City of Vancouver Coastal Flood Risk Assessment Phase II

Final Report

Prepared for

City of Vancouver

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Executive Summary

The City of Vancouver recognizes that despite global mitigation efforts, climate change will have profound implications for its future. As with all coastal locations, over the coming decades and centuries Vancouver will be subjected to sea level rise, as well as more intense and frequent storms. This has significant implications for the City. With 1 m of sea level rise almost 13 km^2 of City lands are in the floodplain; the assessed value of land and buildings in this floodplain today is $7Bn.

To address the issue of sea level rise, a Coastal Flood Risk Assessment (CFRA), was identified as a priority action in the City of Vancouver's Climate Change Adaption Strategy. This report summarizes the findings of Phase II of the CFRA. It follows the foundational modelling and exploratory work undertaken in Phase I that identified and quantified the people, property, services, infrastructure, and environment at risk from sea level rise in Vancouver.

Vancouver developed over a time where sea levels were stationary, and risk tolerances and related standards were different than today. Our existing flood mitigation strategies will not work into the future, and as such, the City has recognized the need to adapt and plan for future sea level conditions.

In Phase II we have outlined a number of specific, distinct alternatives that could be implemented in eleven potentially at-risk zones to mitigate the impacts of sea level rise. Using a scenario-based, multi-attribute approach, we have characterized the trade-offs of each alternative in each zone using a mixture of quantitative and qualitative measures.

Tough, values-based decisions will need to be made in several zones as the sea level rises. We have learned much about possible relative preferences for each of the alternatives from interactions with City staff and a small group of invited external stakeholders. However, our intent is to provide a basis for ongoing conversations with stakeholders, and to inform consultation and engagement, both city-wide and with other communities, in the years and decades to come.

From the outset of this work we recognized the challenge of balancing a number of important points:

1. The need to plan with the best available information and avoid the paralysis associated with multiple and compounding uncertainties.
2. The need to make specific short-term decisions, but also to develop an adaptive and robust planning framework to manage future uncertainties in climate change, development, and stakeholder values.
3. The need to consider both scenario-based and risk-based (i.e., probability of X consequences) approaches to evaluation.
4. The need to consider multiple objectives—some of the key trade-offs that emerge from this work relate to issues that are difficult to adequately address through traditional cost-benefit methods, including issues of liveability, aesthetics, and the displacement of vulnerable populations.

To address these challenges, we first worked with City staff and external stakeholders to clarify objectives—"the things that matter"—when evaluating alternatives to respond to sea level rise. We then developed quantitative and qualitative measures for estimating how these objectives might be affected by changes to sea level rise or by management activities themselves. Next, we identified a long list of specific individual adaptation options (including policy, planning, and engineering options), and considered their appropriateness in each zone. Where possible, we assembled selected options into distinct alternatives for each zone, organized around generic adaptation strategies.

After surveying the issues surrounding all zones, we undertook a more detailed analysis of the trade-offs associated with the alternatives for False Creek and Flats, Fraser River Foreshore, Southlands, Kitsilano, and Jericho-Spanish Banks. The remaining zones were not selected for detailed analysis because either:

- The issues surrounding adaptation alternatives at these locations are relatively straightforward, or
- Because of complex multi-jurisdictional issues that require a co-ordinated approach at this stage.

In this report we provide specific suggestions on both city-wide issues and by zone. However, a study of this scope should not be used for making irreversible decisions about the long-term future. Rather, we focus on identifying and recommending solutions required in the short-term, identifying, characterizing and preserving potential options for the future, and also creating an adaptive management planning framework to facilitate timely future decision making.

The future is uncertain, so focus on preserving future options

A small number of zones may experience some flooding today. In these cases, we have presented specific strategies that may be considered. However, for the majority of zones for which immediate decisions are not required, we suggest that it is more important to identify and take steps to preserve options that might need to be implemented over the coming century.

Continue to seek ways of decreasing vulnerability in at-risk areas

The City has already implemented higher flood construction levels in potential flood areas. We encourage the City to consider further policy options that help at-risk areas become less vulnerable to the effects of sea level rise and flood events over the natural course of infrastructure cycles.

Monitor developments and plan to actively adapt to them

Sea level rise predictions are inherently uncertain, as are forecasts of increased frequency and intensities of storm events. We believe it is important that the City design and implement a formal adaptive management plan to help structure the timing and process of the decision making that will need to be done on an ongoing basis. This will also require improved monitoring of local sea level and sea state.

Engage with communities, partners, and other levels of government

Finally, we urge the City to continue its efforts to engage partners and other jurisdictions, and to initiate its planned formal community engagement, to begin and maintain a wider public dialogue about the difficult choices that lay ahead.

Zone-by-zone findings

A summary of the high-level issues and our key findings for each of the eleven zones are as follows. Note that this work does not identify who should be responsible for implementing or funding specific activities.

False Creek and Flats (FC) - False Creek and Flats—coastal areas east of Burrard Bridge and the flat area that extends east from Science World to Clark Street—is a zone that has many key existing and future infrastructure assets, including plans for a new St. Paul's Hospital, a new energy facility serving the downtown core, Pacific Central Train Station, Main Street-Science World SkyTrain Station, BC Place, Rogers Arena, and the rail yards, among others. This area is projected to be vulnerable to flooding in the future. City staff and stakeholders were clear that protecting these assets is both important and feasible. Depending on actual observed rates of sea level rise, significant protective flood-management actions will be required before 2100. Of the protective alternatives we examined, a sea barrier seemed to be somewhat preferred by stakeholders over a raised seawall, though more refined engineering explorations would need to be undertaken to properly clarify the trade-offs, costs, and feasibility associated with these alternatives. A small proportion of False Creek, particularly Granville Island, will be subject to inundation during *rare* flood events over the coming two to three decades.

Fraser River Foreshore (FR) - The Fraser River Foreshore zone encompasses the southern edge of Vancouver along the bank of the Fraser River, extending east to the Burnaby border, west to the edge of Fraser River Park, and north to Marine Drive. It has two distinct areas: newer multi-family residences and amenities in the east, and a largely industrial west. Parts of this zone are at risk for flooding today and therefore it was a priority for investigation in this study. The residential area east of Argyle Street is, for the most part, relatively new and built to an appropriate elevation and therefore the flood risk is mostly mitigated. For the remaining industrial area west of Argyle Street, a dike alternative appears to be appropriate, although more detailed engineering design is required to clarify technical and timing issues.

Southlands (SL) - The Southlands zone is a primarily residential area that borders the Fraser River, and which we have taken as extending from Angus Drive in the east to the border with Musqueam lands on the west, and including Deering Island. The existing dike, that runs on the mainland parallel to the River, will not protect this area during a major flood event. The dike is considered an orphan, non-standard dike; there is no diking authority, and the original design parameters of the dike, completed many decades ago, is unknown. The City of Vancouver is not currently responsible for the dike; however, it may wish to facilitate conversations among stakeholders around how to proceed. In the meantime, the City may also take action to avoid increases in density in this area in particular. Continued consultation on this issue with Southlands residents and the Musqueam Nation will be essential.

Kitsilano (KL) - Kitsilano is a residential zone with a destination beach and park. We examined the zone in detail and believe that although an immediate response is not warranted, consultation and planning will need to be underway by 2020 in order to avoid significant impacts to the beach, park, and neighbouring residences. In the meantime, the City should focus on preserving technical options for the future and, over the medium term, engaging with residents to discuss reconfiguration opportunities to protect beach and/or park areas.

Jericho-Spanish Banks (J-SB) - The beaches of Point Grey—Spanish Banks, Locarno, and Jericho—extend from Alma Street in the east to the city's border with UBC in the west. This zone is expected to see flooding in *common* events today. We analyzed the trade-offs associated with a range of potential alternatives with City and external stakeholders. Following these discussions, a potentially preferred plan for a fine-grained shoreline protection approach was identified that would conserve both beach and park features.

Coal Harbour (CH) - Coal Harbour contains a number of businesses, residences, and parks that will be subject to significant flooding from around 2050 and onward, and will need to be protected. Action in this area is not needed immediately, given the limited extent of possible flooding in the near term.

Waterfront (WF) - The Waterfront zone is a regional transportation hub. It contains the terminus for multiple transportation networks including Translink's SkyTrain and SeaBus, the CN rail yards, Canada

Place, the Vancouver Harbour Flight Centre, and the Cruise Ship Terminal. Another key regional asset in this zone is the Convention Centre. Due to the complexity of property ownership, elevations, and potential points of water entry underneath the Convention Centre and Canada Place, it is difficult to assess flood risks for these assets. However, a high-hazard area was identified along Waterfront Road, west of the SeaBus Terminal; short-term protection for this area is recommended as a priority. Given the high-value regional assets in this zone, it is crucial that the City and other stakeholders work together to obtain more detailed geographical and property-owner information to assess and manage the flood risk.

Port Lands (PL) - Port Metro Vancouver is an economic driver for Vancouver. Although outside the direct jurisdiction of the City of Vancouver, and though action is not imminently needed to protect this area, we encourage the City and Port Metro Vancouver to continue ongoing conversations concerning adaptation risks and options for mitigating them.

Brighton Beach (BB) - The Brighton Beach zone consists of New Brighton Park and the Terminal to the west of Second Narrows Bridge, Bates Park and the westernmost section of Montrose Park to the east of the bridge. While immediate action is not required for this area, the Terminal, operated by the Port, is at risk of significant flooding at current sea levels, and action should be taken in the near future (the next five years) to explore adaptation options. New Brighton Park is not expected to flood in the near future, but may experience increased flood risks by mid-century. The City should monitor the area and further explore risks and adaptation options for New Brighton Park in the next decade or two to protect facilities from flood damage and erosion.

Stanley Park (SP) - This zone consists primarily of beaches, seawall, parkland, and park facilities, as well as residences and small businesses northwest of Denman Street and along Beach Avenue from Stanley Park to Burrard Bridge. While flood risks for a number of structures in this area will increase over time, immediate action is not required given the limited extent of flooding and relatively few locations that will experience damage in the near-term. We recommend that the City and Park Board monitor the area and, prior to 2025, further investigate flood risks and adaptation options for beaches, parkland, and structures including the Aquatic Centre, Second Beach Pool and concession, Sunset Beach concession, Royal Vancouver Yacht Club, Vancouver Rowing Club, and the Stanley Park Causeway at Lost Lagoon.

Point Grey Road (PG) - The Point Grey Road zone consists of the stretch of waterfront west of Kitsilano between Trafalgar and Alma Streets. It is characterized by steep topography with low flood risk to properties well into the future. No residential properties or businesses are within the floodplain, though the shoreline is prone to erosion, and this erosion could eventually lead to limited property damage. The City should monitor the rate of erosion and re-evaluate if action is required at a future date.

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1 Introduction

1.1 City of Vancouver Coastal Flood Risk Assessment (CFRA) Overview

The City of Vancouver recognizes that despite global mitigation efforts, climate change will have profound implications for its future. As with all coastal locations, over the coming decades and centuries Vancouver will be subjected to sea level rise, as well as more intense and frequent storms. This has significant implications for the City. With 1 m of sea level rise almost 13 km^2 of City lands are in the floodplain; the assessed value of land and buildings in this floodplain today is $7Bn.

In 2012, the City identified a Coastal Flood Risk Assessment (CFRA) as a priority action to study what these changes might be, how the City might be affected by them, and what options exist to minimize harmful impacts. The investigation has been divided into three phases.

Phase I of the CFRA was completed in 2014 and focused on characterizing the nature of the coastal flood hazard. It comprised both coastal and overland flood modelling under various future climate scenarios. This helped to understand which specific locations in the city are most at risk from coastal flooding. Basic vulnerability mapping and consequence assessment was also completed as a part of the first phase of work.

This report summarizes the findings of Phase II, in which potential management responses to these hazards have been identified and their effectiveness characterized. The main objectives of this phase have been to assess a number of adaptation alternatives (including hard- and soft-engineered designs and policy options) for flood zones across Vancouver, and to generate a shortlist of alternatives for further investigation and consideration.

A third phase of work will focus on specific questions and recommendations raised during Phase II, and will include more detailed engineering feasibility studies and planning activities that are outlined in the conclusions of this report. All project-level activities will be studied and evaluated with the input of affected stakeholders.

1.2 Brief Summary of Phase I Findings

In Phase I[1], detailed hydrographic and hydraulic modelling investigations were carried out for different climate-change scenarios, including simulating the base case (2013), and conditions in 2100 and 2200. Focus was placed on identifying floodplain extents, flood depths, and flood construction levels, to assess vulnerable areas and the consequences to people, property, and infrastructure. New flood construction levels were ultimately incorporated into a bylaw update.

