWSA).

9.3.2 Northwest Seaport Alliance – Terminal 5 Final Environmental Impact Statement

Purpose

The Port of Seattle is developing a draft climate change adaptation plan to address projected rates of sea level rise at Port facilities. In addition, through the Northwest Seaport Alliance they are advancing the Terminal 5 Cargo Wharf Rehabilitation, Berth Deepening and Improvements project to accommodate larger container vessels (up to 18,000 TEU). The project includes installation of heavier cranes with a longer outreach and deeper drafts to simultaneously handle two 18,000-TEU vessels.[28]

Approach

The Port of Seattle's draft adaptation plan (unpublished) stresses the impact of asset design life in assessing potential sea level rise impacts. It notes that the longest design life that the Port assigns to an asset is 50 years and the most likely amount of sea level rise that an asset will

[28] Northwest Seaport Alliance https://www.nwseaportalliance.com/about/strategic-plan/t5

experience over the next 50 years is about nine inches (.23 m). However, an assessment of potential impacts of sea level rise was included in the Final Environmental Impact Statement for the Terminal 5 Cargo Wharf Rehabilitation, Berth Deepening and Improvements project.[29]

Findings

Inundation from rising sea levels could challenge the capacity of storm drains and treatment facilities at the terminal. Rising sea levels could inundate or disrupt numerous nearshore facilities due to flooding caused by the increased elevation of receiving water bodies. Drainage facilities may need to be enlarged to provide storage for additional storm water volumes that may result from water backing up due to sea level rise.

Sea-level rise impacts could also potentially include changes to shoreline slope stability due to changes in tidal flux and wave action and higher frequency of flooding; higher ground water elevations which may affect pavement and foundation performance, settlement, subsurface utilities and berthing functionality.[30]

The analysis included three potential options. Alternative 1 was “no action” (in which modernization of the terminal would not proceed). Alternative 2 proposed to rehabilitate the existing T5 container cargo pier to support larger container cranes. The rehabilitation includes upgrades to the existing apron area and crane rails to support the large container cranes. Upgrades to the apron will not include changes to apron or upland surface elevations. Slope stabilization measures under the wharf will be implemented with apron upgrades, to maintain the existing slope stability.

Alternative 3 includes the wharf improvements included in Alternative 2, with additional improvements including relocation of buildings, densification of the rail yard, and optimized cargo handling efficiency and volume. Additionally, the majority of the stormwater collection system will be reconfigured to accommodate the new terminal stacking system. Existing outfalls will be maintained where possible. A stormwater management plan and potential treatment facilities will be installed to aid the facility in achieving Department of Ecology Industrial Stormwater Permit

[29] “Appendix I Sea Level Rise Considerations” Terminal 5 Cargo Wharf Rehabilitation, Berth Deepening and Improvements Project Moffat & Nichol April 20, 2016.

[30] “Appendix I Sea Level Rise Considerations” p.5.

compliance. Excavation will be required for trenching of utilities and site preparation work and the new crane beams. Utility excavations are expected to be up to 10 feet below ground surface, and dewatering may be required to accommodate construction.

The assessment concluded that Alternative 3 will most likely provide the most opportunities to accommodate sea level rise. It was noted that the project is proposed on an existing site, with existing rail, vehicle, and vessel access and support infrastructure already in place. Continued use of and connectivity to existing infrastructure are critical design considerations. The proposed opportunities for Alternatives 2 and 3 present ideas could be implemented now as a part of this project, or at a later date in an adaptive management strategy to minimize sea level rise risks and maintain terminal efficient operations. Possible actions could include:

- Replacement of the fender system could incorporate design to account for some sea level rise.

- The installation of backflow prevention devices (flap gates) could prevent saltwater from backing up into the enclosed drainage system of T5.

- The installation of larger diameter storm system piping, modification of existing outfalls, and/or installation of new outfalls could provide additional system capacity and prevent overtopping during high tidal events.

- The majority of the pavement in the container yard will be removed and replaced as part of Alternative 3. The subgrade of the replaced pavement could be designed to accommodate increased groundwater elevations.

The study also noted significant unavoidable adverse impacts of sea level rise based on the project limitations. Under all alternatives the existing elevation of the wharf deck will not be increased. As sea levels rise, increased tidal flux and wave action will result in waves overtopping the wharf during storm events at higher tide cycles. Although rebuilding of the outer wharf deck under Alternative 2 and Alternative 3 would allow for the elevation of the outer portion to be raised to account for higher tidal elevations, the inner portion of the terminal would remain at the existing elevation and would result in grade changes that are not suitable for containerized port facilities.

9.3.3 Washington State Projected Sea Level Rise

Purpose

An updated study on projected sea level rise for Washington State was published in 2018 as part of the Washington Coastal Resilience Project (WCRP), a three-year effort to rapidly increase the state's capacity to prepare for coastal hazards, such as flooding and erosion, that are related to sea level rise. The project has been undertaken to improve risk projections, provide better guidance for land use planners and strengthen capital investment programs for coastal restoration and infrastructure. Partners include Washington Sea Grant; Washington Department of Ecology; Island County; King County; NOAA Office for Coastal Management; Padilla Bay National Estuary Research Reserve; The City of Tacoma; The Nature Conservancy; U.S. Geological Survey; University of Oregon; University of Washington Climate Impacts Group; University of Washington Department of Earth and Space Sciences; Washington Department of Fish and Wildlife; and Pacific Northwest National Laboratory.[31]

Approach

The study produced a single set of absolute sea level rise projections for the entire state of Washington. However due to important differences in vertical land movement along the state's coastlines,[32] the study produced projections of relative sea level rise for 171 locations along the coastline. The relative sea level rise projections reflect the distributed estimates of vertical land motion, showing higher sea level rise in some places than in others. Although the rate of vertical land movement is generally small compared to absolute sea level rise projections – especially later in the 21st century – it can have a noticeable impact on observed and projected sea level in some locations.

Findings

The absolute sea level rise projections suggest a central estimate – corresponding to a 50% chance that absolute sea level will rise by at least that amount – of 1.6 ft (.49 metres) for a low

[31] Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., Grossman, E. Projected Sea Level Rise for Washington State – A 2018 Assessment A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project http://www.wacoastalnetwork.com/files/theme/wcrp/SLR-Report-Miller-et-al-2018.pdf

[32] For example, the study notes that "on the northwest Olympic Peninsula near Neah Bay, where the land is uplifting rapidly, the relative sea level rise projections are lower than the absolute sea level rise projections. In areas where the land is subsiding, such as central Puget Sound, the relative sea level rise projections are slightly higher than the absolute sea level rise projections." Ibid., p. 8.

greenhouse gas scenario and 2.0 feet (.61 metres) for a high greenhouse gas scenario, by 2100. At the low end, the projections give an 83% probability that sea level will rise by at least 1.0 (.6 m) or 1.4 feet (.43 m), again for a low and a high greenhouse gas scenario, respectively. At the high end, the projections suggest a rapid acceleration in the rate of sea level rise over the 21st century: the projections give a 1% probability, for example, that absolute sea level rise will reach or exceed 4.1 feet (1.25 m) for a low greenhouse gas scenario, and 4.8 feet (1.46 m) for a high greenhouse gas scenario, by 2100.

The major seaports in Washington State are the Ports of Seattle and Tacoma, located in Puget Sound. Due to ongoing subsidence, the projected relative sea level rise at the Port of Seattle is .9 metres higher than the absolute sea level rise.

Figure 9-3 Port of Seattle Projected Sea Level Rise

Port of Seattle Projected Sea Level Rise - Central Estimates 2100		
	Low GHG Scenario (metres)	**High GHG Scenario (metres)**
Absolute Sea Level Rise	0.49	0.61
Relative Sea Level rise	0.58	0.70

No research on potential impacts on port facilities was included in this study.

9.4 New York/New Jersey

9.4.1 Port of New York/New Jersey

Port Authority of New York – New Jersey Climate Resilience Design Guidelines

The Port of New York and New Jersey, which spans both the New York and New Jersey sides of New York Harbor, is the third largest port in the U.S. and the largest port on the Atlantic Coast. Cargo operations are supported by facilities including container ports, oil terminals, vehicle terminals, and other bulk and break-bulk cargo facilities located on the New Jersey, Staten Island, and Brooklyn waterfronts. These facilities are not managed comprehensively under one agency or organization. PANYNJ, as a landlord port, owns some of the land hosting these facilities, while other facilities, including oil terminals, are privately owned.

Port operations were severely disrupted by Hurricane Sandy in 2012. Hurricane Sandy made landfall in the north-eastern U.S. near Brigantine, NJ on October 29, 2012. According to the NOAA PORTS system and tidal data sensors, storm tides reached a record 14.06 feet (4.3 m) at the southern tip of Manhattan and 14.58 feet (4.5 m) at Bergen Point, a critical area between New York and New Jersey along the Kill Van Kull and Arthur Kill waterways that hosts a concentration of oil refineries and petroleum-chemical holding facilities. As a result of these conditions, and in particular because of the storm duration and extent of flooding, there were extensive and prolonged disruptions to many Port activities and facilities. Much port activity was shut down for nearly a week.[33]

Purpose

In June 1993, PANYNJ formally issued an environmental policy statement recognizing its longstanding commitment to provide transportation, terminal, and other facilities of commerce in an environmentally sound manner. In 2008, the Board of Commissioners reaffirmed its support of the Port Authority's continuing sustainability initiatives and expanded the Authority's environmental policy to include climate change. The Sustainability Policy directs the Authority to "develop strategies that reduce the risk posed by climate change to its facilities and operations and, in collaboration with other regional stakeholders, develop strategies that mitigate the risk to the region posed by climate change in a manner that will promote a sustainable environment."

Approach

To help fulfil this policy mandate, the Port Authority Engineering Department responded in 2009 by issuing a Design Memorandum dictating that "the design of all new construction and major rehabilitation projects is to be evaluated based on … climate change variables", including temperature, precipitation, and sea level rise.[34] This was followed by issuing of the first edition of the PANYNJ Climate Resilience Design Guidelines in 2015; the most recent version was released in June 2018.

Objectives of the Guidelines include supporting the incorporation of climate change projections—particularly sea level rise— into the full range of Port Authority engineering and architectural

[33] Assessing the Impacts of Hurricane Sandy on the Port of New York and New Jersey's Maritime Responders and Response Infrastructure p. 7.
[34] Climate Resilience Design Guidelines Port Authority of New York – New Jersey Engineering Department June 2018 p. 1. https://www.panynj.gov/business-opportunities/pdf/discipline-guidelines/climate-resilience.pdf

design standards, as a supplement to applicable building code requirements; and providing a clear methodology for factoring projected future sea level rise into project design criteria, while maintaining the flexibility of project teams to develop cost-effective design solutions.

The Port Authority takes a code-plus approach to designing for future sea level rise, meaning that the Climate Resilience Guidelines supplement, but do not supersede, applicable codes and standards. The American Society of Civil Engineers (ASCE) standard Flood Resistant Design and Construction (ASCE 24) is fully incorporated into New Jersey Building Code and serves as the basis for New York City Building Code Appendix G (Flood-Resistant Construction). ASCE 24 dictates that construction in the FEMA 1% ("100-year") annual chance floodplain is subject to specific, safety-driven requirements, most notably the establishment of a Design Flood Elevation (DFE) comprising:

- Base Flood Elevation: The project-specific FEMA Base Flood Elevation (BFE) — the elevation of the 100-year flood including waves—is derived from the FEMA Flood Insurance Rate Map(s); and

- Freeboard. Freeboard is a factor of safety usually expressed in feet above the BFE, as dictated by the requirements of ASCE 24 or the applicable code. Freeboard requirements are based on classification of assets as "critical" or "not critical" under the applicable code.

The Climate Resilience Guidelines supplement ASCE 24 and applicable local codes in two primary ways:

- Adjustment of the BFE for Sea Level Rise: The Guidelines augment the applicable FEMA BFE by adding the relative increase in future sea levels (based on the NPCC projections) over the project's expected service life;

- Consideration of future floodplain expansion: Rising sea levels may also lead to expansion of the 100-year tidal floodplain over time, depending on local conditions. Therefore, the Guidelines apply to projects sited in or proximate to today's 0.2% annual chance ("500 -year") floodplain or in the projected future tidal 100-year floodplain, in addition to the current FEMA 100-year floodplain. FEMA does not map flood hazards based on anticipated future sea levels or climate change.

Climate change projections incorporated in the Guidelines were estimated by the New York City Panel on Climate Change (NPCC) in 2015.[35] These projections were used as the basis for adjustment factors to be taken into account for construction of new facilities or major rehabilitation projects, depending on the projected service life of the assets, as specified in PANYNJ's Asset Class Manual. The table below shows the appropriate sea level rise adjustment factors to be added to Base Flood Elevation based on the anticipated end year of an asset's expected service life.

Figure 9-4 Port of New York New Jersey Projected Sea Level Rise

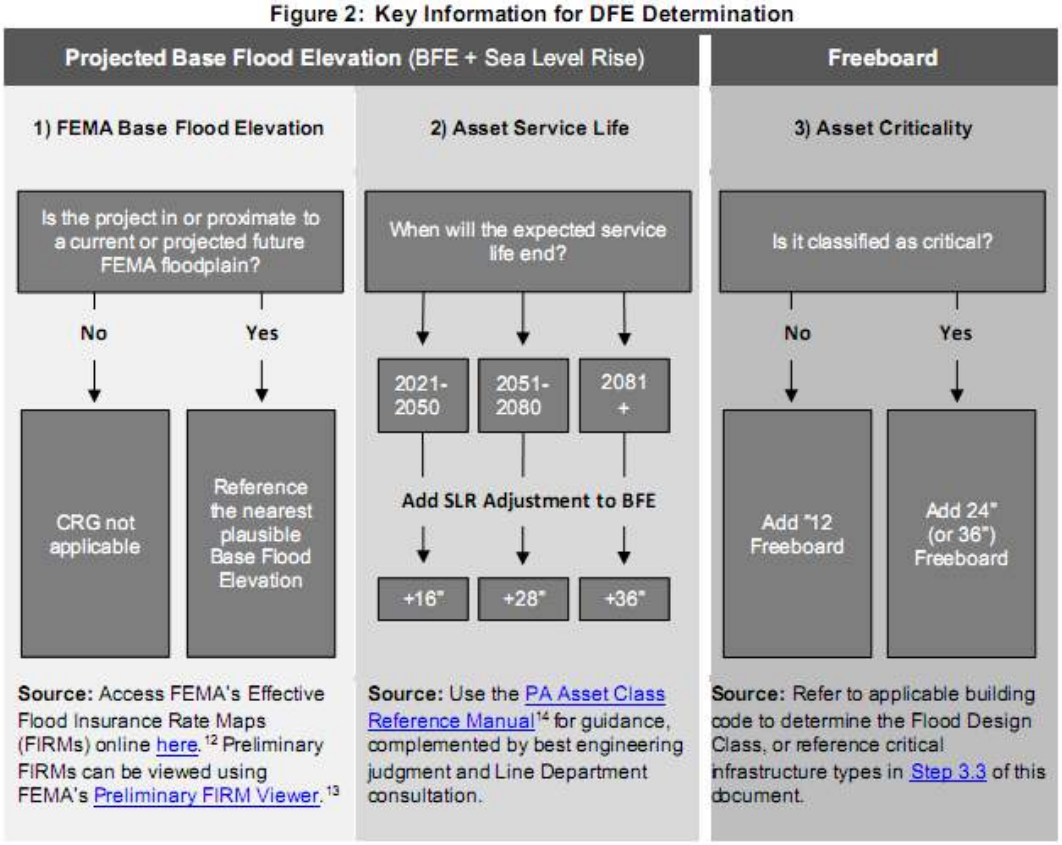
PANYNJ Sea Level Rise Adjustment Factors	
End of Anticipated Asset Service Life	**Sea Level Rise Adjustment (metres)**
2012 - 2050	+0.41
2015-2080	+.71
2081+	+.91

The diagram below summarizes the key information used to define the Design Flood Elevation under PANYNJ's Climate Resilience Design Guidelines.[36]

[35] Building the Knowledge Base for Climate Resiliency New York City Panel on Climate Change 2015 Report Chapter 1: Climate Observations and Projections Radley Horton et al NY. Acad. Sci. ISSN 0077-8923 Annals of the New York Academy Of Sciences 2015 https://nyaspubs.onlinelibrary.wiley.com/doi/epdf/10.1111/nyas.12586

[36] Climate Resilience Design Guidelines p. 6.

Figure 2: Key Information for DFE Determination



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Appendix F

Potential Sea Level Rise Impacts to Intertidal Areas and Marine Riparian Areas

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1. Introduction

Intertidal and marine riparian habitat along the North Shore was mapped to help quantify the impacts of sea level rise to natural habitat and land cover types. The assessment area included the portion of the North Shore shoreline between Point Atkinson in the District of West Vancouver and North Woodlands along Indian Arm in the District of North Vancouver, and covered portions of land on and adjacent to the City of North Vancouver, Squamish Nation reserves, and Port of Vancouver jurisdiction in between. The assessment area was limited to less than the overall North Shore sea level rise project study area due to the extent of data available to complete the analysis.

2. Intertidal Area Change

The intertidal zone is defined by the limits of low tide and high tide and characterized by alternating periods of inundation and exposure during the tide cycle. Table 1 presents the current tidal elevation range and the projected tidal elevation range under 1 m and 2 m sea level rise scenarios.

Table 1: Intertidal Zone Elevation Bounds Under 1 m and 2 m Sea Level Rise Scenarios

Intertidal Zone Bounds	Elevation (m, CGVD28)		
	Current Sea Level	1 m Sea Level Rise	2 m Sea Level Rise
Average Lower Bound - Lower Low Water Mean Tide (LLWMT)	-1.8	-0.8	0.2
Average Upper Bound - Higher High Water Mean Tide (HHWMT)	1.5	2.5	3.5

As sea level rise occurs over time, the low tide line (defined here as the LLWMT) elevation will rise and the lower boundary of the intertidal zone will move up in elevation and move horizontally landward, resulting in a reduction of intertidal area. As the high tide line (i.e., HHWMT) elevation rises, the upper boundary or the intertidal zone will move up in elevation and move horizontally landward, resulting in an increase of intertidal area, and a reduction of shoreline land area.

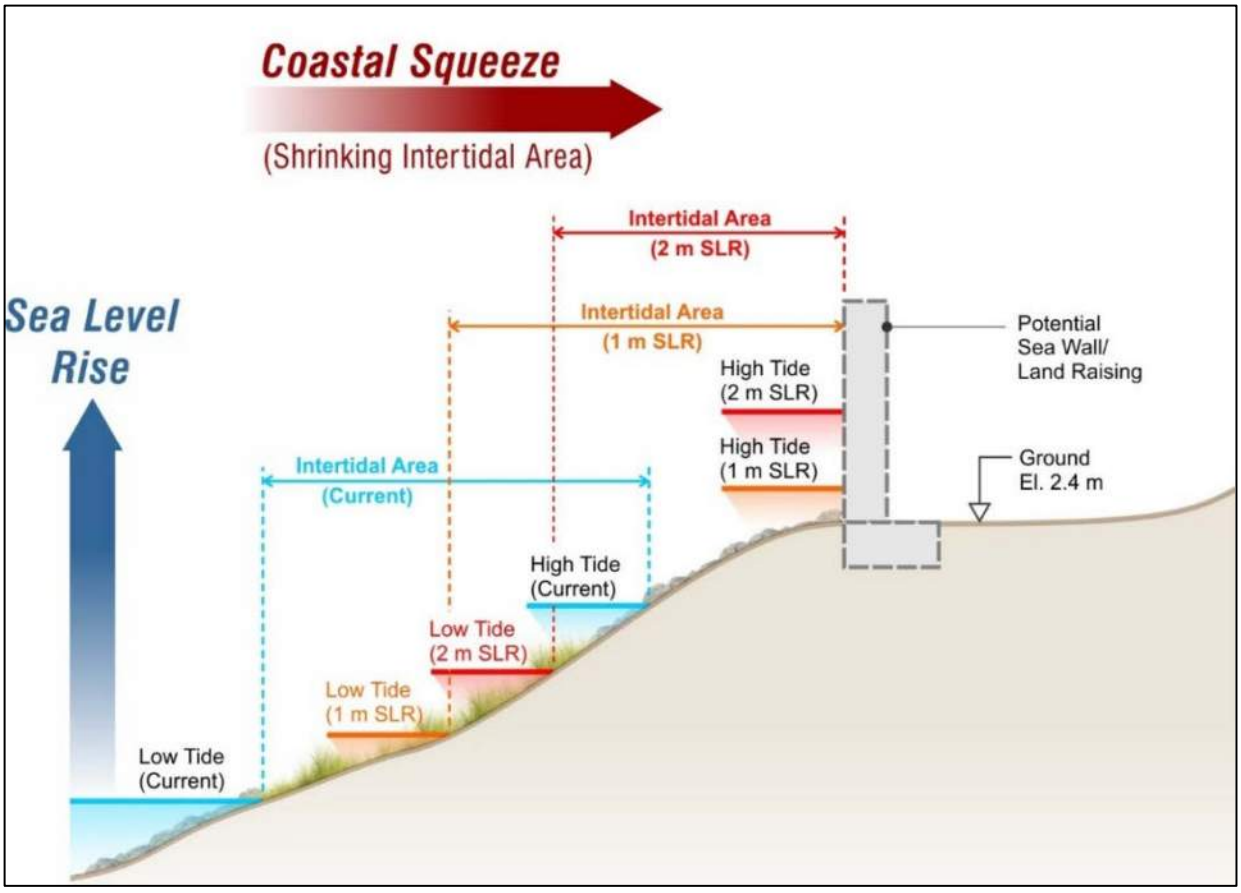
2.1 Intertidal Adaptation Spectrum: Coastal Squeeze to Managed Retreat

The impact of sea level rise on intertidal area is linked with how waterfront land uses are managed.

For this high-level assessment, two extreme ends of the spectrum of management approaches were investigated to show the potential range of impacts.

Coastal Squeeze with Vertical Walls to Prevent Tidal Inundation

Coastal squeeze can occur when waterfront landowners construct vertical walls to prevent regular tidal flooding due to sea level rise and therefore cut off the potential increase in intertidal area due to a rising high tide. Under this approach, the high tide elevation in the future will be higher, but the high tide line on the shoreline will be held at the same horizontal location by a vertical wall. This scenario is conceptualized in the graphic below which shows the impact of a vertical wall.



The level of impact of coastal squeeze associated with vertical walls will depend on where vertical walls are constructed. The largest impact will occur where vertical walls are constructed at or below the existing high tide line on the shoreline, such that as sea level rises the future high tide cannot go inland.

It should be noted that a less severe type of coastal squeeze can also occur without the construction of vertical walls. Because shorelines are often armoured or developed and have a steeper slope than the existing intertidal zone, the area of intertidal zone gained by a rising high tide is often restricted. This means that as the low tide line rises, and the lower boundary of the intertidal zone moves landward, the high tide line is not moving as far inland and an overall decrease of intertidal area occurs. This type of coastal squeeze can occur even under a do-nothing approach.

Managed Retreat for Future Intertidal Area

A managed retreat for future intertidal area approach would involve allowing rising high tides due to sea level rise to inundate inland areas and allow those areas to become future intertidal areas. Areas that are undeveloped (e.g., parks and green space) can accommodate future intertidal area without significant retreat efforts (although landscape and habitat management efforts may be required). For developed lands, land use policies and tools can be used to vacate the land over time to allow for some inland movement of the high tide line.

It is important to note that these two approaches represent the extreme ends of the spectrum of approaches and a future reality may likely fall somewhere in between and vary by location and context.

2.2 Methodology

Four sea level rise and response scenarios were used to quantify the range in changes in intertidal area and habitat from current sea level:

1. 1 m sea level rise with managed retreat (-0.8 m LLWMT and 2.5 m HHWMT);
2. 1 m sea level rise with coastal squeeze (vertical walls at current high tide, -0.8 m LLWMT and 1.5 m HHWMT);
3. 2 m sea level rise with managed retreat (0.2 m LLWMT and 3.5 m HHWMT); and
4. 2 m sea level rise with coastal squeeze (vertical walls at current high tide, 0.2 m LLWMT and 1.5 m HHWMT).

To assess potential changes in intertidal habitat caused by projected sea level rise, future high and low tide boundaries were compared to the current extent and distribution of both intertidal and terrestrial habitat types.

First, a map of intertidal habitat types was created using existing spatial data (BIEAP 2009). Second, predicted high and low tide boundaries with 1 m and 2 m sea level rise were superimposed on top of high-resolution images of the North Shore to determine the change in area of intertidal habitat types. The mapping exercise assumed that the shoreline geometry would stay consistent. This is a simplification as the shoreline shape is likely to evolve over time with sea level rise due to enhanced coastal erosion.

The habitat classification system used for the assessment was based off existing spatial data on Intertidal Vegetation Areas from the Burrard Inlet Environmental Action Program (BIEAP 2009). Due to the large number of classes in each data set, some classes were combined to simplify the data. For example, the Intertidal Vegetation Areas classes, ‘High Marsh’ and ‘Low Marsh’, were combined and classed as ‘Marsh’ habitat. Additionally, the existing spatial data for both datasets was completed for larger areas throughout Burrard Inlet, classes that were not found within the current and future tidal ranges were removed from the assessment.

It is important to note that the habitat types that will establish in the newly gained intertidal area (i.e. areas that are not currently intertidal) were not predicted for this assessment. More detailed modelling or analysis would be required to make these predictions.

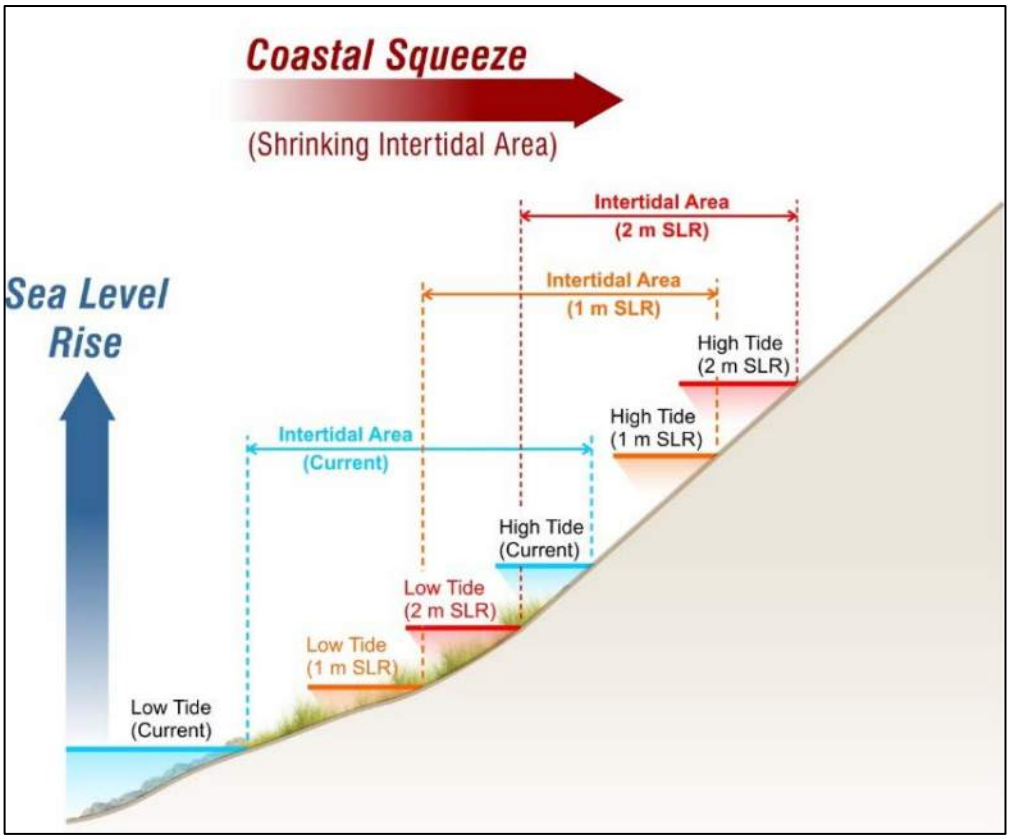
2.3 Results

In the assessment area, the existing intertidal zone has an area of about 1,906,300 m^2. The four assessment scenarios were used to compare against the existing area.