Five scenarios were developed, in consultation with the City and a Technical Advisory Group, that encompassed possible future sea level rise (SLR) conditions to 2200 combined with design flood events:

- Scenario 1, 2013, 0.0 m SLR, 0.2% flood event (i.e., a flood event with a 0.2% chance of occurring in a given year, sometimes referred to as a 500-year event)
- Scenario 2, 2100, 0.6 m SLR, 0.2% flood event
- Scenario 3, 2100, 1.0 m SLR, 0.2% flood event

[1] Phase I report available at: http://vancouver.ca/files/cov/CFRA-Phase-1-Final_Report.pdf

- Scenario 4, 2100, 1.0 m SLR, 0.01% flood event (i.e., a flood event with a 0.01% chance of occurring in a given year, sometimes referred to as a 10,000-year event)
- Scenario 5, 2200, 2.0 m SLR, 0.01% flood event

Vulnerabilities and consequences associated with coastal flooding were then considered. Modelling undertaken in Phase I showed significant anticipated impacts to buildings and people for coastal flood events in the present day, and increasingly in the future. Quantitative results showed that in the present day, a 0.2% flood event would result in 1700 displaced households and almost 500 damaged buildings across the city. The same flood event with 1 m of sea level rise, would incur dramatically greater impacts: 4000 displaced households with more than 800 damaged buildings. The majority of the damaged buildings are residential, but there are also a significant number of industrial buildings affected, particularly along the Fraser River. A Hazus[2] damage-estimation model estimated that the debris generated from the 0.02% flood event with 1 m of sea level rise would fill 4,500 dump trucks—enough to cause a significant waste-management concern for the city and the region. The disruption of major transportation routes—for local traffic and goods movement—were also identified in the first phase of work. Further impacts to City infrastructure, facilities, and cultural sites were also discussed.

Many of the anticipated impacts are intangible and are therefore difficult to quantify, but would nonetheless cause significant hardship to the city. These include the many indirect economic impacts associated with the disruption created by floodwaters, the environmental impact of mixing floodwaters with contaminants, and the destruction of habitat by pounding coastal seas, as well as the many long-term social implications (such as trauma) associated with flood events. Further information on specific impacts can be found in the Phase I report, as well as in the Outcomes section (Section 3) of this report—where results from the Phase I work were refined and expanded to look at broader measures of flood impacts.

2 Phase II Approach

2.1 Conceptual Approach Considerations

In Phase II, the City is seeking to:

- Develop alternatives for adaptation to sea level rise and clearly outline the trade-offs between alternatives.
- Outline at which sea level rise thresholds, expected in which years, various responses should be implemented.
- Develop policy options that can minimize the hazard, exposure, or vulnerability of residents and property at risk.
- Inform the amendment of flood-proofing policies.
- Inform short-term, near-shore development and infrastructure projects, and long-term strategic sea level rise response planning.

[2] Hazus is a tool developed by the Federal Emergency Management Agency (FEMA) in the US, and recently adopted by Natural Resources Canada, that can be used to calculate the consequences of natural hazard events like flood, fire, and earthquake.

This is a challenging array of tasks for a variety of reasons:

- There are significant uncertainties about the rate of change in sea levels (will it be linear? non-linear?) and the frequency and magnitudes of storms (will they be more frequent? more severe?) that need to be addressed thoughtfully.
- It is impossible to predict what infrastructure or assets, or population density might be present in the city in 2100[3] that might be vulnerable to flood hazard.
- There is a need to incorporate consideration of the potential for advances in adaptation and mitigation technology between now and 2100.
- It is important to not only consider impacts from future *very rare*[4] events (i.e., a 0.2% flood in 2100), but to also consider the impacts of much more frequent but lower-magnitude flood events of various return periods (i.e., *king tides* and *common* flood events) between now and 2100. These events might have less impact individually, but the cumulative impact of multiple smaller flood events over time could be just as significant.
- There is a very wide range of things people value that are important to consider—it is often not enough to just estimate changes in impacts in dollars with and without flood protection. It is necessary to assess the degree to which flood-management options might protect a range of valued components during a flood event (e.g., life, dislocation of people, property damage, environmental harm).
- Some flood-management options (e.g., dikes) may have associated unintended impacts (positive or negative) on people and the environment that should also be evaluated, such as construction costs, changes in access to areas, changes in viewscapes.
- People's values about preferred solutions should be expected to change over time. Some options that seemed reasonable during the previous century would not be preferred today. Likewise, we should expect that future decisions may be viewed differently than they are now.

It is important to consider *when* an option should be implemented because the option can have impacts, other than flood protection, which are largely, but not necessarily, negative. If action is taken too early, then unnecessary costs, losses, and inconveniences may be encountered for no justifiable reason. If action is taken too late, protection benefits might be missed. Timing is therefore a critical factor in this evaluation. Furthermore, the uncertainty associated with the rate of sea level rise and the rate of development in the city mean that decisions made today may result in negative impacts. If sea level rise rates and development rates are slower than anticipated, then the proposed adaptation options may be over-designed at increased cost. Alternately, if sea level rise and development rates are faster or greater than anticipated, the proposed option may be under-designed, resulting in flood impacts that could have been avoided (Figure 1). The alternatives in this report were developed with a 0.2% annual probability flood event with 1 m of SLR in mind, though stakeholders engaged in this work noted that it was important to ensure that these solutions are relatively robust and adaptable should sea levels increase beyond this scenario. While the performance of the alternatives considered here has not been evaluated

3 The year 2100 was defined as the planning horizon for this work. As discussed throughout this report, there are many challenges and significant uncertainties associated with making decisions about the distant future, and the year 2100 is already many decades away. Although not referred to explicitly in this report, it is worth being reminded that sea level rise will not stop in the year 2100. An adaptive-management approach (as outlined in this report) is an appropriate option for updating decisions based on the progress of time (in the year 2100 we will make better decisions about the year 2200 than we can possibly do now). Hazard mapping for the year 2200 was completed in Phase I to bookend the problem.

4 See Table 4 for definitions of *very rare*, *rare*, *common*, and *king tide* flood events.

for more severe flood events or for average sea level increases beyond 1m, the alternatives are conceptually robust for reasonably foreseeable futures. Further consideration should be given to such events if the concepts are taken forward into more detailed engineering design.

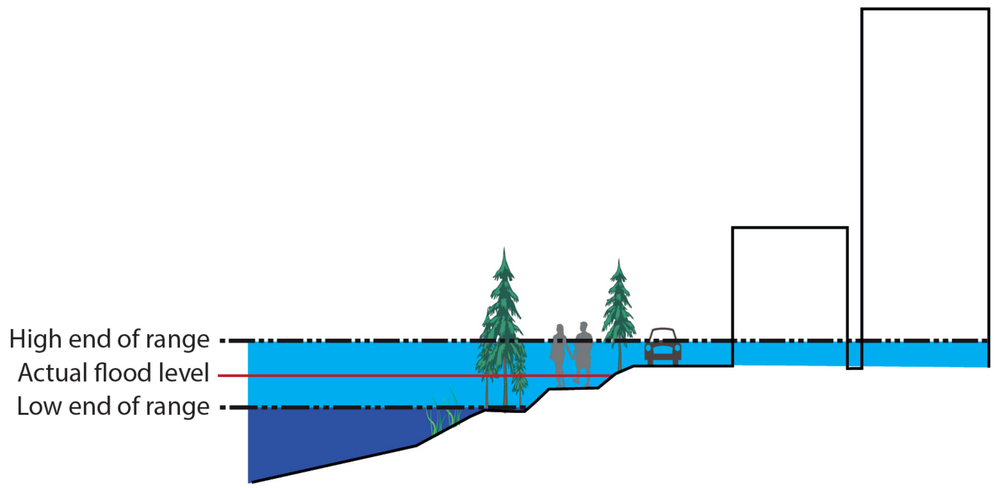


Figure 1: Risks associated with uncertainty in sea level rise

Making decisions based on overestimated sea level rise estimates (high end of range above) will result in over overinvestment. Making decisions based on underestimated sea level rise estimates (low end of range above) may result in catastrophic flood impacts.

Our chosen approaches to resolving each of the issues listed here are discussed further below, but their consideration early in this project led to an approach to Phase II that focused on four key ideas:

1) Making the best use of available information
2) Adaptability
3) Scenario-based versus risk-based evaluations
4) Exploring trade-offs between multiple objectives

2.1.1 Making the Best Use of Available Information

Definitive information on these issues will always be lacking, but it is essential not to succumb to "analysis paralysis" or to defer time-sensitive decisions in order to pursue further data gathering. Our goal was to identify and use the best information currently available that helps focus and structure the flood-management choices that the City will need to make at various points now and into the future. We strove to utilize the latest models and collect the best information available throughout this Phase II work. Moving forward, we recommend the design of an ongoing adaptive flood-management framework (see Section 4) to monitor key environmental, social, and economic indicators, and subsequently to undertake periodic reviews of the City's adaptation strategies in light of new science, evolving technology, and changing social values.

2.1.2 Adaptability

Given the inherent uncertainties, our focus is on separating those decisions that the City may wish to make in the near term from decisions that should more appropriately be made in the future. The City does not need to detail a deterministic strategy on day one, but instead needs to identify urgent and major decisions that can and should be considered in the near-term, and to set up an adaptive flood-management framework (see Section 4) from which to base decisions moving forward into the medium and long-term future.

Near-term focus areas include:

- **Specific decisions** that have near-term implications. Several coastline areas, including Southlands, are vulnerable to flooding now, when the highest tides of the year (king tides) coincide with severe winter storms.
- **Identifying "low hanging fruit" activities**, that is, flood-management options that are readily implemented and that have much greater long-term benefits relative to short-term costs. An example activity, implemented after Phase I of this project, was to implement higher flood construction levels (FCLs) for new construction in flood-prone areas.
- Planning activities that **preserve potentially viable options** that might need to be taken in the future (e.g., where some form of barrier structure might ultimately be of value in the longer term, the City may wish to ensure it acquires, or does not relinquish, rights to access the land there).
- Preparing now to take advantage of opportunities that may arise through **infrastructure lifecycles** in the future (e.g., planning seawall height increases to integrate with long-term upgrade schedules).
- Exploring the potential for **flexible solutions** that can change or be adapted over time as required (e.g., variable-height barriers).
- Developing strategies to create a culture of **resiliency** in flood-prone areas, in order to reduce the vulnerability during flood events of the things we value.
- Preparing a long-term **adaptive flood-management strategy**.

These principles were taken into consideration in the Phase II work, and are reflected in the recommendations for appropriate actions for each coastal zone for the near, medium, and long term (see Section 3 – Outcomes). City managers should keep these principles in mind in future planning activities and decisions.

In addition to these near-term areas of decision-making focus, we suggest that the City should also soon consider major decisions for the medium and long term, by:

- Conducting detailed feasibility studies to more fully consider large-scale and expensive engineering solutions that may be warranted for prominent locations at some point in the future (e.g., False Creek and Flats).
- Developing strategies for zones that might involve long-term land purchases to accommodate a dike or other adaptation option (e.g., Southlands).

These suggestions are reiterated for each zone in the Outcomes section (Section 3) of this report.

2.1.3 Scenario-based Versus Risk-based Evaluations

An ongoing consideration in this work is related to the choice of *scenario-based* versus *risk-based* approaches to the evaluation of flood-risk adaptation alternatives. A scenario-based approach is one in which potential consequences are discussed for a stated level of probability (e.g., "during a 0.2% flood event in 2100, the consequences could be X"). A risk-based approach instead looks at expected impacts by finding the product of the consequences of various events and their probabilities.

Each approach alone is problematic. Scenario-based approaches allow for a robust and rich exploration of impacts associated with a particular discrete event (e.g., a 0.2% flood event), and of the potential benefits of options to mitigate those specific impacts. However, they de-emphasize the fact that any one specific event is unlikely to ever happen (e.g., a 0.2% chance of occurring in any given year). Therefore, attention is focused on just one of many ways in which events could unfold. Further, since there will be a large number of events between now and 2100 that have a lower expected intensity than this one extreme event, the cumulative effects of these smaller events could be just as problematic as one big one, if not worse.