1 m sea level rise scenarios

If the current high tide line (i.e., HHWMT) is maintained by constructing vertical walls (coastal squeeze), an overall decrease of about 950,900 m^2 or 50% of the current extent of the intertidal area is projected with 1 m of sea level rise due to the inland movement of the low tide line (i.e., LLWMT). The high tide line would not move due to the vertical walls.

If coastal waters are allowed to move inland and development is pulled back from the current shoreline (e.g., managed retreat), based on the current land elevations, the above loss will be offset by a 260,800 m^2 gain in intertidal area above the current high tide line. This results in a net loss in area of about 690,100 m^2 or 36% of the current extent of the intertidal area with 1 m of sea level rise. The net loss even under a managed retreat scenario may be explained by the existing topography of the shoreline. Even under a managed retreat scenario, if the newly gain intertidal area is on steeper topography than the lost intertidal area, then there would be a net loss. This is conceptualized on the graphic below. It should be noted that this scenario is uncertain because a managed retreat approach could also involve gradual changes to the shoreline geometry through erosion which could offset this coastal squeeze.



2 m sea level rise scenarios

If the current high tide line is maintained by constructing vertical walls, an overall decrease of about 1,540,600 m^2 or 81% of the current extent of the intertidal area is projected with 2 m of sea level rise due to the inland movement of the low tide line. The high tide line would not move due to the vertical walls.

If coastal waters are allowed to move inland and development is pulled back from the current shoreline, the above loss will be offset by a 2,037,900 m^2 gain in intertidal area above the current high tide line. This results in a net gain in area of about 497,300m^2 or 26% of the current extent of the intertidal area with 2 m of sea level rise. The net gain may be explained by the large, relatively flat topography that currently sits above the intertidal area but would become part of the intertidal area under 2 m of sea level rise.

Table 2 and Table 3 present the predicted intertidal area change under coastal adaptation scenarios of managed retreat versus coastal squeeze (vertical walls) for 1 m and 2 m of sea level rise.

Table 2: Predicted Intertidal Area Change Under Different Coastal Adaptation Scenarios for 1 m of Sea Level Rise

	Current Intertidal Area (2009, m^2)	Managed Retreat and Naturalization – Allow High Tide Expansion Into Inland Areas				Resist - Vertical Walls at Current High Tide Line	
		Intertidal Area Lost (m^2)	Intertidal Area Gained (m^2)	Net Change in Intertidal Area (m^2)	Future Intertidal Area (~Year 2100) (m^2)	Intertidal Area Lost (m^2)	Future Intertidal Area (~Year 2100) (m^2)
Overall Assessment Area	1,906,338	950,885 (49.9%)	260,786 (13.7%)	-690,099 (-36.2%)	1,216,239	950,885 (49.9%)	955,453
Note: Areas rounded to nearest 1 m^2							

Table 3: Projected Intertidal Area Change Under Different Coastal Adaptation Scenarios for 2 m of Sea Level Rise

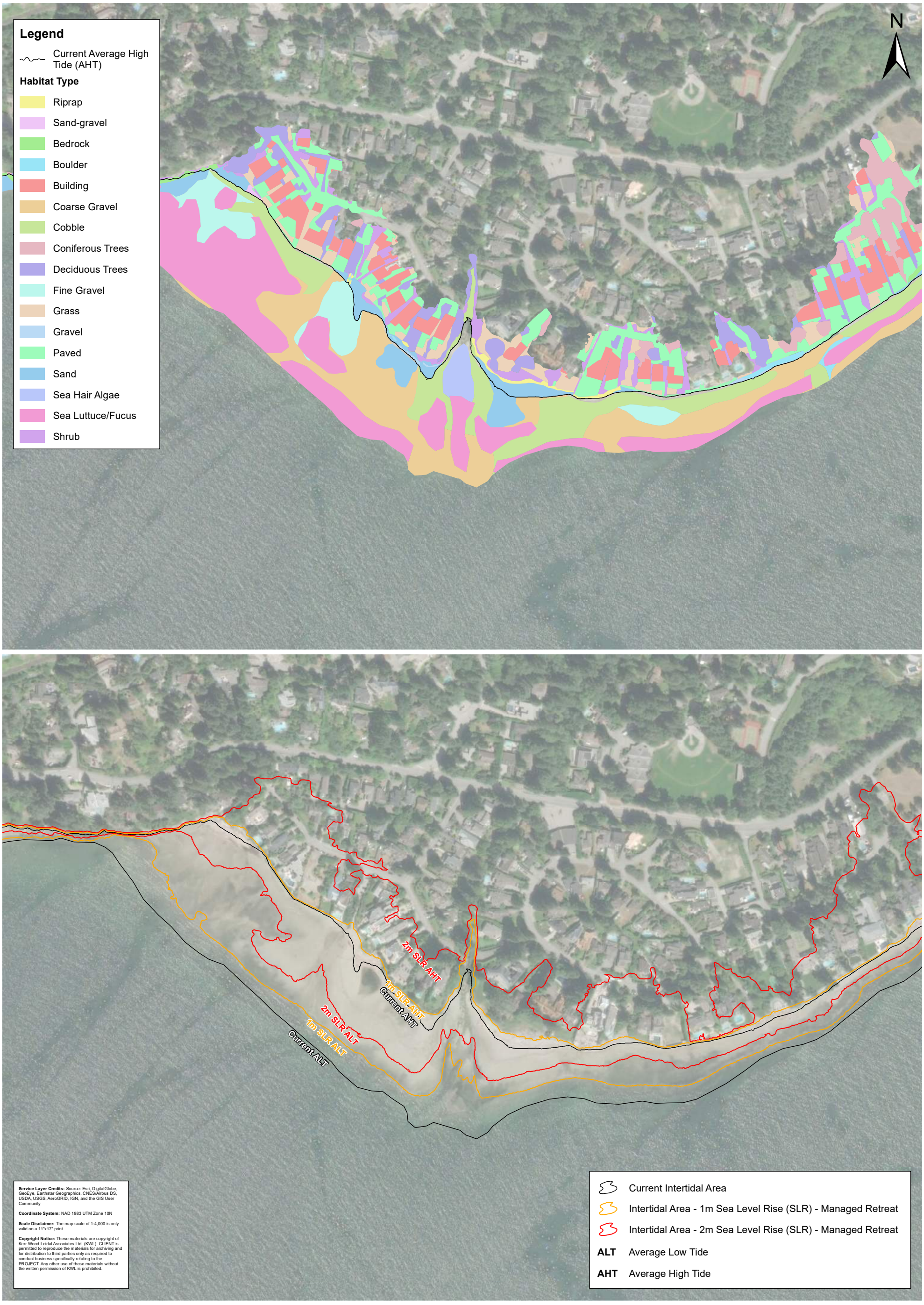
	Current Intertidal Area (2009, m^2)	Managed Retreat and Naturalization – Allow High Tide Expansion Into Inland Areas				Resist - Vertical Walls at Current High Tide Line	
		Intertidal Area Lost (m^2)	Intertidal Area Gained (m^2)	Net Change in Intertidal Area (m^2)	Future Intertidal Area (~Year 2100) (m^2)	Intertidal Area Lost (m^2)	Future Intertidal Area (~Year 2100) (m^2)
Overall Assessment Area	1,906,338	1,540,621 (80.8%)	2,037,925 (106.9%)	+497,304 (26.0%)	2,403,642	1,540,621 (80.8%)	365,717
Note: Areas rounded to nearest 1 m^2							

Figures 1, 2, and 3 show examples of existing intertidal habitat and future intertidal areas undermanaged retreat. The example locations are: Stearman Beach, Seymour River Mouth, and Deep Cove.

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Project No. 031-548

Date December 2019

Scale 1:4,000 0 25 50 100 (m)

Representative Example 1 - Stearman Beach

Figure 1

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers

N

Legend

Current Average High Tide (AHT)

Habitat Type

- Bull Kelp
- Dock
- Exposed soil
- Riprap
- Sand-gravel
- Boulder
- Broad Iodine Seaweed
- Building
- Coarse Gravel
- Cobble
- Coniferous Trees
- Deciduous Trees
- Fine Gravel
- Grass
- Gravel
- Herb
- Impervious
- Mud
- Mud-Sand
- Railroad
- Sand
- Sea Luttuce/Fucus
- Shadow
- Shallow Water
- Sulphur/Coal
- Water

2m SLR AHT

1m SLR AHT

Current AHT

2m SLR ALT

1m SLR ALT

Current ALT

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:3,000 is only valid on a 11"x17" print.

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- Current Intertidal Area
- Intertidal Area - 1m Sea Level Rise (SLR) - Managed Retreat
- Intertidal Area - 2m Sea Level Rise (SLR) - Managed Retreat

ALT Average Low Tide

AHT Average High Tide

Project No. 031-548

Date December 2019

Scale 1:3,000 0 25 50 100 (m)

Representative Example 2 - Seymour River Mouth and Surrounding Area

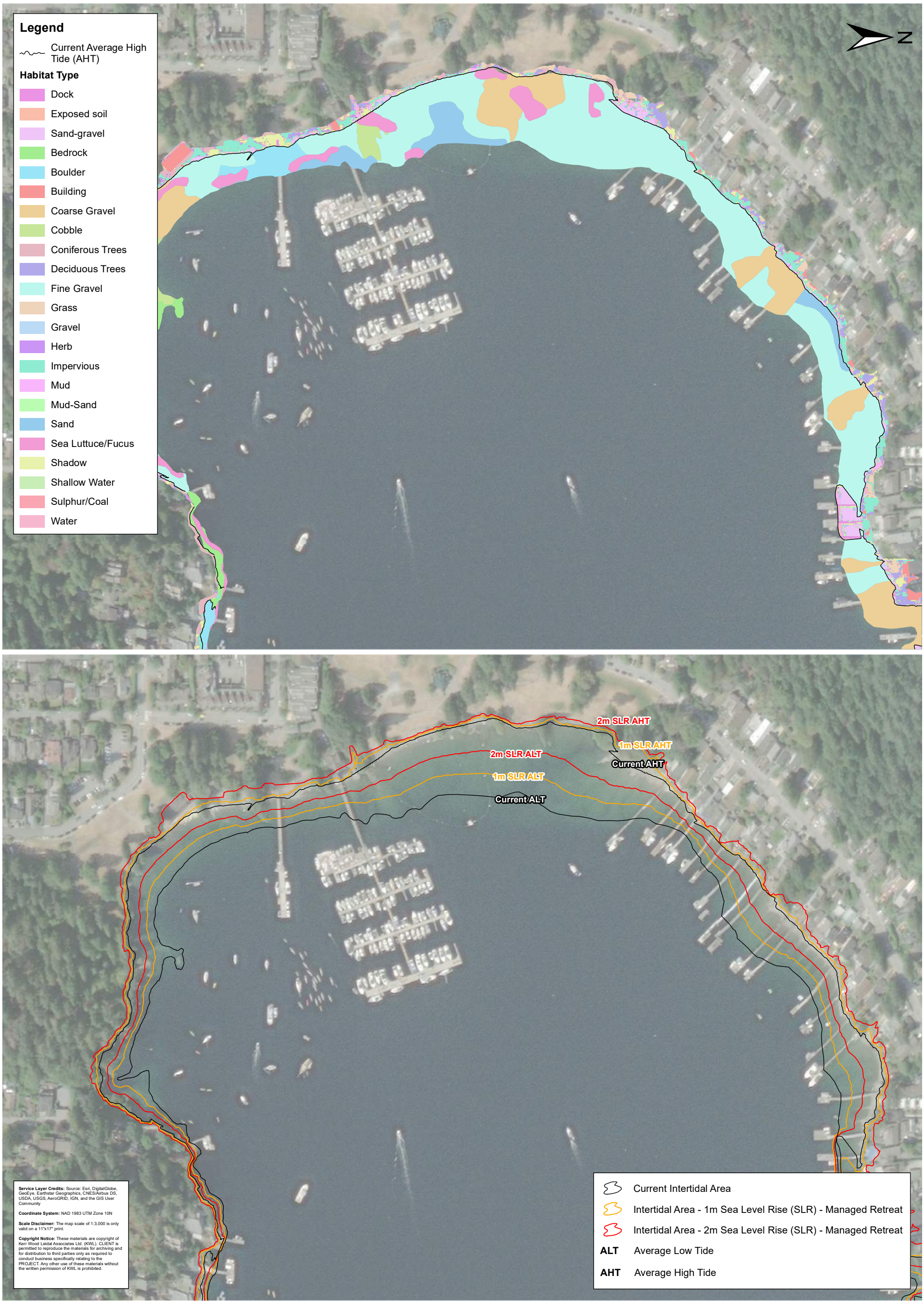
Figure 2

Path: \\bbyfs1.kwl.ca\0000-0999\0000-0099\031-548\430-GIS\MXD-Rp\031548_DeepCove_Rotated_.mxd Date Saved: 2019-12-06 4:32:37 PM | Author: GOConnell

District of North Vancouver

North Shore Sea Level Rise Risk Assessment and Adaptive Management Strategy

KERR WOOD LEIDAL consulting engineers



Project No. 031-548

Date December 2019

Scale 1:3,000 0 25 50 100 (m)

Representative Example 3 - Deep Cove

Figure 3

Habitat Types Mapped in Intertidal Area Predicted to be Lost

As the low tide line moves inland under sea level rise, existing intertidal habitat that is located below the future low tide line will be lost (converted to sub-tidal).

Table 4 shows the area of each habitat type mapped and the area of each habitat type predicted to be removed with an inland shift of the LLWMT mapped for the entire study area. This table shows the potential decrease of habitat under a coastal squeeze (vertical walls) scenario where no new intertidal habitat would be gained because the future high tide is prevented to move inland by vertical walls.

The habitat type bull kelp will have the greatest habitat loss for the North Shore under 1 m sea level rise (19,249 m^2, -98.6%). Under 2 m sea level rise, the habitat type black felt mat will have the greatest habitat loss (6,875 m^2, -100%). Intertidal habitat types sea lettuce and/or fucus and marsh will have the next greatest loss under 1 m sea level rise, while bull kelp, and sea lettuce and/or fucus will have the next greatest loss under 2 m sea level rise.

Table 4: Predicted Area Change (Area and %) in Intertidal Habitat Types on the North Shore Under "Coastal Squeeze" for 1 m and 2 m of Sea Level Rise

Intertidal Habitat Type	Current Mapped Area (m^2)	1 m SLR with Coastal Squeeze		2 m SLR with Coastal Squeeze	
		Predicted Area (m^2) Decrease	Predicted % Decrease	Predicted Area (m^2) Decrease	Predicted % Decrease
Bedrock	36,726	7,337	20.0	17,654	48.1
Black Felt Mat	6,875	0	0.0	6,875	100.0
Boulder	80,660	32,753	40.6	53,160	65.9
Broad Iodine Seaweed	10,066	1,707	17.0	5,861	58.2
Bull Kelp	19,525	19,249	98.6	19,430	99.5
Coarse Gravel	190,489	83,358	43.8	129,295	67.9
Cobble	124,059	33,371	26.9	62,012	50.0
Fine Gravel	306,432	182,465	59.5	250,062	81.6
Marsh	7,957	4,772	60.0	4,772	60.0
Mud	2,370	0	0.0	1,029	43.4
Mud-Sand	124,327	5,159	4.1	81,988	65.9
Sand	427,134	225,170	52.7	383,314	89.7
Sea Hair Algae	2,984	422	14.1	912	30.6
Sea Lettuce and/or Fucus	565,955	355,122	62.7	524,165	92.6
Witch's Hair	779	0	0.0	92	11.8
Note: Areas rounded to nearest 1 m^2					

3. Impacts to Marine Riparian Zones

The marine riparian zone is defined as the terrestrial land cover located immediately above the current high tide and is influenced by its proximity to the ocean but is not subject to daily inundation. Marine riparian habitats also provide overhanging cover, slope stability, and introduction of food and nutrients to the intertidal zone.

3.1 Methodology

Similar to the assessment of intertidal area change, two sea level rise scenarios were used to quantify changes in land cover type throughout the North Shore from current sea level:

1. 1 m Sea Level Rise with managed retreat (-0.8 m LLWMT and 2.5 m HHWMT); and
2. 2 m Sea Level Rise with managed retreat (0.2 m LLWMT and 3.5 m HHWMT).

Scenarios involving coastal squeeze (vertical walls) were not examined as part of this assessment as vertical walls to prevent coastal flooding from sea level rise would also prevent the loss of marine riparian area to the intertidal zone. However, there would likely be impacts from the walls themselves, including disconnection of the marine riparian area from the intertidal area.

To assess potential changes in intertidal habitat caused by projected sea level rise, future high and low tide boundaries were compared to the current extent and distribution of marine riparian land cover types.

First, a map of marine riparian land cover types was created using existing spatial data (Caslys 2009) and high-resolution images of the North Shore. Second, predicted high and low tide boundaries with 1 m and 2 m sea level rise were superimposed on top of the map to determine the change in area of marine riparian land cover type. The mapping exercise assumed that the shoreline geometry would stay consistent. This is a simplification as the shoreline shape is likely to evolve over time with sea level rise due to enhanced coastal erosion.

The habitat classification system used for the assessment was based off existing spatial data on Land Cover Classes from the Burrard Inlet Air Photo-Based Land Cover Mapping by Casyls Consulting Ltd. (Casyls 2009). Spatial data for the marine riparian area was incomplete for the District of West Vancouver. Mapping of this spatial data was completed by Kerr Wood Leidal Associates Ltd. (KWL). Due to the large number of classes in each data set, some classes were combined to simplify the data. For example, the marine riparian land cover types “paved” and “paved road” were combined and classed as “paved” land cover. Additionally, some classes from the Casyls dataset were removed such as “no data”, and “shadow” as they did not contribute to the mapping exercise. However, the areas these classes occupied were included in the future marine riparian area calculations.

3.2 Results

The inland movement of the high tide line (i.e., HHWMT) would result in a loss of marine riparian land cover type as this area becomes part of the intertidal zone.

Table 5 shows the area of each land cover type mapped and the area of each land cover type predicted to be removed with an inland shift of the high tide line.

Table 5: Predicted Area of Marine Riparian Area Inundated Under 1 m and 2 m of Sea Level Rise

Marine Riparian Land Cover Type	Predicted Area (m^2) Inundated Under 1 m SLR Scenario	Predicted Area (m^2) Inundated Under 2 m SLR Scenario
Bedrock	10,347	12,786
Boulder	1,602	2,471
Bridge	0	41
Building	187,249	194,141
Coniferous Tree	178,013	195,739
Deciduous Tree	179,162	220,949
Dock	40,994	47,614
Exposed Soil	88,548	111,304
Grass	129,256	141,572
Gravel	2,156	8,309
Herb	47,108	61,612
Impervious	560,352	572,394
Mud	1,566	25,022
Mud-Sand	1,447	13,712
Paved	130,137	153,260
Railroad	51,449	51,632
Riprap	7,875	16,354
Sand	17,742	21,599
Sand-Gravel	19,075	42,677
Shrub	16,266	17,686
Sulphur-Coal	46,894	47,111
Note: Areas rounded to nearest 1 m^2		

Figures 1 through 3 also show examples of existing marine riparian land cover and the amounts expected to be affected if inundation is allowed to occur over time.

4. Conclusion

This high-level assessment shows the potential for significant impacts to intertidal habitat and marine riparian land cover due to sea level rise and different sea level rise adaptation approaches. The approaches presented represent extreme ends of the spectrum of adaptation approaches and therefore the impact estimates serve primarily as contextual information to inform the development of adaptation measures that will consider habitat challenges and opportunities.

Statement of Limitations

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Appendix G

North Shore Sea Level Rise Adaptation Measures Toolkit



North Shore Sea Level Rise Adaptive Management Strategy

Adaptation Measures Toolkit

JULY 2020

KERR WOOD LEIDAL
consulting engineers

CATEGORIES	ID	ADAPTATION MEASURES	APPLICABILITY
Category A: Planning and Governance Measures	A-1	ENCOURAGE THE UPTAKE OF PRIVATE FLOOD INSURANCE	MEDIUM
	A-2	RISK AVOIDANCE AND TOLERANCE POLICIES	MEDIUM
	A-3	FLOODPLAIN DEVELOPMENT MANAGEMENT TOOLS	HIGH
	A-4	COASTAL FLOODPLAIN URBAN STORMWATER MANAGEMENT PLANNING	HIGH
	A-5	FUTURE INTERTIDAL AREA LAND PRESERVATION	HIGH
	A-6	FORMALIZE NORTH SHORE COLLABORATIVE ADAPTATION PLANNING GOVERNANCE	HIGH
Category B: Building and Site Measures	B-1	BUILDING AND SITE-SCALE MEASURES FOR EXISTING PROPERTIES	LOW
	B-2	BUILDING-SCALE MEASURES FOR NEW CONSTRUCTION	HIGH
	B-3	PARCEL-SCALE LAND RAISING AND SITE GRADING	MEDIUM
	B-4	PARCEL-SCALE WAVE ATTENUATION (SHORELINE SITES)	MEDIUM
Category C: Community-scale Structural Flood Protection Measures	C-1	DIKE AND SEAWALLS	HIGH
	C-2	TEMPORARY / DEMOUNTABLE FLOOD BARRIERS	LOW
	C-3	STORM SURGE BARRIERS	LOW
	C-4	INTERNAL URBAN DRAINAGE ADAPTATION	HIGH
	C-5	NEARSHORE WAVE ATTENUATION STRUCTURES	MEDIUM
Category D: Community-scale Nature-Based Measures	D-1	RESTORATION OF NATURALLY RESILIENT ENVIRONMENTS	MEDIUM
	D-2	ENGINEERED NATURE-BASED MEASURES	HIGH
	D-3	SHORELINE RESHAPING	LOW
Category E: Critical Infrastructure Resilience	E-1	MUNICIPAL PUMP STATION RESILIENCE	HIGH
	E-2	POWER TRANSMISSION INFRASTRUCTURE RESILIENCE	HIGH
	E-3	TRANSPORTATION INFRASTRUCTURE RESILIENCE	HIGH
Category F: Response & Recovery Phase Risk Reduction Measures	F-1	FLOOD FORECASTING AND OPERATIONAL PLANNING	LOW
	F-2	RECOVERY PHASE RISK REDUCTION	LOW
Category G: Community and Cultural Resilience Measures	G-1	PUBLIC AWARENESS AND RISK REDUCTION EMPOWERMENT	HIGH
	G-2	PROTECTION OF CULTURAL SITES	HIGH
	G-3	EMPOWERING NON-GOVERNMENTAL STAKEHOLDERS TO INCREASE RESILIENCE	HIGH

INTRODUCTION

The Adaptation Toolkit is a reference document containing options for the North Shore partners to consider exploring as they develop detailed adaptation plans. The categories are:

- **A – Planning and Governance Measures,** which include policies and objectives that North Shore partners can use to regulate and reduce risk levels,
- **B – Building and Site Measures,** which are site-specific and reduce risk on an individual building or lot level,
- **C - Community-scale Structural Flood Protection Measures,** which are large-scale, engineered measures to reduce flood exposure,
- **D – Community-scale Nature-based Measures,** which utilize landscape features that reduce flood risk while providing environmental or social co-benefits,
- **E – Critical Infrastructure Resilience Measures,** which are strategies to increase the resilience of existing critical infrastructure
- **F - Response and Recovery Phase Risk Reduction Measures,** which can be planned in advance to make the consequences of flooding less severe and to leverage the recovery phase for effective and long-term risk reduction, and
- **G – Community and Cultural Resilience Measures,** which encourage preparedness from other actors and aim to reduce risk to cultural assets.

The sub-measures contained within each category should be thought of ‘tools’ within the toolkit of each partner, to be drawn upon as a resource when developing detailed adaptation plans for a specific area. The applicability ratings were developed based on professional judgement, with considerations of the unique characteristics of the North Shore region.

CATEGORY A:

PLANNING AND GOVERNANCE MEASURES

A-1 ENCOURAGE THE UPTAKE OF PRIVATE FLOOD INSURANCE

High Level Approach

Accommodate



Sub-measure

A-1-1	Provide information to residents and businesses about coastal flood risk (now and in the future) and introduce the option of flood insurance
A-1-2	Provide information about flood insurance during development application process
A-1-3	Encourage flood insurance for development permit
A-1-4	Encourage flood insurance for businesses during licensing process

Description

As of the writing of this report, coastal overland flood insurance is an emerging opt-in private insurance product in the region. Similar to other insurance policies, coastal overland flood insurance can be used to reduce the impact of flooding and accelerate recovery.

Flood insurance is an alternative approach to provincial/federal disaster financial assistance (DFA) programs. This is also an area of emerging policy as provincial policy indicates that DFA may not provided in areas where flood insurance is available for purchase. As the private coastal flood insurance market develops further, this policy may be applied widely.

The North Shore partners could develop and implement policies and programs to encourage flood insurance for new developments and/or business licenses.

Pros

- Shares flood risk with the insurance market
- Alternative to disaster financial assistance programs
- May lead to risk reduction through discouraging occupation of high-risk areas and/or densification of risk areas

Cons

- Potential equity and affordability issues
- Careful implementation required to avoid undesired outcomes (e.g., the introduction of flood insurance subsidies can encourage development in high-risk areas)
- Uncertainty related to emerging market

A-1 ENCOURAGE THE UPTAKE OF PRIVATE FLOOD INSURANCE

Applicability on the North Shore

Flood insurance is particularly applicable for commercial and industrial land uses where economic risk is a primary consideration for sea level rise adaptation. The availability and structure of flood insurance for First Nation reserves, including commercial tenants of reserves, requires further study. A recent study (Thistlethwaite *et al.,* 2020) found that Canadians have limited knowledge of flood insurance coverage, expect governments to fund most of flood recovery through disaster assistance and are reluctant to pay for both insurance and property-level flood protection measures.