Risk-based approaches may perform better in this regard, providing an "expected value" for monetary impacts incurred by flood events of various magnitudes and probabilities over time. However, they are less compelling in dealing with risks to other types of elements we value (i.e., beyond those that can be readily and meaningfully monetized). The City is clear that it is not simply seeking advice on the lowest-cost solution on a monetized, expected-value basis; rather, it is seeking to understand the diverse range of monetary and non-monetary values and trade-offs at stake in order to develop a thoughtful, robust, and adaptive strategy to guide it through the complexities of decision-making over time. This is particularly important given the difficulty of establishing reliable quantitative estimates of consequences and probabilities, as discussed further in Section 2.7.

We believe that both perspectives are valid and important, and have sought throughout this project to find an approach that captures the important essence of each. As more detailed planning and development of adaptation options is carried out, we recommend that the City utilize both scenario- and risk-based evaluations to understand the implications of flood events, and adaptation options, over time. Although most of the analysis presented here is focused on a multi-attribute, scenario-based approach, we have developed a novel quantitative, expert judgment-driven methodology for estimating the risk-adjusted consequences of multi-objective impacts. This work is not included in the reporting at this time.

2.1.4 Exploring Trade-offs Between Multiple Objectives

Most flood-management options involve the *definite* expenditure of resources and alteration of current land uses or environments to create new situations that, except during future *potential* flood events themselves, are otherwise less-desirable than they were before: a scenic beach becomes spoiled by a berm; a café near the coastline has its view of the water obscured by a raised seawall. It is certainly not inevitable that all changes are negative; with creativity and skill, such physical features can become seamlessly integrated into the landscape to the point that their function is not obvious to the casual observer, and form and functionality may even be increased. Nevertheless, where there is a need to take an existing location and intervene to incorporate design features that are only necessary in *very rare* flood events, controversy is to be expected, no matter which mitigation approach the City selects.

The selection of preferred options will often be reduced to questions of values-based trade-offs. Is it better to accept the partial loss of a park during a *rare* flood event, or build a wall? Should the City help a location become more resilient to occasional floods rather than trying to prevent it from ever getting wet? These questions have no technically optimal answers, and ideally the City will engage its residents in specific discussions about the choices that they collectively face. An informed consultation of this kind requires communication about what the choices might entail and analysis on how these choices might affect the things people value the most.

2.2 Approach to Engagement

In addition to periodic meetings with senior management, two groups were convened during this process to ensure that a diverse range of expertise and viewpoints were considered. The invitees to these workshops were selected by City of Vancouver staff.

A City Adaptation Working Group (AWG) met twice and comprised City of Vancouver staff from the Streets, Structures, Infrastructure, Sewers, Planning, Parks, Engineering, Buildings, and Sustainability departments.

During these meetings, we clarified decision-scoping questions and began the process of identifying infrastructure, housing, businesses, parks, and other valued assets across a number of flood zones that would be affected under each flood scenario. AWG members reviewed flood-extent maps to identify risks to the things we value, discussed potential objectives and performance measures to assess flood impacts, and developed potential adaptation options for each zone (see Appendix B). These maps indicated flood extents for:

- 0.2% flood events at today's sea level (Scenario 1, with 0 m SLR);
- at high tide[5] in 2100 (with 1 m SLR, without flood events); and
- 0.2% flood events in 2100 (Scenario 3, with 1 m SLR);

thereby enabling workshop participants to consider today's potential flood risks versus those in 2100 with 1 m of SLR.

Figure 2. External stakeholder workshop, June 2015

5 Specifically, a higher high water large tide (HHWLT), defined as the average of the highest high waters, one from each of 19 years of predictions.

From these discussions, we were able to propose, and later refine, specific objectives and measures to be used for our analysis. In addition to conventional considerations such as cost, City staff and stakeholders were also interested in the full range of implications for parks, public access, and displacement of the most vulnerable populations.

Following these meetings, an External Stakeholder Advisory Group (ESAG) was formed, comprising City staff and members of invited organizations potentially affected by flood risks and any adaptation options. The ESAG invited participants from the following groups[6]:

- BC Hydro
- BC Ministry of Forests, Lands, and Natural Resource Operations
- Canadian Housing and Mortgage Corporation (CMHC)/Granville Island
- City of Surrey
- CN Rail
- Metro Vancouver
- Natural Resources Canada
- Port Metro Vancouver
- Simon Fraser University, Adaptation to Climate Change Team (ACT – SFU)
- Translink
- University of British Columbia, Institute for Resources, Environment and Sustainability (IRES)
- Urban Development Institute

These ESAG meetings sought broader stakeholder input on objectives, performance measures, and flood risk adaptation alternatives, and provided focused feedback on adaptation measures.

2.3 Structured Decision Making Approach

With future deliberations in mind, in Phase II we have adopted an approach based on the principles of Structured Decision Making (SDM), a decision-analytical approach that encourages the consideration of trade-offs in this way.

SDM is centered on a set of generic planning steps (see Figure 3) that serve as a guide for working through decisions.

[6] Note that not all organizations that were contacted attended the meetings.

Figure 3: Steps in Structured Decision Making (SDM)

In Step 1, we clarify what the decision is, who the decision makers are, who needs to be involved, what's in and out of scope, what assumptions are made, how the technical analysis and the consultation process should be structured, and what the constraints are. Step 2 is focused on defining the objectives (values-based statements of the things that matter to people), and the specific performance measures that will be used to estimate and report the consequences of flood-management options. Step 3 involves the development of alternatives or strategies that could be taken to address the objectives. In Step 4, the expected performance of each option across the objectives is estimated (using the performance measures), and key uncertainties are clarified. Step 5 is focused on identifying the key trade-offs between alternatives and which options deliver the best balance across multiple objectives. Finally, Step 6 is focused on how the decision can be implemented in a way that addresses key uncertainties, promotes learning over time, and ensures that there will be opportunities to revise flood-management options based on what is learned.

The following section is structured around the first five SDM steps, and describes the approach and process utilized throughout this Phase II work. Recommendations on implementation, monitoring, and review can be found at the end of this report.

2.4 Step 1: Clarify Decision Context

This section summarizes some of the key assumptions made in collaboration with the City and stakeholders during this study to help bound the analysis.

2.4.1 Geographic Scope

The study focused entirely on the City of Vancouver's jurisdiction, though there are cases where flood-management options would affect other jurisdictions (e.g., Granville Island, the Port Lands, the False Creek Flats rail yard) and in some of these cases, a preliminary analysis was undertaken. Moving forward, the City should continue to collaborate with affected jurisdictions to coordinate responses to sea level rise.

To facilitate a zone-level analysis for Phase II, the city was divided into eleven zones based on the similar geographical, zone-type, and flood-hazard characteristics (Figure 4). These zones are summarized as:

1) Stanley Park (SP)
2) Coal Harbour (CH)
3) Waterfront (WF)
4) Port Lands (PL)
5) Brighton Beach (BB)
6) Jericho-Spanish Banks (J-SB)
7) Point Grey Road (PG)
8) Kitsilano (KL)
9) False Creek and Flats (FC)
10) Southlands (SL)
11) Fraser River Foreshore (FR)

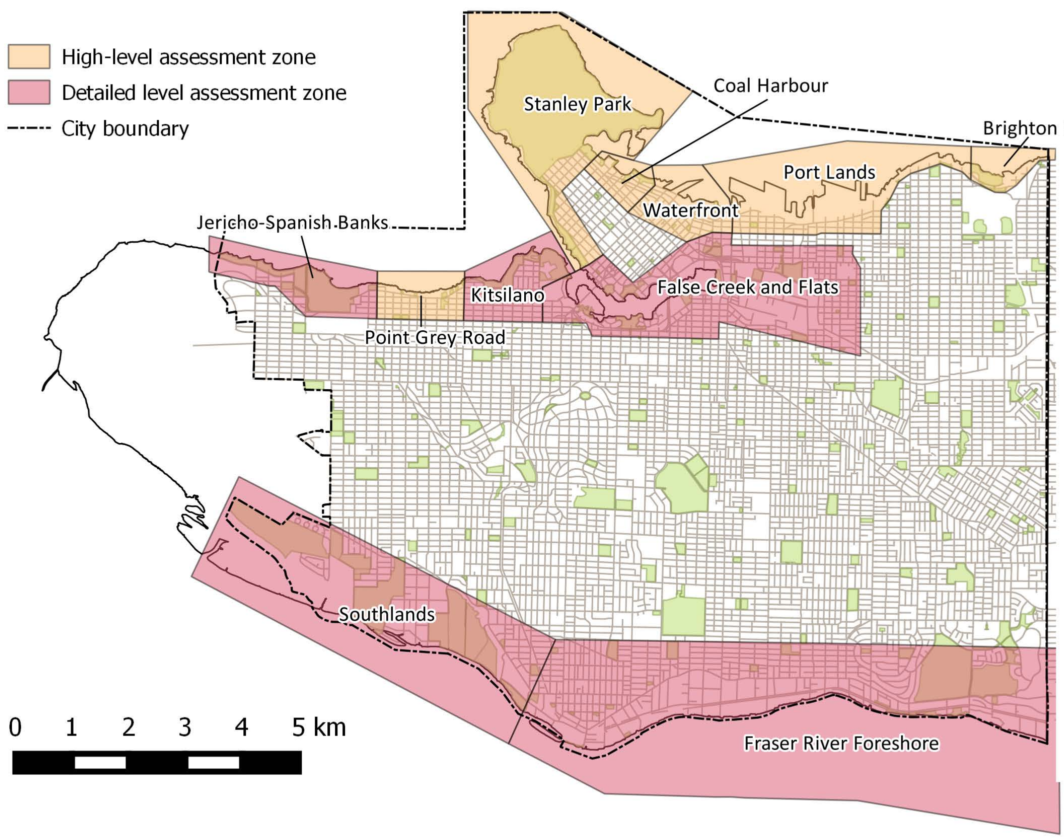


Figure 4. Map of 11 flood zones across Vancouver

Adjacent jurisdictions such as the University of British Columbia, City of Richmond, City of Burnaby, and the Musqueam Indian Band Lands were not included in this analysis. City staff have been involved in discussions with these jurisdictions individually or through regional forums.

2.4.2 Hazard Assumptions

In collaboration with technical advisors, the City of Vancouver made the decision to select sea level rise Scenario 3 (from the Phase I work) as its baseline assumption for analysis in Phase II—a 0.2% flood event with 1 m rise in sea levels in 2100. This scenario considered the effects of sea level rise (SLR), high tide, storm surge and wind set-up, wave set-up, wave effect, and 0.6 m freeboard[7]. Each of these components of flood level that determine extent estimates (see Figure 5) are discussed in detail in Phase I. While this scenario considers the effects from a rise in sea level, it does not account for the effects of more intense and more frequent storms that may also be anticipated in the future with a changing climate. More detail on the flood hazard definition can be found in the Phase I report.

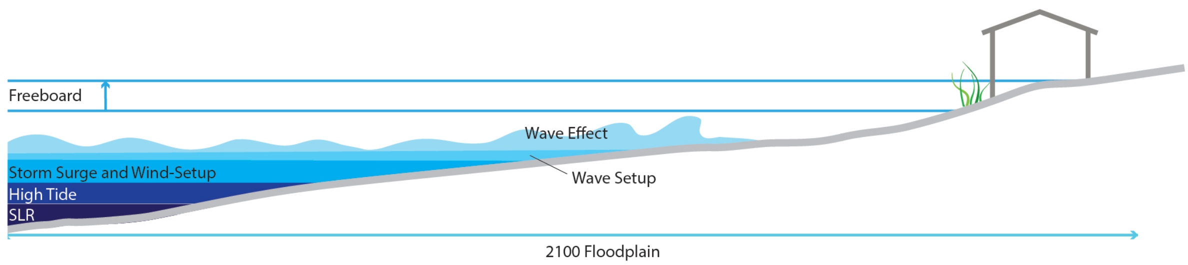


Figure 5. Components of coastal flood level that determine extent estimates

With a rising sea level, flood events will be caused by a rise in the still-water level, especially at high tide conditions. Flooding may also be caused by water carried inland by storms (Figure 6). These are considered to be two different design conditions in this work, and analysis carried out here takes into account both conditions.

[7] See Glossary for definitions of these terms.