APPLICABILITY: MEDIUM

A-2 RISK AVOIDANCE AND TOLERANCE POLICIES

High Level Approach

Avoid



Sub-measure

A-2-1	Coastal flood risk tolerance definition in risk-based or hazard scenario-based terms (OCP, by-law, or DPA) for different asset classes and/or land uses (e.g. critical infrastructure/facilities, commercial, residential, etc.)
A-2-2	Special flood risk tolerance areas by land use (e.g. non-hazardous industrial) through OCP/DPA/area planning tools
A-2-3	Density restriction in higher hazard areas (zoning/covenant)
A-2-4	Existing critical infrastructure relocation policy (at replacement/upgrade)
A-2-5	New critical infrastructure location policy
A-2-6	Proactive property acquisition in high-risk areas
A-2-7	Post-flood property acquisition
A-2-8	Development potential transfer/swap

Description

The North Shore partners can use a wide variety of land use planning tools to limit and/or disincentivize occupation of areas at risk from coastal hazards.

Examples include voluntary programs such as development potential transfer, moving critical infrastructure, and social and operations facilities out of the floodplain at the end of building life cycle (or sooner if necessary), or by creating a comprehensive buy-out strategy to actively reduce population numbers and development in the floodplain. An example of an in-progress buy-out strategy in BC is the municipality of Grand Forks.

An important initial step to support these activities would be to define a baseline risk tolerance thresholds which could be used to guide the development and application of policy tools. Risk tolerance can be defined in either risk-based terms (e.g. tolerable annualized property damage cost per hectare due to coastal flooding) or hazard scenario-based terms (e.g. flooding not tolerable at a return period less than 10-years, and 200-year return period maximum flood depths greater than 0.5 m are not tolerable).

After a baseline level of risk tolerance is defined, policy tools can be designed to manage land use to maintain risk below the tolerance threshold. Other tools can be developed for areas and situations where a higher level of risk tolerance may be permitted to enable certain economic activities (e.g. water-oriented industries, other industrial activities) with certain conditions (e.g. management of hazardous waste risk).

A-2 RISK AVOIDANCE AND TOLERANCE POLICIES

Pros

- Risk avoidance is the most effective form of risk reduction
- Risk tolerance policies support transparent and evidence-based policy and decision making
- Shoreline property acquisition can be linked with measures to preserve intertidal habitat or create new waterfront park space as sea level rise occurs

Cons

- Difficult to define risk tolerance (lack of senior government policy)
- Land use and development restrictions have secondary impacts (e.g. economic, equity)
- Property acquisition is an emerging approach in Canada, but can still be contentious

Applicability on the North Shore

There is already a history of managing natural hazards through tolerable risk criteria on the North Shore; the District of North Vancouver has risk tolerance criteria for geohazard risk management including loss-of-life risk tolerance criteria.

Many of the policy tools required to manage land use and density for flood risk exist (e.g. OCPs, DPAs, etc.). However, there are few examples of proactive property acquisitions or density restrictions for future sea level rise risk.

The risk avoidance concepts have limited applicability for Port lands. Generally Port lands are already low-lying areas along shoreline margins; moving to higher ground would require that the Port acquire more lands, which becomes less feasible when adjoining areas are already built out for other development types.



APPLICABILITY: MEDIUM

A-3 FLOODPLAIN DEVELOPMENT MANAGEMENT TOOLS

High Level Approach

Accommodate



New construction with a concrete raised foundation

Sub-measure

A-3-1	Building floodproofing (flood construction level (FCL), setback, allowable uses below FCL, etc.) requirements policy tools (by-law, DPA), including variation by land use / asset type
A-3-2	Site-level land raising and grading requirements policy tools (DPA, area-wide design guidelines, etc.)
A-3-3	Special measures for industrial sites with hazardous material storage and/or generation

Description

These measures focus on policy tools to require the implementation of building and site level measures for risk management.

Requirements for building-level floodproofing (including flood construction levels, setbacks between shorelines and structures and/or between flood protection infrastructure and structures, and allowable uses below the FCL) can be specified in a variety of tools including floodplain by-laws, development permit areas (DPAs), and site-wide design guidelines for special areas.

The existing program of floodproofing can be expanded upon and made more flexible by specifying different requirements by building type, land use, and development life cycle (temporary/permanent). In particular, if achieving the FCL is very difficult due to site grade, policies can be created to specify acceptable land uses below the FCL (e.g., parkade below FCL but all residential is required to be above the FCL). Adding these types of variations are preferred over blanket, area-wide exemptions to FCLs.

Specific approaches for implementing floodplain development management requirements are presented as separate adaptation measures (B-1 for new developments and B-2 for existing developments).

Floodplain building standards are also starting to receive more attention at the national regulatory / building code level. It is understood that CSA standards are being developed for building resilience to flooding.

Floodproofing hazardous materials storage and generation sites lessen the risks of a potential release into floodwaters during a coastal flood event. Further to this point, a contamination response plan ensures that staff have a preplanned protocol to follow in case of the failure of floodproofing measures.

A-3 FLOODPLAIN DEVELOPMENT MANAGEMENT TOOLS

Pros

- Cost of adaptation shared with development costs

Cons

- Risk reduction is reliant on redevelopment
- Careful balance required as strict policies may lead to the need for area-wide exemptions (if developments are unable to meet the requirements) which can negate the risk reduction benefit.
- Requires updates to other policies (e.g., max allowable building height)
- Does not address areas between buildings

Applicability on the North Shore

Floodproofing (with a focus on flood construction levels) already occurs on the North Shore through a variety of policy tools. This policy tool is highly applicable for Port lands and objectives; making use of lands which are marginal or unsuitable for other developments is a good fit if terminals and other port-related industries can be made somewhat tolerant of minor flood conditions. However, if certain Port lands were designated as flood tolerant, and employed floodproofing tools, then lands inland of Port sites would need to employ their own flood protection measures.



APPLICABILITY: HIGH

A-4 COASTAL FLOODPLAIN URBAN STORMWATER MANAGEMENT PLANNING

High Level Approach

Resist

Accommodate



Storm drain



Storm drain

Sub-measure

A-4-1	Coastal floodplain urban stormwater level of performance studies and policy
A-4-2	Storm sewer network upgrades for sea level rise
A-4-3	Overland urban drainage route and pump station land tenure planning

Description

Master drainage planning and integrated stormwater management planning on North Shore watersheds can be updated to identify the impacts of sea level rise on drainage systems, update design criteria for drainage infrastructure, and plan for required drainage work upgrades in the future. The typical level of performance for drainage infrastructure on the North Shore involves conveying rainfall storms ranging in size up to the 10-year return period event through the subsurface sewer network and conveying larger events through overland drainage paths (typically roads). Both subsurface and surface drainage routes lead directly to the sea or indirectly via a creek. As sea levels rise, the level of performance of existing drainage systems in low-lying areas will be impacted.

To maintain the level of performance, upgrades to sewer network capacity may be required. In particular, existing sewer outfalls into the sea may need to be upgraded to flapgates/floodboxes and possibly pump stations, which would involve a very significant cost, likely on the order of hundreds of millions of dollars. Alternatives to converting all outfalls to pump stations may include adopting a different level of performance for stormwater systems in coastal floodplain areas, implementing pressurized stormwater sewer systems, implementing large storage ponds to reduce pumping capacity requirements, and incorporating new overland drainage routes directly to the sea into shoreline land raising concepts.

A-4 COASTAL FLOODPLAIN URBAN STORMWATER MANAGEMENT PLANNING

Pros

- Incorporates sea level rise into short- and long-term stormwater management and watershed management
- Opportunities for new approaches (e.g., pressurized highland to lowland stormwater pipes, overland drainage routes incorporated into land raising, large stormwater storage ponds) to reduce the need for converting outfalls into pump stations

Cons

- Maintaining the existing urban stormwater level of service through existing systems may require very significant capital costs for floodboxes and pump stations

Applicability on the North Shore

Urban stormwater management planning is already a well-established practice and program on the North Shore. Incorporating sea level rise considerations and adaptation planning can be implemented into on-going and future planning activities.



APPLICABILITY: HIGH

A-5 FUTURE INTERTIDAL AREA LAND PRESERVATION

High Level Approach

Accommodate

Advance



Cates Park / Whey-ah-Wichen in the District of North Vancouver



Ambleside Park in the District of West Vancouver

Sub-measure

A-5-1	Designate existing shoreline parks for future intertidal area	A-5-3	Land reclamation (advance) to build future intertidal area
A-5-2	Acquire shoreline properties for future intertidal area	A-5-4	Intertidal area habitat balance and habitat banking

Description

Sea level rise will impact intertidal areas and the environmental habitats they support. Coastal squeeze (intertidal area loss) will occur in areas where dikes and seawalls are built to prevent the landward shifting of the high tide line.

This measure involves various policy tools to preserve land for future intertidal area and habitat. Existing shoreline parks could play a major role in adapting intertidal area habitat if park spaces are designated for future reshaping to support intertidal habitat. If adaptation concepts include dikes, locating them along a setback alignment will provide more opportunities for future intertidal area.

New parks or habitat areas could be established if shoreline properties are acquired, either through a comprehensive buyout strategy or through opportunistic purchases.

An alternative approach would involve gradual land reclamation over time to build land for future intertidal habitat.

Finally, the land preservation efforts could be managed and tracked through an intertidal habitat offsetting and banking program which could be used to support dike and seawall projects in other areas on the North Shore that would result in intertidal area loss. Examples of existing habitat banking in BC include the North Fraser Habitat Compensation Bank (established in 1993).

A-5 FUTURE INTERTIDAL AREA LAND PRESERVATION

Pros

- Preserve land for intertidal area habitat to offset habitat loss in other areas
- Environmental co-benefits

Cons

- Land acquisition may be required

Applicability on the North Shore

Without an existing system of seawalls and dikes, the North Shore is well suited to thoughtfully plan for sea level rise adaptation that minimizes intertidal area habitat impacts. This measure would also be complementary to a suite of other historic and on-going environmental stewardship initiatives in Burrard Inlet and Howe Sound, including intertidal habitat restoration in Maplewood Flats.



APPLICABILITY: HIGH

A-6 FORMALIZE NORTH SHORE COLLABORATIVE ADAPTATION PLANNING GOVERNANCE

High Level Approach

Avoid | Resist | Advance | Retreat | Accommodate



Sub-measure

A-6-1	Formalize a North Shore sea level rise adaptation working group or office
A-6-2	Establish North Shore wide sea level rise adaptation utility charge
A-6-3	Establish Development Cost Charge (DCC) for sea level rise adaptation infrastructure

Description

The multi-jurisdictional partnership formed to address North Shore sea level rise adaptation in this report could be continued as a permanent working group, potentially chaired by NSEM.

Examples of taxes similar to adaptation utility taxes can be found in low-lying jurisdictions such as Richmond and Delta to fund diking systems and maintenance.

Specific implementation requirements of establishing a Development Cost Charge for sea level rise adaptation infrastructure will require further study.

Pros

- More efficient coordination and pooling of resources.
- Potentially more access to funding.

Cons

- On-going consensus building across communities requires significant effort.

Applicability on the North Shore

The North Shore is uniquely suited to establishing a regional sea level rise or general adaptation planning authority/office given its topographic conditions, history of collaboration, the existing structure of NSEM, and its current condition without significant existing flood protection infrastructure.

APPLICABILITY: HIGH

CATEGORY B:

BUILDING AND SITE MEASURES

B-1 BUILDING AND SITE-SCALE MEASURES FOR EXISTING PROPERTIES

High Level Approach

Accommodate



Demountable flood barrier around a doorway

Sub-measure

B-1-1	Temporary or demountable flood barriers around structure
B-1-2	Flood doors, floodproof coatings, and backflow prevention valves
B-1-3	Foundation alterations to raise structure

Description

Building and site measures for retrofitting existing buildings increase their resilience and enable them to withstand coastal hazards. Site-scale floodproofing can reduce exposure to hazards until it is time for the redevelopment of the site.

The role of North Shore partners in this measure would largely be to enable individual property owners to access technical resources and to enable implementation through permitting requirements and potential risk reduction incentives.

Pros

- Allows existing structures to remain in place
- Not reliant on redevelopment
- Share cost of adaptation with property owners
- Enable property-level resilience and adaptation empowerment

Cons

- May not be feasible for all sites and for deep flood hazard areas
- Significant education and household-level responsibility needs (e.g. difficult to enforce how people use areas below flood level within private property)
- Typically requires variances for additional height (to accommodate raising buildings) or other development regulation changes
- Reliant on property owner interest and uptake.

B-1 BUILDING AND SITE-SCALE MEASURES FOR EXISTING PROPERTIES

Applicability on the North Shore

Applicability may be limited to special cases where adaptation timeframe or other reasons would not allow the implementation of adaptation measures through redevelopment. Unlikely to be required or desired in the short-term, except for very low-lying properties. Community interest may rise after coastal flood events.



APPLICABILITY: LOW

Additional Reference Photos

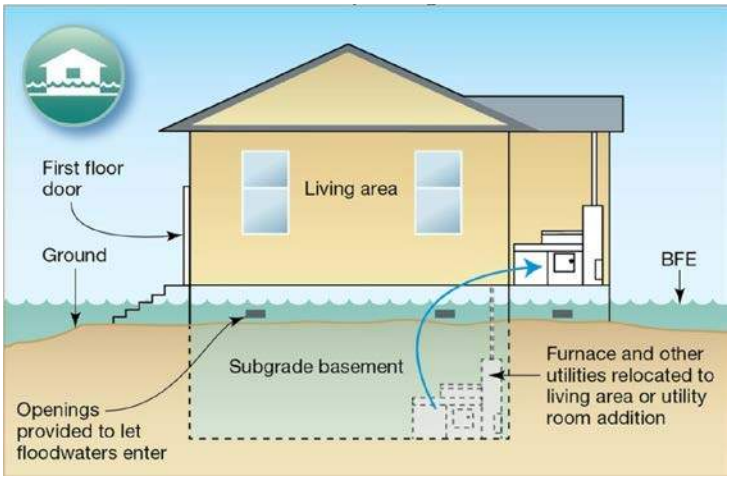


Flood barrier at site entryway

B-2 BUILDING-SCALE MEASURES FOR NEW CONSTRUCTION

High Level Approach

Accommodate



Wet floodproofing

Sub-measure

B-2-1	Dry floodproofing by fill or structure (e.g. reinforced concrete)
B-2-2	Wet floodproofing (flow-through paths and flood-resistant materials)
B-2-3	Building foundation tanking and sump pumping
B-2-4	Electrical/mechanical/district energy equipment flood proofing by tanking or elevation
B-2-5	Parkade entrance flood barriers
B-2-6	Amphibious architecture (experimental)
B-2-7	Modular architecture for adaptive raising / adding floors (experimental)

Description

Building measures for new building construction consist of requirements to ensure that new buildings are built to either avoid impacts or lessen the impacts of coastal flooding.

Conventional and best practice sub-measures include dry floodproofing (flood construction level (FCL) elevation by fill or structure), setbacks, and elevation/tanking of electrical and mechanical equipment.

In medium-density buildings, parkades are often acceptable below the FCL, but flooding could still result in significant property damages to vehicles and other storage in parkades. Accordingly, new building designs can include automatic floodgate barriers at parkade entrances to prevent parkade flooding.

Other forms of architecture may emerge in the future for sea level rise adaptation, including concepts that have received some recent research such as amphibious architecture or modular/adaptive buildings. Development and building regulations may require updates to enable future concepts.

Pros

- Cost of adaptation shared with development
- Highly effective in areas undergoing redevelopment

Cons

- Highly reliant on redevelopment
- Raised buildings potentially impact neighbourhood character.
- Loss of developable living space below FCL.

B-2 BUILDING-SCALE MEASURES FOR NEW CONSTRUCTION

Applicability on the North Shore

Floodproofing (with a focus on flood construction levels) already occurs on the North Shore through a variety of policy tools. A local example of raised buildings is the Seaspan office on Pemberton Ave, which is built on stilts.

APPLICABILITY: HIGH

Additional Reference Photos



Amphibious architecture



Parkade entrance flood barrier

B-3 PARCEL-SCALE LAND RAISING AND SITE GRADING

High Level Approach

Accommodate



Land raising to flood construction level



Grade transition from land raising down to existing road incorporated into public plaza

Sub-measure

B-3-1	Full site-wide land raising to flood construction level	B-3-4	Setback between shoreline and flood protection infrastructure or land tenure for future setback
B-3-2	Partial site-wide land raising to tolerable flood level for access and egress	B-3-5	Overland drainage path incorporation into shoreline land raising
B-3-3	Setback between shoreline and structure		

Description

Parcel-scale land raising is a significant opportunity for effective sea level rise adaptation on the North Shore. This measure involves raising the elevation of land on a property (in addition to the building itself) either to the full flood construction level or to a lower elevation above which flooding impacting access/egress would only occur on an infrequent and tolerable basis. In industrial areas where the implementation of shoreline dikes may impede water access, land raising can be an effective solution by enabling individual properties to choose to raise their property elevation based on their flood risk tolerance.

While effective through essentially raising the property out of the floodplain, land raising requires close coordination with neighbouring properties and is best achieved after an area-wide planning process has identified land raising areas and elevations. Land raising is also likely a preferred measure for areas located outside of community-scale structural measures (e.g. dikes).

B-3 PARCEL-SCALE LAND RAISING AND SITE GRADING

Key features for land raising to consider include grades for utilities, site grading for access/egress, and the preservation/upgrading of overland drainage paths to the sea for shoreline sites. Individual parcels can have more agency in choosing when and how much they want to raise their grade.

Land raising would also reduce the reliance on the redevelopment of waterfront parcels to enable the implementation of a specific dike alignment. Additionally, this approach can also be advantageous over diking by incorporating new overland drainage routes into the land raising plans instead of dikes that may trigger the need for the construction of drainage pump stations. Finally, another advantage of land raising is that it may be compatible with site capping practices typically involved in the redevelopment of properties with contaminated soils.

Pros

- Cost of adaptation shared with development
- Highly effective in areas undergoing redevelopment
- Can be implemented over time

Cons

- Highly reliant on redevelopment
- Site-wide land raising requires close coordination with neighbouring properties and area-wide planning
- Potential to increase risk if density increased in floodplain

Applicability on the North Shore

Parcel-scale land raising is not common on the North Shore, but would be applicable to much of the low-lying industrial sites (that do not need waterside land at sea level for their operations) as they redevelop and for redevelopment areas resulting in medium or high density construction where land raising is cost effective. The Port has a history of in-filling and building up sites (including Neptune, G3, and Lynnterm), mainly using dredged river sand.



APPLICABILITY: MEDIUM

B-4 PARCEL-SCALE WAVE ATTENUATION (SHORELINE SITES)

High Level Approach

Accommodate

Resist



Greenshores shoreline



Riprap revetment shoreline

Sub-measure

B-4-1	Greenshores and natural shorelines for low slope wave attenuation
B-4-2	Engineered beach shoreline
B-4-3	Riprap revetment shoreline
B-4-4	Seawall shoreline
B-4-5	Near-shore engineered/nature-based breakwaters

Description

For shoreline sites, particularly west of the Lions Gate bridge, wave attenuation is a key aspect of building/site floodproofing.

A variety of shoreline approaches are available to attenuate waves and reduce erosion risk, ranging from natural shorelines which reduce wave energy through vegetation and shallow slopes to engineered seawalls and nearshore breakwaters.

Pros

- Wave attenuation reduces flood construction level

Cons

- Potential environmental impacts if not designed for environmental co-benefits
- Seawalls and engineered shorelines may contribute to coastal squeeze (loss of intertidal habitat)

B-4 PARCEL-SCALE WAVE ATTENUATION (SHORELINE SITES)

Applicability on the North Shore

Applicability is low for port-related waterfront lands where deep water is required for industry and wave attenuation (other than through seawalls) may not be feasible. Applicability is higher for park and public space shorelines. Applicability will likely vary by site specifics for residential waterfront parcels.



APPLICABILITY: MEDIUM

CATEGORY C:

COMMUNITY-SCALE STRUCTURAL FLOOD PROTECTION MEASURES

C-1 DIKE AND SEAWALLS

High Level Approach

Resist

Advance



Dike incorporated in between development and waterfront public trails

Sub-measure

C-1-1	Shoreline dike
C-1-2	Setback dike
C-1-3	Dike incorporated into linear park corridor
C-1-4	Dike incorporated into road corridor
C-1-5	Dike incorporated into rail corridor
C-1-6	Dike incorporated into land reclamation (advance)
C-1-7	Dike with seawall edge
C-1-8	Standalone seawall / floodwall

Description

Dikes and seawalls are often the primary line of flood protection and a key component of different adaptation concepts; it is worthwhile to note that there is currently no diking system on the North Shore.

Dikes are linear, raised earthfill embankments that hold back water from the sea and rivers/creeks. Dikes with a 4 m wide crest and 3H:1V side slopes are the conventional form of flood protection in BC with consistent application along the lower Fraser River and its estuarine islands, including Richmond and Delta.

Seawalls are engineered, impermeable vertical walls that form the water-side edge of waterfront lands. In some cases, sea walls are standalone flood walls as they are taller than the land behind them.

While conventionally treated as standalone infrastructure, there is an emerging movement towards incorporating dikes and seawalls into other land forms and infrastructure to provide co-benefits in response to multiple pressures on sparsely available land, particularly along the shoreline. For example, dikes and seawalls can be incorporated into parks, urban waterfront areas, larger and higher density developments, road corridors and rail corridors.

The alignment of dikes and seawalls will have a significant impact on future intertidal area. If aligned along the existing shoreline edge, they will contribute to coastal squeeze (loss of intertidal area), but set back from the shoreline, they can accommodate future intertidal habitat.

Dikes can generally be constructed to heights of several metres, but as dike height increases so does the expected settlement of the dike due to pressure on underlying soils. In very soft ground (e.g. mudflat areas), a dike may need to be at first constructed to double its required height to accommodate 50% settlement post-construction. While dikes are an effective measure for managing flood risk, they can also contribute to increasing risk in certain situations without careful planning. For example, new dikes in river/creek mouth areas can increase river/creek flood hazards if they limit or prevent the free overflow of river/creek flooding into the sea. Dikes also introduce a new hazard into the

C-1 DIKE AND SEAWALLS

management framework: dike breach hazard. In certain situations, dike breach hazards and related risk could be more severe than the pre-diking condition. Additionally, as dike height increases, the hazard intensity related with dike breaches increases as well. Without careful land use planning behind dikes, it is even possible that dikes can increase the flood risk immediately behind the dike based on the potential damage related to a dike breach. Finally, dikes can also contribute to increasing risk by introducing a false sense of security and/or through encouraging higher density development. Careful technical analysis, planning, and repeat risk assessments are required for the implementation of dikes.

Pros

- Can be incorporated into other infrastructure and land uses for co-benefits
- Protects existing buildings and land behind structure (preserves status quo land use behind dike)
- Several opportunities for use of rail lines on the North Shore for dike rights-of-way.

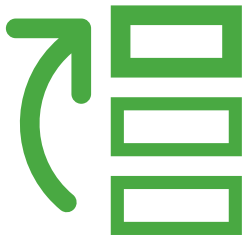
Cons

- Significant financial and administrative resources required for implementation and management
- Challenging to implement into urban and natural areas without pre-existing right-of-way for diking
- Can increase flood hazards/risks through dike breach introduction and/or attraction of density increase
- Can contribute to coastal squeeze (intertidal area loss) and can disrupt natural sediment dynamics
- Aesthetic and view impacts if not incorporated into landscapes well
- Cannot be implemented piecemeal (no benefits until whole dike completed).

Applicability on the North Shore

Diking in BC is regulated by the Province through the Inspector of Dikes Office (Ministry of Forests, Lands, and Natural Resource Operations and Rural Development) which provides technical and administrative guidance defining standard diking in BC. The Province requires new dikes to be under the jurisdiction of local government diking authorities. There are few examples of standard dikes on the North Shore and the municipalities are not currently undertaking formal diking authority roles.

Implementing standard dikes on the North Shore will be challenging due to a combination of factors including a lack of existing rights-of-way for diking and due to the existing urban and natural shoreline typologies that are not well suited for application of provincial guidelines (most suited for rural and agricultural settings).



APPLICABILITY: HIGH

Dikes and seawalls on the North Shore would be most successfully implemented through integration with other infrastructure and land uses. Examples include incorporating dikes into linear park corridors, road corridors, and land raising as part of large development parcels; dikes do not need to be at water's edge when combined with other measures.

Additional Reference Photos

C-1 DIKE AND SEAWALLS



Flood wall



Existing Lower Mainland coastal diking system

C-2 TEMPORARY / DEMOUNTABLE FLOOD BARRIERS

High Level Approach

Resist



Vehicle entrance automated flood gate

Sub-measure

C-2-1	Rail crossing manually-operated flood gate
C-2-2	Vehicle and pedestrian entrance automated flood gate (e.g., floodbreak)
C-2-3	Flexible linear tube flood barrier (e.g., tigerdam) / temporary modular flood barriers
C-2-4	Vertical extension additions to dikes and seawalls

Description

Temporary flood barriers are structural measures that are activated (either manually or automatically) ahead of or during a flood event.

They are often applied as secondary measures for individual developments or in some cases as part of primary flood protection systems in conditions where a permanent dike or seawall is not feasible, such as crossing of transportation corridors.

Temporary flood barriers are useful to safeguard specific sites or close specific gaps, but typically need labour to erect in advance of flooding. These can include sliding flood gates, stop log style structures, a series of barriers that can be linked for a desired length, and linear plastic tubes that can be filled with water to act as a vertical barrier.

Another type of barrier is a passive flood barrier which can rise automatically without human intervention and without a power source. Applications of this technology exist mostly in the United States for vehicle/pedestrian entrances to buildings and larger applications where levees cross major roads.

Pros

- Solution to conditions where structures or infrastructure is in conflict with dike/seawall alignment
- Potential to add to sites that have not redeveloped and may not meet current FCLs

Cons

- Risk of failure due to mechanical systems
- Reliance on operational labour force
- Reliance on uncertain flood forecasting

C-2 TEMPORARY / DEMOUNTABLE FLOOD BARRIERS

Applicability on the North Shore

Temporary / demountable flood barriers are not a preferred structural measure for providing a primary line of flood protection on the North Shore due to several factors. In particular, they are not a passive form of flood protection and would rely heavily on an operational context that does not exist at this time. As a comparison of other more appropriate contexts, the United Kingdom does use and deploy demountable flood barriers for coastal flood risks, but they have a national level agency (UK Environment Agency) which coordinate and implements the works. While North Shore municipalities do have operational capacity to prepare and respond to minor flood events, a move to a major system of demountable barriers would require a significant expansion of this capacity.



APPLICABILITY: LOW

The measure is likely most applicable on the North Shore as a secondary approach to add resilience and redundancy to developments in the coastal floodplain, particularly for properties where the risk tolerance is lower than the normal (e.g. industrial sites with hazardous materials or critical operation facilities). The measure may also be applicable to certain low-lying facilities that are at risk now and a permanent solution has not been developed. For example, the District of West Vancouver deploys a tube-style barrier around its waterfront Silk Purse Gallery and Music Box building during the winter season to protect against current flood hazards."