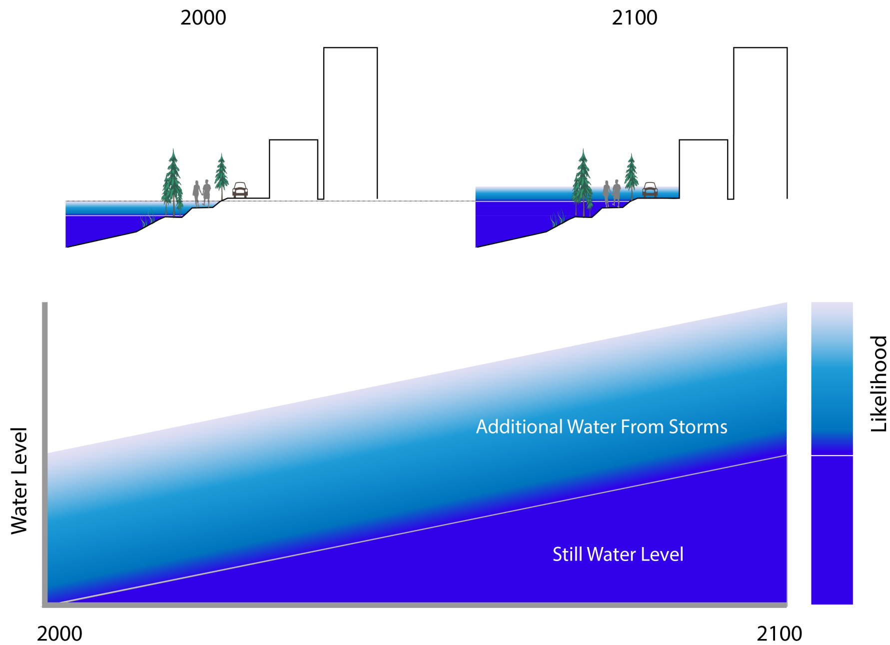


Figure 6. Flooding from 2000 through 2100

In the year 2000, flooding results from storms, where the largest, most unlikely storms are represented as the lightest shade of blue. Over time, the still-water level will increase—and some areas will be flooded permanently. This is represented in dark blue. By the year 2100 some areas will be permanently flooded (especially at high tide), and other areas further inland will be subject to occasional flooding during storm events (represented by lighter shades of blue).

2.4.3 City Growth to 2100 Assumptions

Analysis conducted on flood risk and impacts for the baseline scenario took into consideration population, infrastructure, buildings, businesses, parks, as well as other assets and things people value, based on what was located in each flooded zone as of the start of the project (2013). The analysis for flood impacts in 2100 took into account the recent adoption of a new flood construction level (FCL) bylaw (Flood Plain Standards and Requirements) in city floodplains that would raise "the underside of a floor system or the top of a concrete slab" of new and some renovated buildings to 4.6 m geodetic datum (GD), adding protection to buildings and assets contained therein in the event of a flood. However, the analysis did not take into account assumptions of city growth in terms of increases in population density and growth in businesses, housing, and infrastructure, as this would be purely speculative. However, it is important to keep in mind that although impacts on today's infrastructure are shown, the impacts in 2100 would most likely be on a much larger scale unless mitigation is implemented.

2.4.4 Civil Liability Assumptions

The limits of the liability of Canadian municipalities associated with acting or failing to act to prevent climate-change related flood impacts is a complex and unresolved legal area. There are several examples of civil suits that have been brought against Canadian municipalities in the past few years that have either been won by plaintiffs or have been settled out of court[8] but the future course of this situation is uncertain at this time. In this study, we explore impacts of flood-management actions that could be undertaken by *someone* to prevent climate-change related flooding impacts, without discussing the legal requirements or the responsibilities for doing so, or for failed attempts to do so.

2.5 Step 2: Define Objectives and Measures

Objectives are simple values-based statements of the things that matter to people when considering coastal flooding. They aim to capture many of the aspects stated by City staff and stakeholders as being important to them. Performance measures (PMs) provide a means of assessing the performance of different alternative options across objectives. Various methods may be used to estimate the value of the performance measures under each of the flood-management options.

A "triple bottom-line" framework (people, environment, economy) was introduced to organize and catalyze thinking about objectives, and a fourth category was added for objectives that capture impacts from the implementation of various options. A summary of objectives and PMs can be found in Table 1, and further details and definitions are provided in Appendix E. Based on feedback from the ESAG and City senior management, additional evaluation criteria are included below in the summary consequence tables for each zone.

[8] http://zadllp.com/2013/08/19/potential-for-municipal-liability-associated-with-extreme-weather-spurs-adaptation/

Table 1. Objectives and performance measures

Flood Protection (Per Event)

Objectives and Evaluation Criteria	Scale
PEOPLE	
People displaced temporarily	# of people displaced from flood events
"at risk" people impacted	Social Vulnerability Index (SVI) weighted displacement
Park and recreational amenity value	Value-weighted area affected per event
Loss of critical services	# of pieces of infrastructure impacted
ENVIRONMENT	
Risk of contaminant release	# of sites with potential contaminants
ECONOMY	
Damage to infrastructure	Value-weighted km of roads impacted
Damage to buildings	$M
Business disruption	# of employees working in impacted businesses
Loss of inventory	$M
Emergency response costs	Estimated cost per event

Implications of the Flood-Management Action (or Inaction)

Objectives and Evaluation Criteria	Scale
PEOPLE	
People displaced permanently	# of people displaced permanently (by SLR or flood-management action)
Aesthetics	-2 to +2 (constructed scale)
ENVIRONMENT	
Environmental benefits	-2 to +2 (constructed scale)
IMPLEMENTATION	
Capital costs	$M
Maintenance costs	$M/Year
Adaptability	1 to 4 (constructed scale)
Ease of implementation	1 to 5 (constructed scale)

2.6 Step 3: Develop Alternatives

In this report we distinguish between the following terms when describing alternatives.

- "Adaptation option" or "option" refers to an individual activity for mitigating flood risk (e.g., relocating services, using flood-tolerant materials).
- "Adaptation strategy" or "strategy" refers to any of four conceptual approaches in any zone—"do nothing", "protect", "adapt" and "retreat".

- "Adaptation alternatives" or "alternatives" refers to specific means by which different strategies could be implemented.
- "Management actions" or "actions" refers to the specific activity undertaken by the City (e.g., "conduct an engineering feasibility study").

Each are discussed in more detail below.

2.6.1 Adaptation Options

There is a large range of potential flood-management options that may help mitigate the impacts of increasing flooding hazards. We can think of each of these as belonging to one of three modes of action:

> Some flood-management options aim to reduce the nature of the hazard itself, as encountered in the city. That is, these options aim to keep excess water from moving inland and reaching assets. Dikes, for example, aim to keep water away from important things we value, and wave-dissipation technologies aim to reduce the height and kinetic energy associated with large waves.
>
> A second mode aims to reduce exposure to the flooding hazard. Rather than keeping water from reaching inland, these flood-management options aim to keep assets dry when flooding occurs. Land-use planning, for example, could help minimize future harm by preventing the development of assets in high-hazard locations. In some locations, it might make sense to move current vulnerable assets away from the area or to protect individual assets to keep water out.
>
> A third mode seeks to reduce the sensitivity or vulnerability of the things we value to the hazard. In some contexts, this can conversely be thought of as increasing robustness. Thus, communities may be made more robust to a large-scale flooding event through the development of a detailed evacuation plan; building code changes could make existing or future buildings less vulnerable to damage in various ways, for example, by requiring the use of waterproof building technologies in flood-prone areas.

Potential options may also be grouped by their source of implementation—whether regulatory, engineering, through building controls, emergency planning, and insurance options. Table 2 is an illustrative table of some of these techniques. This table also illustrates the potential applicability for the use of each adaptation option in each of the strategies discussed in the next section.

Table 2. Illustrative table of adaptation options to mitigate coastal flooding

			Mode of Action			Applicability for Strategy		
	Adaptation Option	Description	Reduce Hazard	Reduce Exposure	Reduce Sensitivity	Protect	Adapt	Retreat
Regulatory	Acquisition - Undeveloped Land	Buyout of property using public funds to sterilize area, thereby decreasing future assets at risk.		Y				Y
	Acquisition - Developed Land	Buyout of property or buildings using public funds to sterilize area, thereby decreasing future assets at risk.		Y				Y
	Relocation - Property	Moving of assets (buildings, businesses, people) out of floodplain.		Y				Y
	Relocation - Infrastructure	Moving of infrastructure (roads, services, etc.) out of the floodplain.		Y				Y
	Transfer of Development Potential	Transfer of allowable development potential to an alternate location out of the floodplain.		Y				Y
	Regulation of Land Use	Zoning bylaw, Development Permit Area or other option used to regulate land use within flood zone with the aim of decreasing vulnerability and risk.		Y	Y		Y	Y
	Covenant on Title	Requirement that flood hazard be disclosed on property title.		Y	Y		Y	Y
	Right to Flood	Provision in law that land be allowed to flood during high-water conditions.		Y			Y	Y
	Building Code	Provisions in code to increase flood resistance of new buildings through the use of flood-proofing or other property-level protections		Y	Y		Y	
Engineering	Ring Dikes / Polders	Structural dike that rings a small area.	Y			Y		
	Linear Dikes, Traditional	An embankment, wall, or fill piling constructed, assembled, or installed to prevent the flooding of land.	Y			Y		
	Multi-Use, or Super-Dikes	An average super-dike is 10 m high by 300 m wide. The extended width of the dike can be integrated into the urban fabric of the city by using the land to develop high-density housing, create a high-quality public realm along the waterfront, and by using the higher ground as a designated, lower-risk evacuation area.	Y	Y	Y	Y	Y	
	Sea Dam / Sea Barrier	A large engineered structure that can close off harbours or river mouths to stop storm surges or high tides from propagating inland.	Y			Y		
	Seawalls	The primary purpose of a seawall is to prevent inland flooding and reduce erosion from major storm events accompanied by large, powerful waves. A seawall is typically a massive concrete structure with its weight providing stability against sea forces.	Y			Y		
	Groins and Breakwaters	Engineering structure placed offshore (parallel: breakwater, perpendicular: groin) to moderate coastal sediment transport and reduce local erosion rates as well as reduce wave energy.	Y			Y		
	Erosion Protection (Rip-rap/Dolos/etc.)	The main purpose of coastal armouring (many variations) is to mitigate erosion by protecting existing shoreline from extreme events and the large powerful waves that accompany them.	Y			Y	Y	

			Mode of Action			Applicability for Strategy		
	Adaptation Option	**Description**	**Reduce Hazard**	**Reduce Exposure**	**Reduce Sensitivity**	**Protect**	**Adapt**	**Retreat**
	Dune Building	Placement of loose materials offshore to mimic natural dunes that provide a buffer between ocean and shore.	Y			Y	Y	
	Barrier Islands	Construction of surface "islands" offshore. These are designed to absorb wave energy, therefore reducing the need for erosion protection on the shore. They can also reduce the required height for dikes or seawalls.	Y			Y	Y	
	Natural Erosion Control (e.g., Wood on Beach, Grasses)	Placement of natural erosion-control materials, which, in the Pacific Northwest, would include wood and grasses. This can reduce wave energy and therefore the impact of coastal flooding.	Y			Y	Y	
	Land Reclamation	The filling in of what is currently ocean to protect inland areas and create new land.	Y			Y		
	Beach Nourishment	Placement of loose sediment material near shore (on subaerial beach), which is designed to reduce erosion rates.	Y				Y	
	Constructed Wetlands	Wetlands can be constructed offshore or on the existing shore with the goal of absorbing some of the wave energy during coastal storm events.	Y			Y	Y	
	Diversion Channels	Diversion channels are used as a river flood-management option. They are designed to take some or all of the flow and divert it around high-value areas. The Red River floodway in Winnipeg is an example of this technique. It is not suitable for coastal applications.	Y			Y		
Building Controls	Object Elevation	The elevation of an individual building above the expected flood level through the use of fill, stilts, or other structural means.		Y			Y	
	Permanent Resistance (Dry Flood-proofing)	Products or actions, permanently in place, designed to stop water from entering buildings through existing openings or by penetrating walls.		Y			Y	
	Temporary Resistance (Dry Flood-proofing)	Products or actions, deployed with appropriate warning times, designed to stop water from entering buildings through existing openings or by penetrating walls.		Y			Y	
	Resilience (Wet Flood-proofing)	Building design and construction aimed at allowing floodwaters, but minimising damage. The use of flood-tolerant building materials (e.g., waterproof replacements for drywall) are an example of this option.			Y		Y	
Emergency Planning and Management	Warning System	A program or automated system that provides a warning of impending flooding (hours to days to onset). More sophisticated systems use text messaging, but can also include media coverage, sirens, etc.			Y	Y	Y	
	Evacuation and Response Planning	A program/plan for emergency response in the case of extreme flooding.			Y	Y	Y	
	Public Education	Programs to educate the public about flood hazard, vulnerability and risk as well as the provision of resources that can aid the public in making good decisions about flood-risk reduction.			Y	Y	Y	Y