Additional Reference Photos



Flexible linear tube flood barrier (tigerdam)



Rail crossing manually-operated flood gate

C-3 STORM SURGE BARRIERS

High Level Approach

Resist

Sub-measure

C-3-1	Large-scale storm surge barrier
C-3-2	Creek mouth storm surge barrier



Thames Barrier in the United Kingdom



Maeslantkering storm surge barrier in the Netherlands

Description

Storm surge barriers, or sea gates, are large-scale dynamic structures that are used to prevent the rise in ocean water level due to storm surge from expanding into harbours, inlets, and upstream into creeks, rivers, and drainage canals.

Storm surge forecasting and water level monitoring is used to determine when to start to close the barrier to prevent the rise of water level on the protected side of the barrier. The threshold for closing the barrier is typically linked to the elevation of the lands being protected by the barrier and the related flood risk tolerance.

The barriers typically replace diking and seawalls as the primary line of flood protection and allow the protected area shoreline to remain in a status-quo condition or allow for diking and seawalls constructed to a lower level of protection.

Large storm surge barriers installed at the mouths of inlets can negatively impact and fish/marine mammal passage by impacting hydraulics. In conditions where the barrier is closed frequently, the water quality and salinity inside the protected side of the inlet can change.

Smaller barriers installed at creek mouths or drainage canal mouths can help reduce the size of required diking upstream along the watercourse.

C-3 STORM SURGE BARRIERS

Pros

- Single infrastructure piece solution that can reduce the need for other measures

Cons

- Addresses storm surge, not sea level rise stillwater levels / nuisance high tide flooding
- Significant environmental impact potential
- Potential negative impacts to navigation and port operations
- Potentially not cost-effective unless local storm surge heights become larger than those observed in today's climate
- Reliance on operational capacity and mechanical systems during flood conditions
- Reliance on uncertain storm surge forecasting

Applicability on the North Shore

A large storm surge barrier located at a narrow location on Burrard Inlet would have many serious negative environmental impacts that would not be in line with various environmental stewardship initiatives on-going in the region. A flood barrier at First Narrows could severely impact shipping operations.

The frequency that barriers are closed generally increases with sea level rise. This measure is typically best suited to areas where the storm surge component of a coastal flood event is a few to several meters (e.g. Atlantic coast of North America) and less suited to areas, such as the North Shore, where the amount of storm surge (~1 m maximum recorded) and the amount of sea level rise are similar (1 m by Year 2100). In the latter scenario, sea level rise may become the primary driver for closing the barrier and the frequency of barrier may be impractically high, particularly for navigation.



APPLICABILITY: LOW

Barriers at the mouths of North Shore creeks are also not preferred because of the potential for impacts to fish habitat and passage. Similar to large storm surge barriers, the benefits would be limited as diking would still be required upstream along the watercourse. Pump stations added to the barriers to reduce the need for diking would likely not be economically feasible given the intense rainfall patterns that define large design flows on North Shore creeks.

C-4 INTERNAL URBAN DRAINAGE ADAPTATION

High Level Approach

Resist



Flapgate at outfall

Sub-measure

C-4-1	Flapgates for stormwater outfalls
C-4-2	Floodboxes and pump stations with drainage canals / surface storage
C-4-3	Floodboxes and pump stations with subsurface reservoirs
C-4-4	Upper stormwater network pressurized pipes and outfalls

Description

Sea level rise adaptation planning is often most well known for ideas on how to resist coastal floodwaters or to accommodate developments to periodic coastal flooding. However, just as important is the consideration of the impact of sea level rise on the performance of urban stormwater (rainfall runoff) systems.

The level of service for these systems involves conveying runoff from rainfall events up to the 10-year return period event (10% annual exceedance probability) in a subsurface stormwater pipe network and safely conveying larger events on roads or other rights-of-way leading to creeks or directly to the ocean. As sea level rise occurs, stormwater systems in low-lying areas may not meet the existing level of service due to loss of the elevation gradient driving gravity drainage. Additionally, existing stormwater outfalls may become paths for coastal flooding which would render dikes and seawalls ineffective.

The conventional adaptation approach involves installing flapgates on stormwater outfalls. These gates prevent coastal floodwaters from entering the outfall and results in backwatering of the pipe. If the backwatering results in performance below the level of service (e.g. surface flooding occurring during events with a return period lower than 10 years), the outfall may need to be replaced by a floodbox and pump station. A floodbox is a large outfall structure and a pump station can pump internal drainage over the sea level / dike. The sizing of floodboxes and pump stations depends on the level of service, inflow to the station, and the volume of storage at the station and in the system which can attenuate peak flows. In urban areas, it is generally more difficult to have large volume storage for pump stations; underground options can also be limited in size and are more costly.

C-4 INTERNAL URBAN DRAINAGE ADAPTATION

Description Continued

An alternative approach to reduce the need for and size of pump stations that may be appropriate for the North Shore is to take advantage of steep topography to convey as much of the rainfall runoff by gravity as possible. Stormwater networks located on elevations above the coastal floodplain could be drained directly to the ocean without pumping through pressurized pipes that would build up enough hydraulic head to convey the water. Internal drainage in low-lying areas could be conveyed using smaller pump stations and/or through developing a different level of performance, particularly for areas where dikes and seawalls are not implemented and a higher level of coastal flood risk tolerance may be established."

Pros

- Adapt stormwater network to sea level rise to maintain level of service (or define new level of service)
- Where effective, pressurized stormwater pipe systems could reduce pump station costs (capital cost comparison will vary by site-specific factors, but operation and maintenance costs are expected to be significantly less)

Cons

- Large costs and land demands for new pump stations

Applicability on the North Shore

Given the dense and comprehensive development existing on the North Shore, internal urban drainage adaptation will be an important component of sea level rise adaptation. Pump stations and their associated storage volume needs will be challenging to implement on the North Shore given existing land uses and density. One opportunity would be to incorporate dikes, pump stations, and parks to make the most use of land and achieve multiple co-benefits. Alternative approaches, such as pressurized pipe systems, require investigation to determine feasibility and cost-effectiveness.



APPLICABILITY: HIGH

C-5 NEARSHORE WAVE ATTENUATION STRUCTURES

High Level Approach

Resist

Advance

Sub-measure

C-5-1 Breakwaters

C-5-2 Groynes



Nearshore breakwater in Virginia.



Ogden Point Breakwater in Victoria.

Description

Wave attenuation structures such as breakwaters are constructed offshore to reduce the intensity of wave action and therefore minimize wave effects. Reducing wave effects through these structures can be used to lower the required elevation of dikes and seawalls and flood construction levels. This measure does not reduce the coastal flood stillwater base level.

Breakwaters and groynes can be designed to incorporate environmental habitat features, but the construction footprint is likely to result in negative environmental impacts. Designs can also incorporate public amenity features (e.g. piers, lookouts, etc.).

Another potential negative impact of this measure is an alteration of natural sediment dynamics, including sediment transport and deposition/erosion patterns. Careful analysis, planning, design, construction, and monitoring is often required.

Pros

- Reduces wave effects and in turn dike crest elevations and flood construction levels
- Can be linked with public amenity and park concepts for co-benefits

Cons

- Construction footprint environmental impacts
- Sediment dynamics interruption potential
- Can be a navigational hazard

C-5 NEARSHORE WAVE ATTENUATION STRUCTURES

Applicability on the North Shore

Wave hazards on the North Shore require further study, particularly for areas west of the Lion's Gate Bridge which are more exposed. Breakwaters and groynes may be applicable in wider floodplain areas east of the Lion's Gate Bridge.



APPLICABILITY: MEDIUM

Additional Reference Photos



Example of a breakwater



Example of a breakwater

CATEGORY D:

COMMUNITY-SCALE NATURE-BASED MEASURES

D-1 RESTORATION OF NATURALLY RESILIENT ENVIRONMENTS

High Level Approach

Resist



North Vancouver mudflats in the 1940s

Sub-measure

D-1-1	Mudflat and salt marsh restoration
D-1-2	Beach nourishment
D-1-3	Submerged vegetation and reef wave dissipation
D-1-4	Clam gardens incorporated into breakwaters and mudflats

Description

Nature-based features have been proven to reduce the severity of coastal flooding, generally through wave dissipation, in addition to providing environmental co-benefits. Mudflats, marshes, beaches, and submerged vegetation all can be incorporated into the shoreline to reduce wave energy and have a direct benefit to flood protection systems.

Beach and/or mudflat nourishment from onshore or offshore sources is a popular adaptation approach that is applied in Europe and in parts of the United States. There are no large examples of sediment nourishment in BC currently. Smaller sediment replenishment projects are often paired with engineered beach designs. One local, successful example is the shoreline restoration work conducted by the District of North Vancouver in partnership with the Tsleil-Waututh Nation in Cates Park (Whey-ah-wichen) to protect the eroding headland which is a cultural site with archaeological assets.

A clam garden breakwater, in addition to wave dissipation, could provide improved water quality, carbon sequestration and cultural co-benefits, like local shellfish harvesting, in line with long-term environmental stewardship initiatives for the Burrard Inlet led by the Tsleil-Waututh Nation.

Pros

- Contributes to managing wave effects for flood risk reduction
- Environmental, social, and cultural co-benefits

Cons

- Not a standalone adaptation solution
- Uncertain performance and required monitoring and maintenance

D-1 RESTORATION OF NATURALLY RESILIENT ENVIRONMENTS

Applicability on the North Shore

The North Shore shoreline is diverse and different sub-measures will be applicable in different areas. Port lands are least well suited for natural shoreline restoration due to the necessity for deep water and the high frequency of vessel-generated waves.

APPLICABILITY: MEDIUM

Additional Reference Photos



Clam garden



Marsh grass plantings

D-2 ENGINEERED NATURE-BASED MEASURES

High Level Approach

Resist

Sub-measure

D-2-1	Dike slope habitat (‘living dike’)
D-2-2	Engineered beach
D-2-3	Barrier island breakwater habitat ('living breakwater')
D-2-4	Nearshore reef wave dissipation



Engineered nearshore reef



Engineered beach

Description

These measures combine natural elements with engineered works. These measures are often desired when nature-based concepts are incorporated into flood protection infrastructure and/or there is other infrastructure nearby which will rely on the measures for protection. Adding an engineering component can increase the reliability of the measure and deliver the required performance from the beginning as opposed to waiting for natural habitats to develop over time.

There is an established practice for engineered nature-based measures in BC, but it is mostly focused on rainwater green infrastructure and creek/river bioengineering for bank protection. A growing movement is to incorporate this approach into sea level rise adaptation and flood protection, but there are no major constructed projects at this time.

Pros

- Contributes to managing wave effects for flood risk reduction
- Environmental, social, and cultural co-benefits

Cons

- Not a standalone adaptation solution
- Uncertain performance and required monitoring and maintenance

D-2 ENGINEERED NATURE-BASED MEASURES

Applicability on the North Shore

The North Shore is well positioned to be a leader in incorporating engineering nature-based measures into its sea level rise adaptation plans because it does not already have a well established system of dikes. Other areas in the Lower Mainland must find ways to incorporate nature-based approaches into existing structures that are often too costly to relocate, replace, or modify significantly. In particular, the North Shore has the opportunity to build any future shoreline sea dikes to a high living dike standard that reduces wave effects and erosion protection requirements and provides multiple co-benefits.



APPLICABILITY: HIGH

D-3 SHORELINE RESHAPING

High Level Approach

Advance

Accommodate

Sub-measure

D-3-1	Shoreline retreat (future intertidal area)
D-3-2	Shoreline advance (land reclamation for future intertidal area)



Shoreline Sediment Nourishment (Before and After)



Shoreline advance in Hong Kong

Description

Shoreline reshaping measures can be used to address coastal squeeze (intertidal area loss) by providing future intertidal area.

Managed land use change and gradual shoreline development retreat can be used to create natural space for migration of the intertidal zone. In some areas, it may be most appropriate to alter the shoreline in advance of sea level rise whereas other areas can be left to change gradually and naturally. An alternative approach would be to use land reclamation approach to build future intertidal areas.

Pros

- Offset and minimize intertidal habitat loss
- Environmental, social, and cultural co-benefits

Cons

- Negative habitat impacts in the short-term
- Challenges related to obtaining space for reshaping (managed retreat)

D-3 SHORELINE RESHAPING

Applicability on the North Shore

Shoreline reshaping is likely only to be applicable in limited areas with existing shoreline parks where park land use can be changed over time. Other areas with existing development may not be applicable unless paired with an opportunistic or comprehensive property acquisition program. Port lands are not well suited for shoreline reshaping given the deep bathymetry required for port activities.



APPLICABILITY: LOW

CATEGORY E:

CRITICAL INFRASTRUCTURE RESILIENCE

E-1 MUNICIPAL PUMP STATION RESILIENCE

High Level Approach

Accommodate

Sub-measure

E-1-1	Pump station floodproofing by elevation
E-1-2	Floodproofing by tanking
E-1-3	Relocation
E-1-4	Backup power



Barrowtown Pump Station in Abbotsford



No. 4 Road pump station in Richmond

Description

Municipal sanitary, stormwater, and potable water pump stations are critical infrastructure components that can significantly complicate recovery efforts after a flood if they are damaged by flooding. Damage to sanitary pump stations, in particular, can result in floodwaters contaminated with wastewater which can be a health hazard both during the flood and after the flood resulting in significant building restoration efforts and delayed re-entry following evacuation orders.

Key components that can be damaged include electrical controls, mechanical components including internal piping, and power sources.

Measures to increase the resilience of pump stations to flooding include relocation away from high hazard areas, floodproofing, and backup power supply. Relocation is not always an option, particularly for sanitary pump stations which by necessity are located at the lowest topography to collect and pump wastewater.