			Mode of Action			Applicability for Strategy		
	Adaptation Option	**Description**	**Reduce Hazard**	**Reduce Exposure**	**Reduce Sensitivity**	**Protect**	**Adapt**	**Retreat**
	Media Education	Programs to educate the media about flood hazard, vulnerability, and risk.			Y	Y	Y	Y
	Recovery Plans (Community Resiliency)	Programs or systems that are in place ahead of a flood event that will ensure a rapid post-event recovery.			Y	Y	Y	
Economic and Insurance Options	Economic (Dis)incentives to Move Out of Floodplain	Until there is a flood, individual property owners have no incentive not to live in a floodplain. Economic (not insurance-based) options to incentivise home-buyers to buy outside the floodplain are not commonly used today, but could be implemented in future. Further, as sea levels rise and the hazard increases, the value of homes in the floodplain may decrease as awareness around the risk and impacts of flooding increase.		Y			Y	Y
	Shift Responsibility to Benefactors	At present, in Canada, where overland flood insurance is not widely available, the monetary cost of catastrophic flooding is mostly borne by the Federal Government through the Disaster Financial Assistance Arrangements (DFAA). Local residents are generally provided monetary assistance through this program, and therefore do not have direct incentive to reduce their individual risk (through moving out of the floodplain, or by implementing property-level protections). Changes to the DFAA could better re-align the responsibility and liability.		Y	Y	Y	Y	Y
	Policies and Premiums	Flood insurance is widely used around the world as a means of exposure to flooding. This functions because homeowners are provided with incentives (reduced premiums) for buying outside the floodplain or by implementing property-level-protections if they live within the floodplain. And, when a flood occurs, insurance monies can be used to partly recover losses			Y		Y	Y

This long list of options served as a basis for selecting a shortlist for a more detailed review in each zone. It is not within the scope of this strategic-level study to perform a detailed analysis of all individual potential adaption options independently or in combination. However, moving forward, the City may wish to begin gathering information on the uses, successes, and failures of these options in other contexts, in order to inform the development of zone-specific plans in future.

2.6.2 Adaptation Strategies

In this study, we considered high-order strategies for mitigating climate change on a zone scale. This was done by working with City staff and technical experts to develop a range of conceptual strategies.

The three strategies were: “Adapt”, “Protect”, and “Retreat” (conceptually illustrated in Figure 7 using icons that were used throughout the stakeholder engagement element of this work).

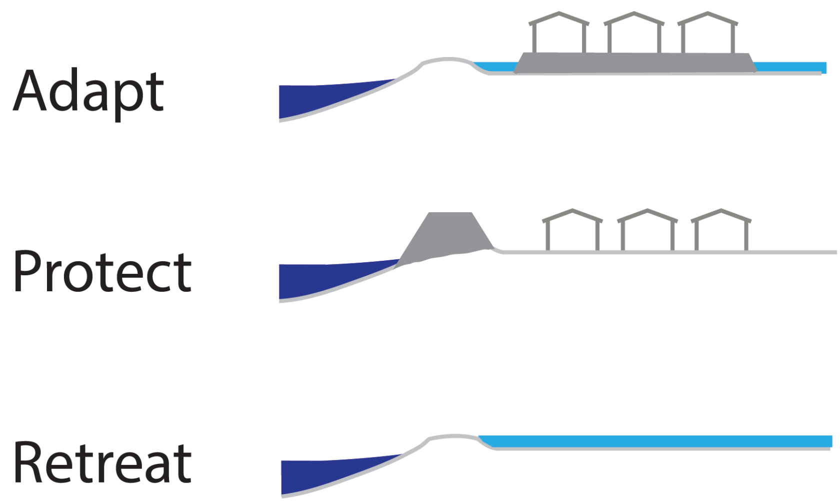


Figure 7. Three generic strategies evaluated at a zone level

<u>Adapt</u>

An Adapt strategy is one where a collection of zone-appropriate options is used to reduce the *exposure* and/or *sensitivity* of vulnerable assets to a flooding event. Typical options used in an Adapt strategy include:

- Using planning options to ensure that no new critical infrastructure is built in at-risk areas of the zone.
- Careful regulation of sub-division and density approvals in floodplains to avoid increasing the zone vulnerability in future.
- Raising the physical height of City services (roads, water, etc.) over time and taking advantage of regular planned infrastructure turnover cycles.
- Incorporating flood-resilient design adjustments to building codes, and using options and incentives to help residents and businesses improve property-level protection.
- Developing and implementing flood monitoring and warning systems.

<u>Protect</u>

A Protect strategy examines the consequences of applying particular options (usually dikes or berms) to reduce the *hazard* by preventing water from accessing valued elements in zones. In some zones, more than one specific protection option was examined where it was thought that the trade-offs involved would be different for each (e.g., two different dike configurations).

<u>Retreat</u>

A Retreat strategy is often considered a special form of exposure-reducing strategy in which vulnerable assets are actively moved away from particular areas over time. While not applicable in all zones, in others it may be viable to encourage the movement of vulnerable assets out of flood-prone areas. This might involve opportunistic buyouts as homes and businesses come up for sale over the next 40–60 years, with more aggressive buyouts 60–90 years from now; opportunistic removal of roads, other infrastructure, and contaminants as land is vacated; and aggressive re-naturalization around 2070.

We assumed that the City might provide compensation to landowners, although, as discussed earlier, the legal requirement to do this is unclear at this time.

2.6.3 Adaptation Alternatives

An adaptation alternative (or simply "alternative") is a specific way of implementing a strategy in a zone. Often there are several ways of implementing a Protect strategy in a zone, for example through the use of different dike configurations. In the case of the Adapt and Retreat strategies, alternatives typically comprise a bundle of options that would be appropriate in each specific zone.

For many of the alternatives analyzed, we focused on the big-picture impacts of certain major pieces of infrastructure or policy options, referred to in workshops as "cornerstone" options. By this, we mean the foundational method of planning, either protection, adaptation, or retreat, without elaborating on secondary options that might be added later to improve performance of the cornerstone options. For example, a basic, traditional dike might be selected to protect an area, but it may be expected to have a negative impact on accessibility or aesthetics. This basic design could later be augmented by other features (e.g., landscaping, cycle paths, or other amenities), or by adding additional adaptation options for redundancy, ultimately improving the performance of the approach. Thus, for this issue scoping exercise, we refer to the alternatives mainly in terms of certain defined cornerstone options, and we assume that the performance of these options could ultimately be improved by integrating them with additional options at another level of planning (i.e., "brick" ideas as shown in Figure 8). These "refining" options would not be limited to any strategic category, but could be added thoughtfully on a case-by-case basis. For example, having identified a particular alternative as a preferred base solution, planners might later decide to elaborate on this with architectural features, redundant options from the adapt category, etc.

The structured decision making process provides a framework for evaluating trade-offs for various designs and additions, and establishing what enhancements would provide the greatest value.

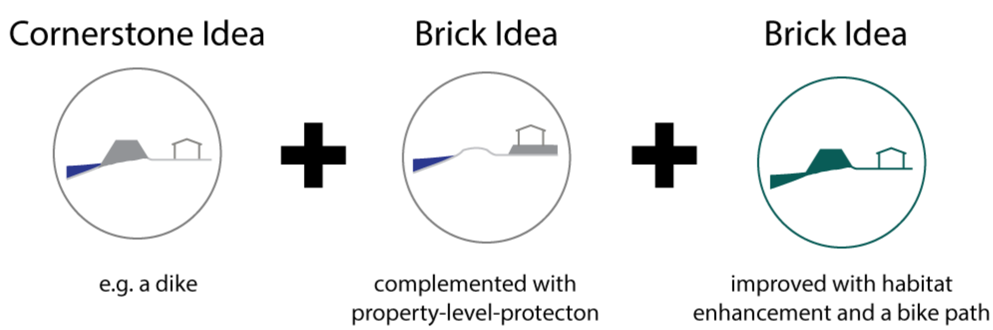


Figure 8. Development of robust alternatives

2.6.4 Degree of Specificity in Each Zone

The strategies selected for review for each zone were specified only to the degree necessary to obtain enough information to estimate the trade-offs. They are not fully developed design concepts. For protective elements such as dikes, site visits were performed to help identify and inform basic-function designs, layouts, and alignments. At this stage, no attempt was made to realistically integrate these design features into their surroundings (functionally or cosmetically). It is unlikely that the City would contemplate the construction of a traditional dike feature in a high profile area such as Jericho beach. Rather, should dike-like functionality be deemed appropriate, the City would likely invest in a fully developed, stakeholder-driven design process to reconfigure affected areas in such a way as to conserve and enhance the desirable qualities of these areas. However, for the purposes of exploring initial trade-offs of Protect versus other strategies, we assumed the use of basic dike configurations. Similarly, the Adapt and Retreat strategies were initially proposed as blanket-type strategies that would require significant refinement if they were selected as a preferred alternative.

Figure 9. City of Vancouver Board of Parks and Recreation Charette Concept Design for Jericho (Provided by: Matthew Roddis, City of Vancouver)

2.6.5 Preserving Options for the Future

Adaptation options may be implemented at various points in time depending upon flood projections and local contexts. Figure 10 conceptually illustrates how the lifecycle of certain adaptation ideas (shown as light bulbs) might progress differently over time.

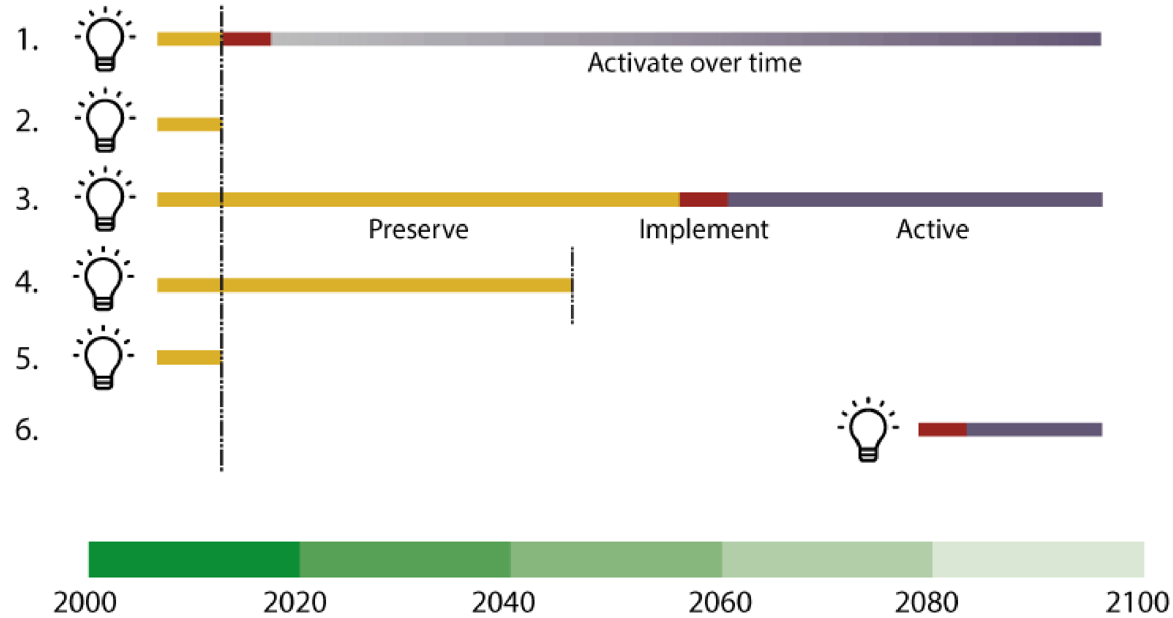


Figure 10. Preserving options for the future

Yellow lines indicate options that are available for implementation. Red lines indicate the point at which an option may be implemented. Grey lines indicate the period during which options are active.

The first five ideas (yellow) are available at the present time for consideration. After careful consideration, idea 2 and idea 5 might be considered unsuitable for whatever reason and not implemented. Idea 1 may be considered a priority to implement immediately, and after doing so, it provides benefits over time. Idea 3 is considered a good one, but not required for implementation for another 50 years; in this case, the City takes steps now to preserve the option to implement this idea in future. Idea 4 is an idea that appears to have promise now, but that promise fades in the mid-term future (i.e., tastes change, or technologies become obsolete). Finally, Idea 6 is not conceived until well into the planning horizon (perhaps because it is based on future technologies), but is implemented immediately as part of an adaptive management plan.

We discuss timing of adaptation alternatives further in Section 2.7.2 (Timing and Sequencing of Flood Protection Actions).