Pros

- Reduced flood impacts and reduced recovery time and effort

Cons

- Relocation is not always an option
- Backup power and floodproofing increase cost

E-1 MUNICIPAL PUMP STATION RESILIENCE

Applicability on the North Shore

The North Shore has many pump stations that would be directly impacted by coastal flooding without adaptation and others that would be indirectly affected due to flood impacts to power sources (substations). Over the coming decades, many pump stations will need to be upgraded and there is an opportunity to add significant resilience to this critical infrastructure.

APPLICABILITY: HIGH

Additional Reference Photos



Wiggins Pump Station (Burnaby)

E-2 POWER TRANSMISSION INFRASTRUCTURE RESILIENCE

High Level Approach

Accommodate

Avoid

Sub-measure

E-2-1	Substation relocation
E-2-2	Substation flood protection and equipment floodproofing
E-2-3	Electrical kiosk and vault floodproofing design guidelines



Substation flood protection



Substation flood protection

Description

Electrical power transmission infrastructure is a critical infrastructure that can significantly complicate recovery efforts after a flood if damaged.

In general, there are 2 layers of infrastructure to consider: substations located in the floodplain and local infrastructure (kiosks, vaults and transmission lines) located in the floodplain. The former is critical because damage would not only impact the floodplain, but could expand far beyond the flooded area. The latter (kiosks, vaults and transmission lines) are also important because without improving the resilience of these infrastructure components, the electrical utility may shutdown the grid in a flooded area as a precautionary step. Furthermore, if the area under transmission lines is to be raised (for land raising or dike concepts), it would be prudent to coordinate with other maintenance work, to avoid moving the lines more than once.

Ideally, new or replacement substations would be located outside of the floodplain. Alternatively, substations can be floodproofed through permanent or temporary structural flood protection works (e.g. ring dike or flood wall with gate) and/or specific critical equipment raising.

Pros

- Increased resilience and reduced recovery time and effort

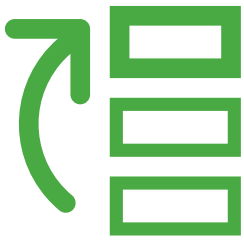
Cons

- Cost of replacing before end-of-life or of floodproofing

E-2 POWER TRANSMISSION INFRASTRUCTURE RESILIENCE

Applicability on the North Shore

Relocating or floodproofing of the BC Hydro substations within the coastal floodplain would significantly reduce the estimated impact of flooding on businesses, critical social facilities, and vulnerable people.

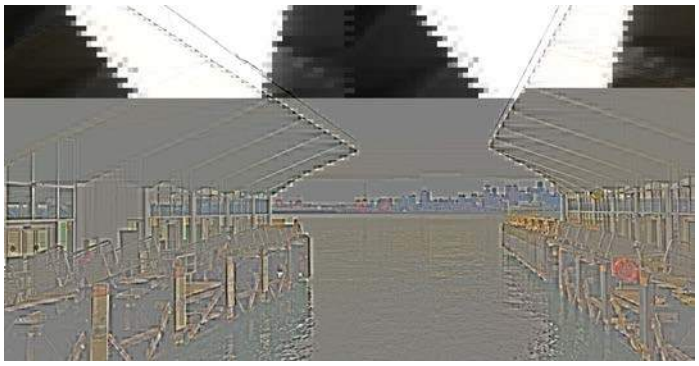


APPLICABILITY: HIGH

E-3 TRANSPORTATION INFRASTRUCTURE RESILIENCE

High Level Approach

Accommodate



Current Lonsdale Quay Seabus terminal

Sub-measure

E-3-1	Translink Lonsdale Quay SeaBus terminal upgrade
E-3-2	BC Ferries Horseshoe Bay terminal upgrade
E-3-3	Gradual road raising through asset management
E-3-4	Emergency routes raising
E-3-5	Railway corridor raising

Description

Upgrading the SeaBus and BC Ferries terminal are site-specific opportunities to increase flood resilience to reduce the impacts of flooding and reduce the recovery time after a flood. For both facilities, it is important to note that access to the water needs to be maintained and upgrades would likely focus on critical mechanical/electrical infrastructure, the use of flood resilient building materials, and access/egress.

Raising linear infrastructure is a more broad, regional option to coordinate along jurisdictions to raise roads above flood levels to either act as flood protection themselves (i.e. roads on top of a dike) or to avoid nuisance flooding on vulnerable roads and emergency routes before structural measures are implemented or in areas where structural approaches are not preferred. Road raising can be achieved gradually through asset management and area-specific planning, or it can be done in some cases as an individual capital project.

Rail corridor raising would provide an opportunity for community scale flood protection and for protection of the rail system, but raising is complicated given slope design constraints of railways. Additionally, the level of risk tolerance for a rail operation may be higher than the overall community.

Pros

- Raising linear infrastructure protects it, and also acts as protection for land behind it
- Ocean transit facilities are critical transportation links in BC

Cons

- High cost to raise large portions of road
- Rail raising may not be feasible

E-3 TRANSPORTATION INFRASTRUCTURE RESILIENCE

Applicability on the North Shore

Given that there are no existing coastal dikes on the North Shore, road raising is a distinct option for achieving flood protection either as part of primary flood protection dikes or through adding secondary resilience in combination with land raising concepts.

APPLICABILITY: HIGH

Additional Reference Photos



Raised road

CATEGORY F:

RESPONSE & RECOVERY PHASE RISK REDUCTION MEASURES

F-1 FLOOD FORECASTING AND OPERATIONAL PLANNING

High Level Approach

Avoid | Resist | Advance | Retreat | Accommodate



Stockpiled sandbags in advance of a flood



GNSS tide gauge in Sweden

Sub-measure

F-1-1 Coastal water level monitoring and forecasting

F-1-2 Wave hazard monitoring and forecasting

F-1-3 Operational response planning

F-1-4 Operational response stockpile (temporary barriers, etc.)

Description

Flood forecasting is an important component of operational response planning. The Province of BC developed the StormSurgeBC (www.stormsurgebc.ca) coastal water level forecast which provides multi-day stillwater level forecasts. This information can be incorporated into local operational planning, including informing flood preparedness during spring perigean (king) tide periods and during significant storm surge events. Water level forecasting information is relevant now to low-lying areas of the North Shore which experience seasonal flooding and will become relevant to larger areas as sea level rise occurs.

Wave hazard forecasting and information sharing may be of interest to areas west of the Lion's Gate Bridge which are more affected by wind-generated waves. However, wave conditions are often very site-specific and general forecasting may not be effective.

Operational response planning and stockpiling of flood-fighting materials and equipment is relevant for current low-lying areas that experience flooding during king tide events and will be impacted most in larger events.

F-1 FLOOD FORECASTING AND OPERATIONAL PLANNING

Pros

- Operational response can reduce impacts and damages associated with flooding, particularly in smaller events

Cons

- Not effective without other measures, particularly in large flood events
- Reliance on forecasting programs which can be uncertain

Applicability on the North Shore

Very few locations on the North Shore currently flood regularly and require seasonal flood forecasting and response. However, as sea level rise occurs, more areas will be exposed to seasonal or infrequent flooding where operational response and flood fighting measures may be effective. There is a potential for NSEM to coordinate response roles as issues emerge over time. This measure may be more effective currently for some of the low-lying industrial and port lands where land raising or diking may not be a preferred approach.



APPLICABILITY: LOW

F-2 RECOVERY PHASE RISK REDUCTION

High Level Approach



Accommodate



Avoid

Sub-measure

F-2-1	Post-damage property acquisition program
F-2-2	Build back better policies for redevelopment after damage

Description

Response and recovery measures include steps that the partners can take in advance of a flood event to ensure that flood recovery is as effective as possible.

In particular, policies can be developed to indicate a desire to discourage redevelopment or densification in high-risk areas after a major flood has caused significant damage. This can involve a post-flood property acquisition program or build back better policies to increase resilience through floodproofing. The concept 'build back better' was defined by the UN Sendai Framework for Disaster Risk Reduction and uses disaster as a trigger to create more resilient nations and societies than before through the implementation of risk reduction measures.

Pros

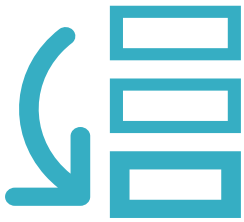
- Post-flood managed retreat or avoid strategies can be highly effective at reducing risk
- Build back better approach can leverage post-flood recovery momentum for increased resilience

Cons

- Resistance to post-flood property acquisitions and redevelopment restrictions

Applicability on the North Shore

Given the timeline for sea level rise projections, proactive planning and managing risk through redevelopment is likely a more efficient route to risk reduction than large programs aimed at using post-flood recovery as an opportunity to reduce risk. The Port may have the capacity and interest to acquire lands which are deemed flood-prone in a post-damage property acquisition program.



APPLICABILITY: LOW

CATEGORY G:

COMMUNITY AND CULTURAL RESILIENCE MEASURES

G-1 PUBLIC AWARENESS AND RISK REDUCTION EMPOWERMENT

High Level Approach

Accommodate



Flood hazard signage

Sub-measure

G-1-1	Education and awareness campaign - everyone has a role to play
G-1-2	Education materials to promote safe use of foreshore, estuaries, and waterfront
G-1-3	Public signage for flood hazard area
G-1-4	Flood insurance education
G-1-5	Neighbourhood level flood maps and response plans
G-1-6	Home and business flood assessment and resilience planning incentive program

Description

Increasing public awareness of coastal flood hazards will allow individuals to take steps towards increasing their personal resiliency to flooding.

Education for the public could include permanent signage in flood hazard areas or in coastal recreational areas like Ambleside Park or Maplewood Flats to increase general awareness of tides, currents, and wave hazards. Signage is relatively cost effective and would require little upkeep. More involved public education work could include awareness campaigns about the steps that individuals can take to become more prepared for coastal flood events, as well as to encourage the uptake of flood insurance by property-owners in the floodplain.

The creation of neighbourhood level flood maps would allow for high resolution, specific analysis of flood consequences and therefore response plans tailored to that area. An example of neighbourhood-level response planning could be the creation of NeighbourHubs (which are designated meeting places that integrate emergency supplies; built examples are on the Arbutus Greenway in Vancouver and Leonard St. in Victoria).

Pros

- A knowledgeable public is a prepared public

Cons

- Educational campaigns would need to occur on a recurring basis, to ensure that the level of knowledge remains high as the North Shore population changes

G-1 PUBLIC AWARENESS AND RISK REDUCTION EMPOWERMENT

Applicability on the North Shore

The difficulty of implementation varies between these sub-measures. Carrying out the low-barrier steps, such as creating signage, would be a straightforward first step to take. Measures such as creating an on-going educational campaign would take more effort. Therefore, the degree of public awareness-raising can be flexible to accommodate the capacity and budget of the partners.



APPLICABILITY: HIGH

Additional Reference Photos



Flood preparedness and resilience public information shared by EMBC on social media

G-2 PROTECTION OF CULTURAL SITES

High Level Approach

Resist

Accommodate



North Shore shoreline

Sub-measures

G-2-1	Special floodproofing measures
G-2-2	Consider options to cap known archaeological sites
G-2-3	Proactive data collection of known cultural and archaeological sites
G-2-4	Drainage measures to mitigate flooding and cross-contamination

Description

Special flood protection measures may be required to protect important cultural and archaeological sites from future flooding and damage. In some areas where flooding cannot be prevented, data collection to record historic use and information about cultural sites may be an important way to preserve important cultural information. For options for heritage buildings, refer to measures B-1 and C-2.

Pros

- Protects or documents critical cultural resources that are important for knowledge sharing, community health, and spiritual practices

Cons

- May be difficult to adequately protect sites without damage or preventing access

Applicability on the North Shore

Archaeological site locations are sensitive, and protected under the Heritage Conservation Act; furthermore, archaeological sites must not be altered without a permit from the Province. Considerations must be made towards the security of private information regarding the locations of cultural and archaeological sites. Therefore, other partners should follow the lead of Squamish Nation and other local First Nations, including the Tsleil-Waututh Nation in supporting these measures.

APPLICABILITY: HIGH

G-3 EMPOWERING NON-GOVERNMENTAL STAKEHOLDERS TO INCREASE RESILIENCE

High Level Approach

Accommodate



Children's drawing about the causes of coastal flooding

Sub-measure

G-3-1	Homeowner flood risk assessment and resilience planning program with incentives
G-3-2	Build awareness of alternative social, health, and emergency response facilities outside of high-risk areas
G-3-3	Encouraging business flood risk assessment and continuity planning program for businesses and social services with incentives/regulations/by providing resources
G-3-4	Youth and school education programs about flood resilience
G-3-5	Flood insurance incentives/requirements

Description

Empowering non-governmental stakeholders to take actions to reduce their flood vulnerability will increase the overall societal resilience to coastal flood hazards. This can be accomplished through a variety of means, through integrating flood hazard awareness in school programs, through incentivizing homeowner/business risk assessments or through public engagement with more detailed adaptation planning.

These measures build on the public awareness-raising from measure G-1, and provide resources to residents so they are able to be more prepared for a coastal flood.

Integrating flood resilience in schools could fall under the current curriculum of Science 7 (under the topic of "evidence of climate change over geological time and the recent impacts of humans") or Earth Sciences 11 ("effects of climate change on water sources").

Pros

- In concert with actions taken by governments, individual actions can increase resilience
- Youth programs allow knowledge into communities that may not engage with other educational programs due to barriers such as language

Cons

- Must be coupled with governmental action to protect all residents, or else is ineffective

G-3 EMPOWERING NON-GOVERNMENTAL STAKEHOLDERS TO INCREASE RESILIENCE

Applicability on the North Shore

Thoughtful design and planning of incentives / resources / educational materials will allow future work towards this measure to proceed more easily. Once the materials exist, raising awareness of incentives and resources would need to be on-going, as well as monitoring their rates of use by residents.



APPLICABILITY: HIGH