2.6.6 Development Process for Alternatives for Each Zone

Development of alternatives involved initial brainstorming with the project team and City staff, and the review of a toolbox of more than fifty options to identify those suitable for specific flood zones across the City (Table 2). This process resulted in a long list of options that was brought to the Adaptation Working Group workshops for review and feedback. Participants engaged in a mapping exercise to identify promising alternatives for each zone, and to develop new alternatives for further consideration. A shortlist of cornerstone adaptation alternatives was then created for each flood zone and reviewed during the External Stakeholder workshops. Some alternatives were further modified based on feedback received at these workshops.

2.7 Step 4: Estimate Consequences

Once alternatives were defined, the next step involved estimating the performance of each one across objectives using the selected performance measures. Performance was estimated using empirical data, models, or expert judgment. Consequence tables were used to facilitate comparison of the performance of each alternative. In a typical consequence table, alternatives are listed in columns and performance measures in rows, with each cell in the matrix indicating an alternative's performance on a particular measure. The performance of each alternative can then be compared against one another, facilitating the identification of key trade-offs for decision-making.

Detailed consequence tables were prepared for Scenario 3 (0.2% flood event with 1 m SLR) for False Creek and Flats, Fraser River Foreshore, Southlands, Kitsilano, and Jericho-Spanish Banks for review and discussion.

2.7.1 Methodologies for Estimating Consequences

We employed a variety of methods to evaluate the consequences of the alternatives on the performance measures. These are summarized in Table 3 below, and are detailed in Appendix E.

Table 3. Summary of estimation methodologies

Objective	Performance Measure	Dir[9]	Estimation Method Summary
PEOPLE			
People displaced — during flood events	# of people displaced	L	Quantitative assessment of affected people using Hazus methodology based on 2011 Statistics Canada census information.
People displaced — permanently	# of people displaced	L	Quantitative assessment of permanently affected people based on project footprint or on permanently wetted flood extents and 2011 Statistics Canada census information.
"At-risk" people affected	SVI-weighted displacement	L	Quantitative assessment of at-risk displacement during flood events. This is a function of People Displaced and a Social Vulnerability Index by census tract as developed by Western University.
Park and recreational amenity value	Value-weighted area affected per event	L	Quantitative assessment of the area of park affected by flood events based on GIS analysis. A qualitative assessment of the value of each flooded parcel was described to stakeholders (e.g., this is a destination park, or this is the only program space of its kind in the city).
Loss of critical services	# of pieces of infrastructure affected	L	Quantitative assessment of the number of identified pieces of critical infrastructure (hydro substations, pump stations, energy facilities, etc.) affected by a flood event.
Aesthetics	-2 to +2	H	Qualitative assessment based on basic design concepts. Multiple City staff were asked to rank options for each zone on a scale of -2 to +2, with 0 meaning no change from the baseline.
ENVIRONMENT			

[9] Dir = Preferred numerical direction; H = Higher numbers are preferred, L= Lower numbers are preferred.

Objective	Performance Measure	Dir[9]	Estimation Method Summary
Risk of contaminant release	# of sites with potential contaminants	H	Quantitative assessment of the number of businesses that might be a contamination source within the floodplain. City of Vancouver Business Licenses were assessed using GIS.
Environmental impacts	-2 to +2	H	Qualitative assessment based on basic design concepts. The project team ranked options for each zone on a scale of -2 to +2, with 0 meaning no change from the baseline.
ECONOMY			
Damage to infrastructure	Value-weighted km of roads affected	L	Quantitative assessment of length of roads within the floodplain, completed using a GIS analysis. Arterial roads were weighted more highly than zone streets or alleys.
Damage to buildings	$M	L	Quantitative assessment of the dollar cost of building damage based on Hazus modelling.
Business disruption	# of employees in affected businesses	L	Quantitative assessment of the number of employees within the floodplain. City of Vancouver Business Licenses data was analyzed using GIS.
Loss of inventory	$M	L	Quantitative assessment of the dollar value of building damage based on Hazus modelling.
Emergency response costs	$M	L	An estimated cost based on the size of the area flooded and the number of people affected. Calibration information was solicited from Canadian cities that experienced recent flood events (Edmonton, Calgary, etc.).
IMPLEMENTATION			
Capital costs	$M	L	Engineering options were costs based on Class D estimate guidelines and designs that conform to provincial seismic standards. Adaptation options were costed based on discussions with other jurisdictions that have implemented parts of the adaptation strategy. Retreat options were costed based on the assessment values of land today plus costs associated with the rehabilitation of land, using area and amount of existing infrastructure as variables.
Maintenance costs	$M	L	Maintenance costs for engineering options were calculated on a project basis. Maintenance costs for adaptation options were assumed to be a percentage of the capital costs.
Adaptability	1 to 4	H	Qualitative assessment based on basic design. Project team were ranked options for each zone on a scale of 1 to 4, where 1 is non-adaptable and 4 is highly-adaptable and reversible.
Ease of implementation	1 to 5	H	Qualitative assessment based on basic design. Multiple City staff were asked to rank options for each zone on a scale of 1 to 5, where 1 is a “no go” and 5 is easily implementable.

2.7.2 Timing and Sequencing of Flood-Protection Actions

In addition to identifying a potentially preferred alternative for a particular location, the question arises as to when is the appropriate time to take action? Compass and Ebbwater developed a spreadsheet tool that estimates, for key locations in the city, the increasing probability of floods, and expected flood depths, as the sea level rises. Additional information is available in Appendix G.

This is based on water level exceedance probability curves developed by Northwest Hydraulic Consultants (NHC) using the coastal model from Phase I. The frequency of a given ocean water elevation was defined for five locations offshore of the Vancouver coast for the baseline year of 2000. Additional curves for each successive decadal horizon year (i.e. 2010, 2020 and so on) were created by adding a 10 cm increment per decade to account for an assumed linear increase in relative sea levels from 0 m in 2000 to 1 m in 2100. The ocean levels associated with these curves were then extended inland to shoreline reaches using the same coastal zones defined in Phase 1. Ground elevations for asset locations in each zone were determined, and the probability of inundation at those elevations was interpolated from the water level exceedance probability curves for each decade. This procedure allowed for the development of probability of inundation curves for each asset location. This is a simplistic approach, but one that adds significant value. By investigating flood probability and flood depth curves for various locations across each vulnerable zone, insights were gathered as to when in the future flooding may become problematic, and when the City should consider taking action to protect these zones.

Figure 11 illustrates a probability of inundation curve for an example location. As the sea rises from its current level to a projected level of 1 m in 2100, the annual probability of inundation for a given location will increase as indicated by the curve (in dark purple). This *curve* indicates the highest probability of inundation for a location, while the shaded *area underneath* the curve indicates that inundation may also occur during lower probability but higher magnitude flood events. Dashed lines indicate when a curve corresponds to a *very rare*, *rare*, or a *common* flood event, as defined in Table 4 below. *King tide* events are indicated at the very top of each figure (occurring with 100% probability annually).

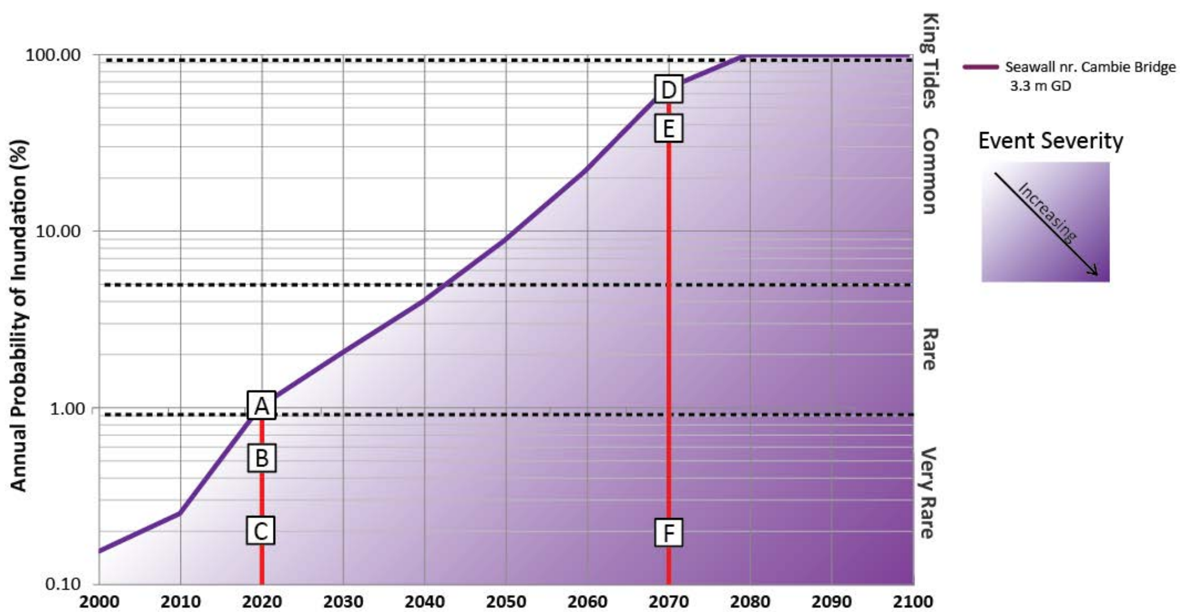


Figure 11. Example annual probability of inundation curves

The elevation for each element is based on the best estimate of the ground elevation (or first floor elevation) at the site and is shown in Geodetic Datum (GD).

In this example, the highest annual probability of this location flooding, based on sea levels in 2020, is approximately 1% (equivalent to a 1-in-100-year flood event), as indicated by point A on the curve. This point indicates that the example location will *begin* to get wet in a 1-in-100-year flood event. Point B (below the curve) indicates that flooding with a greater depth is possible for this location with a lower probability flood event (e.g., 0.3 m depth with a 0.5% probability annually), while point C indicates even deeper flooding with less frequent events. By comparison, point D indicates that this location will begin to get wet in 2070 with an annual probability of 60%, while point E indicates a 40% chance of flooding to depths of 0.3 m, and point F indicates even greater flood depths with less frequent flood events. In summary, the annual probability of inundation curves indicate that the probability of a location getting wet in a given year increases over time, while floods with greater depth may also occur, albeit with lower probability. The annual probability of inundation curves illustrated throughout the report omit the shading under the curves for clarity.

A value judgment must be made when deciding at which inundation probability the risk of flooding is unacceptably high for an area. Different assessors may have different "risk tolerances"—one may find that a 1% annual probability of a flood is an acceptable level of risk, and another may find that risk to be too high. Risk tolerances may also differ based on whether the asset at risk is parkland, or whether it is a neighbourhood of homes or businesses. Ultimately, decision makers will have to decide what their risk tolerance is and identify suitable thresholds for action for locations across the city. These probability of inundation curves (and the associated Excel tool described above) provide an excellent tool for supporting decision makers in selecting the appropriate timing for adaptation actions. Once a risk threshold is defined for a zone, decision makers can look across the chart to identify when action is required to protect various assets.

For each zone investigated, we analyzed flood-probability curves to understand how these probabilities increase over time for key locations, and provide guidance on when actions by the City may be triggered. These actions may include convening a working group to further study flood risks and adaptation options, if the threat of flooding is further in the future, or to take urgent action to protect an area, if flood risks are high and significant flooding could occur in the near term.

Each annual probability of inundation curve includes 0.6 m of freeboard in the estimation model, making them a relatively conservative estimate for timing when assuming 1 m of SLR by 2100. These curves should not be taken as precise estimates of flood risks, but rather are designed to provide some indication of when flooding may be expected in each zone. This uncertainty should be taken into consideration when assessing risk tolerance and making decisions.

2.8 Step 5: Evaluate Trade-Offs

This step involves comparing the performance of alternatives across objectives and performance measures to understand how they perform relative to each other, and to identify key trade-offs to be considered when selecting an alternative. It is also an opportunity to review and refine objectives and performance measures, and to iteratively improve alternatives and develop new hybrid alternatives designed to take the best aspects of existing alternatives to improve performance.

Workshops with the External Stakeholder Group involved a detailed evaluation of flood implications and adaptation alternatives for False Creek and Flats, Fraser River Foreshore, Southlands, Kitsilano, and Jericho-Spanish Banks. The workshops began with an overview of the flood extent under three scenarios:

- *Very rare* events (0.2% flood) at today's sea level (0 m SLR in 2013).
- Flooding at high tide (HHWLT) with 1 m SLR in 2100.
- *Very rare* events (0.2% flood) with 1 m SLR in 2100.

The suite of available adaptation alternatives was then presented, flood-extent maps for each zone were shown for each flood scenario, and the key assets in the floodplain protected by the adaptation alternatives (e.g., dikes, sea barriers, seawalls) were reviewed.

Participants were given time in small breakout groups to review the flood-extent maps, and to discuss the pros, cons, and key questions for each alternative, taking into consideration implications for people, environment, economy, and implementation. Each group reported back to the larger group on their discussions. Once all alternatives were discussed, a consequence table was presented, with each alternative scored across a detailed set of performance measures. Participants were able to review the performance of each alternative in relation to one another and against a baseline (with no additional adaptation action taken). Key trade-offs were discussed, and uncertainties and key questions for further investigation were also identified at this stage. More detailed results from the stakeholder workshops are presented in Appendix C.

A number of zones received only a high-level assessment, which included a presentation of flood extents and assets at risk, and discussion on potential adaptation options and strategies. These zones include Brighton Beach, Coal Harbour, Point Grey Road, Stanley Park, Waterfront, and Port Lands. These zones received a basic level of analysis and consultation either because the zone is much less complex in terms of adaptation options to consider and did not necessitate a full analysis of consequences and trade-offs, the projected flood extents do not pose an urgent threat, or additional stakeholder groups will have to be engaged (i.e., Port Lands). Consequence tables were not developed for these zones, and trade-offs between potential alternatives were not discussed in detail at the time. Details on these zones are included in the Outcomes section below.

3 Outcomes

This section provides a summary of findings and stakeholder feedback based on a zone-by-zone analysis, as well as a review of city-wide implications and priorities. An analysis aimed at identifying optimal timing and sequencing for implementing actions across the city is also provided.

3.1 Definitions Used in this Discussion

To minimize the use of numbers and generally to enhance readability, the following definitions are used when describing the frequency and magnitude of different flood events[10]:

Table 4. Frequency terms used to describe flood events

King tide	An infrequent, but predictable high-tide event without exacerbation from an accompanying storm. This would occur on average two to three times a year (100% chance of occurring in any given year).
Common flood event	High water levels associated with a combination of tide and additional storm components that has a 5% to 99% chance of occurring in any given year.

[10] The descriptors outlined in Table 4 and used throughout this report have been defined specifically for this project. No international standard descriptors are available.

Rare flood event	High water levels associated with a combination of tide and additional storm components that has a 1% to 5% chance of occurring in any given year.
Very rare flood event	High water levels associated with a combination of tide and additional storm components that has a <1% chance of occurring in any given year. The City of Vancouver flood construction level (FCL) is currently set to the 0.2% event with 1 m of sea level rise. This would be considered a *very rare* flood both in the present day and in 2100.

The flood hazard for the City of Vancouver is predominantly coastal, and therefore the duration of flooding will be relatively short. Storm events that produce surges and waves will increase water levels for between 1 and 3 days, however over this period waters will ebb and flow with the tides. Duration is therefore not a big concern for damage in Vancouver.

However, coastal flood events mean that flood waters will be saline, which can increase damages as compared to clear-water floods. Furthermore, coastal floods often have great energy from waves for example. This energy can translate into additional damages on top of those that would be seen in a river flood. Only some zones of the city are particularly prone to wave damages (Kitsilano and parts of Jericho-Spanish Banks). Further details on this are available in the Phase I report.

3.2 Uncertainty — Important Reminders

Our analysis is subject to compounding uncertainties from a range of sources. It is important to understand the assumptions that are required to enable a discussion about impacts that may arise over the next 100 years or so. For the most part, uncertainties affect the *timing of when effects might first be felt*; there is less uncertainty about the sequence of which locations might first be affected by sea level rise, since this is to a large degree determined by a coastal location's elevation.

Key uncertainties include:

- **Selection of the base climate-change scenario**—this analysis assumes sea levels will rise from year 2000 levels by 1 m by 2100 based on current provincial guidelines, (see Phase I report[11] for further details). The degree of uncertainty in the selection of this scenario is high, but it is the best estimate available at the time of writing this report.
- **Assets at risk over time**—as discussed in the Approach section (Section 2), it is impossible to meaningfully predict what assets will be at risk in Vancouver over the coming century any more than an analyst in 1915 could have predicted the current form of the city. Further, approaches to climate risk reduction actually taken by the City will change the array of assets that would be at risk in the future, creating a circular logic (e.g., a decision by the City to protect False Creek and Flats with a barrier in 2050 would affect what assets are built and at risk in the zone by 2100). All that is possible at this time is to examine what assets currently exist.

For decision makers, understanding the timing of likely effects is key to crafting an overall climate-change adaptation strategy. For this reason, we are presenting our current best estimates on timing, but these estimates should be carefully reviewed and monitored over time (see Adaptive Management in Section 4). We emphasize situations that we think require attention in the near term, either in terms of

[11] Phase I report available at: http://vancouver.ca/files/cov/CFRA-Phase-1-Final_Report.pdf

immediate actions (e.g., see the discussion below about the Fraser River Foreshore zone in Section 3.3.2), or that may benefit from immediate steps to preserve options for actions in the future (e.g., to retain or acquire land rights for engineered barriers, as described in the False Creek and Flats Section 3.3.1 below).

3.2.1 Freeboard Assumption

A freeboard is a safety factor used by hydraulic engineers and water managers to account for uncertainties in the calculation of water levels and to account for localised increases in water levels. In line with convention in BC, the flood mapping used here includes a 0.6 m freeboard.

However, while a freeboard assumption is helpful in ensuring that possible problems are not missed, it also potentially confuses matters when the management goal is to optimize the timing of interventions. A 0.6 m freeboard brings forward the actual expected timing of flooding impacts to a particular location by several decades. There is a concern that being overly conservative in estimating when locations might experience coastal flooding could result in costly infrastructure expenditures that may later prove to have been better deferred. However, the flood timing-probability curves presented here do include a freeboard assumption as per best practice and engineering standards. This methodology could be changed once the City has a greater understanding of its risk tolerance (see section 2.7.2).

3.3 Zone-by-Zone Analysis: Detailed Assessment Zones

This section provides a summary of flood extents, key assets affected, alternatives considered including the flood protection provided by each alternative, a comparison of consequences and key trade-offs across alternatives, and stakeholder feedback for each zone across the city.

3.3.1 False Creek and Flats

3.3.1.1 Zone Summary

This zone consists of coastal areas east of Burrard Bridge, including the False Creek Flats that extend east from Science World into Strathcona. Today, False Creek and Flats is a significant area of the city, with many key infrastructure assets including Pacific Central Station, Main Street-Science World SkyTrain Station, BC Place, Rogers Arena, and rail yards, among others. The City itself has many assets in this zone, including community centres, the National Works Yard, and the VPD Tactical Training Center. Commercial, residential, and industrial buildings are currently located within the designated floodplain, with further development expected in the near future (including the proposed new St. Paul's Hospital).

Key assets in zone:

- Proposed new St. Paul's Hospital
- Granville Island
- Pacific Central Station
- BC Hydro's Murrin Substation
- City of Vancouver public works yard
- Main Street-Science World SkyTrain Station
- Science World
- Olympic Village
- Rail yards
- BC Place and Rogers Arena
- Neighbourhood Energy Utility (NEU)

3.3.1.2 Flood Extents and Assets Affected

For the most part, False Creek is not expected to experience flooding in the present day. The major exceptions to this are Granville Island, Hinge Park (just west of the Olympic Village), and low sections of the seawall in North East False Creek, which would currently be flooded during a *very rare* flood event. As we look to the future and take account of anticipated sea level rise, the flood extents, depths, and therefore, effects become greater. By mid-century, lower-lying areas on Granville Island and parts of the Olympic Village will be commonly flooded. A major tipping point is experienced towards the end of the century—around the year 2070—when the False Creek Flats are vulnerable to flooding (without any adaptation or protection measures) during *very rare* flood events (e.g., a 0.2% flood event). By then, even during calm periods, the western portion of Granville Island and lower-lying parts of the Olympic Village will be regularly under water at extreme tides. By the end of the century, a *very rare* flood event would result in 2.5 km^2 of the city being flooded. Many critical assets that service the surrounding zones lie within the floodplain and would be significantly affected (see text box and Figure 12).

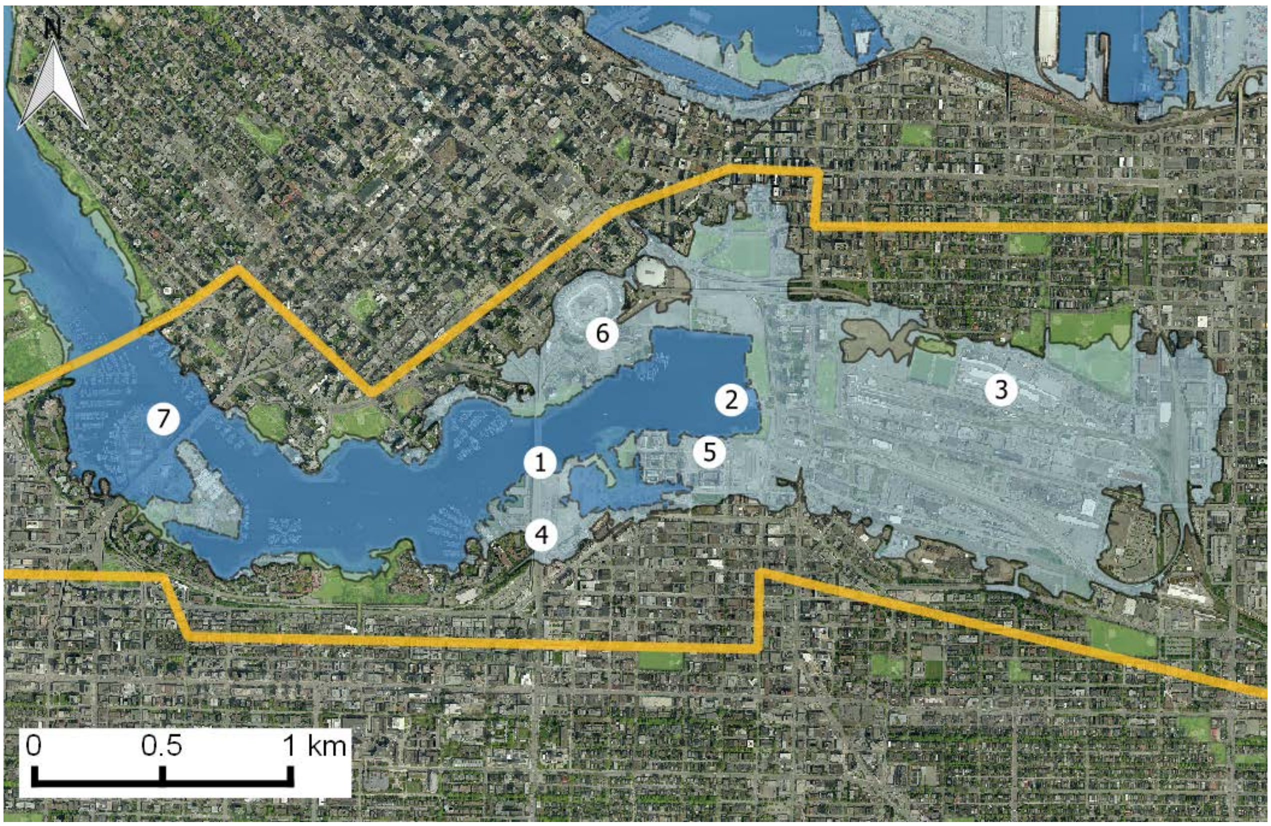


Figure 12. Flood-extent map of False Creek and Flats

Flood extent (with freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue (these scenarios have a similar flood extent), and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. Zone is defined by yellow lines. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.3.1.3 Flood Probability, Magnitude, and Timing

Flood probability curves for a range of representative locations in False Creek and Flats (east of Cambie Street Bridge, with freeboard) are shown in Figure 13. The curves provide some insight into when in future the probability of flooding major city assets might be considered too high, thereby requiring some form of adaptation. For example, the curves below (along with the mapping provided above in Figure 12) show that low spots in the seawall are at low risk of flooding today, but will be flooded in common events by 2050 and annually with king tides by 2080. The ground floor of Creekside Community Centre is not at risk today, but by 2060 would be flooded in a *very rare* event, and by the end of the century would be wet even under *common* flood events. This insight into the timing and probability of events, along with the consequences of each of these assets getting wet, helps define priorities and timing for adaptation interventions.

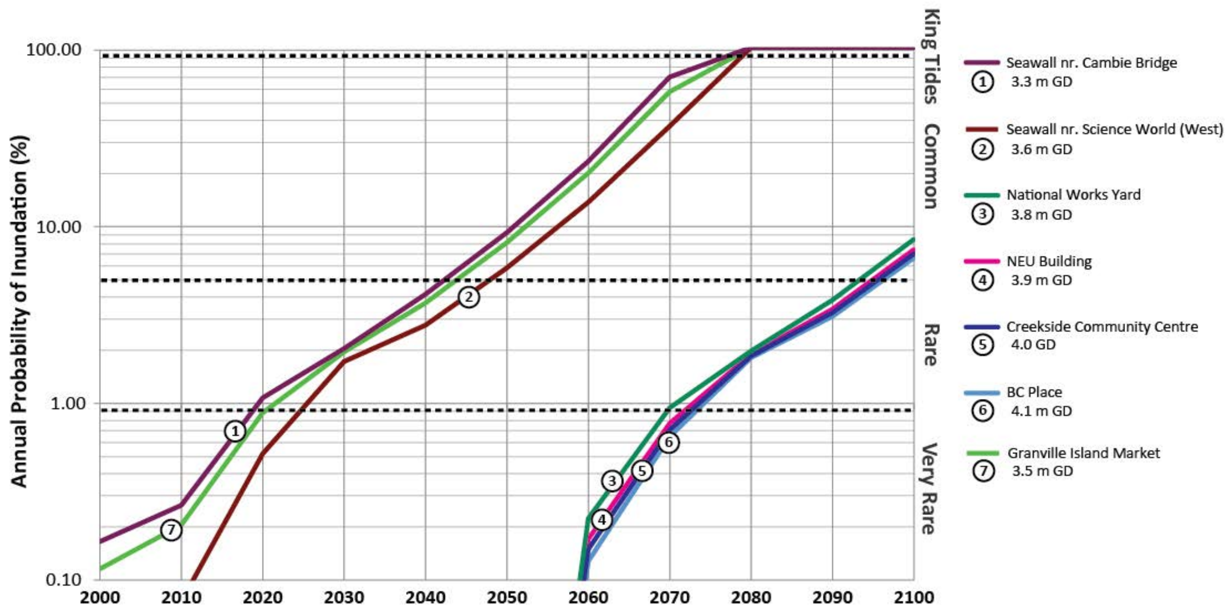


Figure 13. Annual probability of inundation for representative locations in False Creek and Flats (east of Cambie Street Bridge)

3.3.1.4 Alternatives Considered

As discussed in the Approach section (Section 2) above, a wide variety of alternative ways of minimizing damage to False Creek and Flats assets over time were considered. Given the current and likely future value and strategic importance of this area, retreat approaches were quickly ruled out. Shortlisted alternatives for False Creek and Flats are as follows:

Strategy	Alternative	Key features
Protect	Sea barrier	A sea barrier in the area of Burrard Bridge.
	Raised seawall	Raising the False Creek seawall to the flood construction level of 4.6 m GD.
	Partial dike	Raising existing sidewalks and cycle lanes along the west side of Quebec Street from E 1st Avenue to Pacific Boulevard.
Adapt	Adapt with multiple tools	Infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding.

Protect with sea barrier

The alternative involves constructing a sea barrier at the mouth of False Creek to prevent coastal flooding from causing damage to the significant number of assets in False Creek and Flats. It would be open during normal conditions and closed in storm-surge/high-tide conditions. Sea barriers are usually applied at narrow tidal inlets where the length of the structure is not required to be great, and where defenses behind the barrier (e.g., seawall) can be reduced in height or length. In the case of False Creek, a barrier approximately 10 m high and 360 m long would be required. If it were to be in place today, it would be activated three to four times a year to reduce impacts to the storm sewer system on Granville Island at high tides, and during storms to protect Granville Island, Hinge Park, and low-lying portions of the seawall. The gate would be closed more and more frequently through the century as sea level rises. A sea barrier at the mouth of False Creek would provide protection against *common*, *rare*, and *very rare* events at both current and projected sea levels (1 m SLR in 2100) for all assets and values in the False Creek area (see Figure 13).

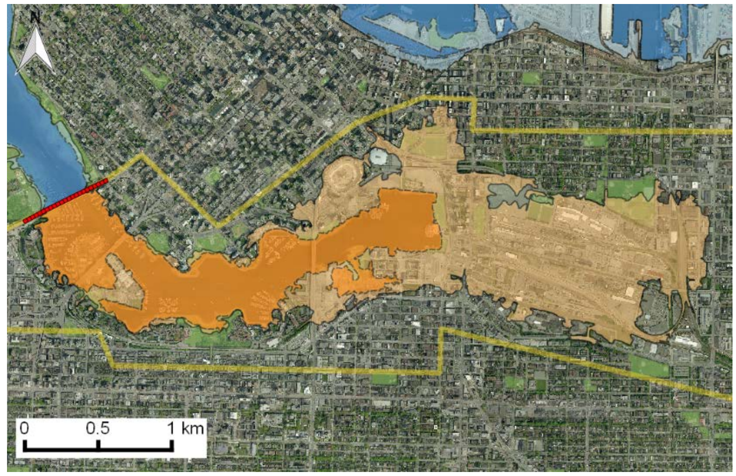


Figure 14. Flood protection for False Creek and Flats provided by a sea barrier

Location of the sea barrier is indicated in red, protected floodplain is indicated in orange.

Figure 15: Rendering of proposed Newtown Creek storm surge barrier in New York City[12]

As part of the SDM process, stakeholders provided their views on the sea barrier option for False Creek and Flats. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

[12] http://www.nycedc.com/project/gowanus-canal-newtown-creek-study

Pros	Cons
• Prevents the displacement of many people during an event. • Prevents building damage and inventory losses. • Technically straightforward to implement, False Creek geometry is ideal for a barrier. • Fairly limited impact to existing public realm and views. • Could be enhanced with a bike and pedestrian path on top.	• Requires additional measures for redundancy. • Flexibility/adaptability is limited. • Moving parts mean more maintenance and greater potential for failure. • Impacts on boaters, aquatic habitat, and water quality in False Creek. • High capital, operation, and maintenance costs. • Unclear whose jurisdiction this would fall under.

<u>Protect with raised seawall</u>

This alternative involves raising the seawall to the flood construction level of 4.6 m GD along the length of the False Creek edge, encompassing the entire seawall east of Burrard Bridge with a total length of 8.6 km. On average, the seawall would have to be raised by 2.3 m above the existing grade, and some sections would require raising up as much as 6.3 m where the existing path is very low. The types of treatment to increase the elevation would vary along the length of the path. In some locations, there are currently large areas of public space where the raising of the seawall could be integrated into the existing landscape. However, in other areas, the existing seawall abuts directly on structures, therefore requiring a more engineered solution using concrete walls or other harder edges. No detailed or scoping-level design was completed as part of this project.

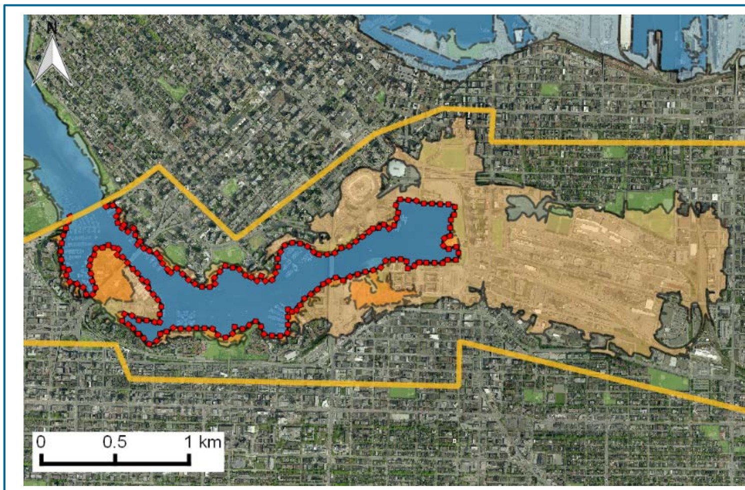


Figure 16. Flood protection for False Creek and Flats provided by a raised seawall

Location of the raised seawall is indicated in red, protected floodplain is indicated in orange.

Much like the sea barrier, a raised seawall designed to the level noted above would provide protection for all assets and values in the False Creek and Flats zone from *common*, *rare*, and *very rare* events at both current and projected sea levels (1 m SLR in 2100) (see Figure 15).

As part of the SDM process, stakeholders provided their views on the raised seawall alternative for False Creek and Flats. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• Prevents the displacement of 4000 people during a *very rare* flood event. • Prevents building damage and inventory losses. • Gradual implementation with development and asset renewal. • Opportunity to improve habitat along shoreline, improve public realm. • No moving parts, more reliable protection.	• Space constraints for upgrades. • Public realm and view impacts. • Implementation and phase-in challenges. • Accessibility challenges. • Potential drainage issues. • Limited flexibility/adaptability over long term.

<u>Protect with partial dike</u>

This alternative involves raising existing sidewalks and cycle lanes along the west side of Quebec Street from E 1st Avenue to Pacific Boulevard. The height of raising ranges from 0.3 m to 0.7 m. It is expected that most of the length will involve retaining walls and guardrails. A partial dike at Quebec Street (see Figure 16) would protect assets and values east of Quebec Street, including the False Creek Flats area, but areas west of the barrier would be subject to flooding. Flood projections do not indicate a potential for flooding east of Quebec Street at current sea levels, but a partial dike would protect against future *common*, *rare*, and *very rare* events.

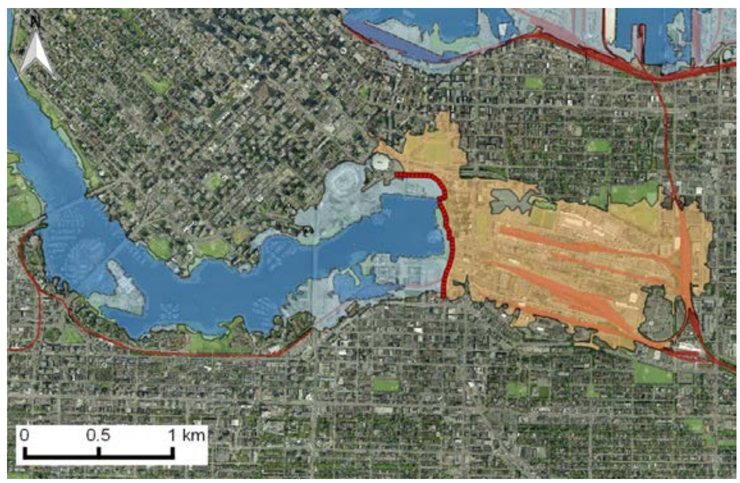


Figure 17. Flood protection provided by a partial dike with alignment near Quebec Street

Location of the dike is indicated in red, protected floodplain is in orange.

As part of the SDM process, stakeholders provided their views on the partial dike alternative for False Creek and Flats. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• Prevents displacement of hundreds of people and effects on employees for *rare* events. • Protects various pieces of critical infrastructure, numerous sites with potential contaminants, and a number of public works. • Relatively easy to implement. • Could be enhanced with other options for additional protection.	• Not a complete solution—only protects Flats. • Not effective in short term—flooding not expected in Flats for several decades. • Potential drainage issues. • Aesthetics. • Equity issue—protects some, but not others.

Adapt

This alternative is based on the idea that coastal communities can accommodate occasional inundation. In this strategy, infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding. This alternative can include a broad base of educational, planning, and building options; more detailed information and examples are provided in Appendix D. Specific options in the alternative used in this study included:

- Bylaws requiring no new critical infrastructure in floodplain.
- Raising of city services (roads, water utilities, etc.) over time.
- Flood-resilient design adjustments to building code, along with the development of options and incentives to help residents and businesses improve property-level protection.
- Education of property owners on individual structural responses for flood-proofing (flood gates, flood barriers, stop-valves, etc.). This strategy also includes incentive programs, for instance, to encourage individuals to flood-proof their homes.
- The development and continued support for a warning system that will warn residents and business owners of impending high ocean levels, allowing them to minimize damage at an individual property level.

This alternative provides more distributed protection from flooding, as it will increase flood-resiliency in areas where the policies are adopted and when buildings are rebuilt or renovated. This alternative can be implemented quickly and will slowly improve flood-resiliency over time. Depending on which components are adopted by individual building parcels, flood protection will be realized for *common* and *rare* events today, and with 1 m of sea level rise.

As part of the SDM process, stakeholders provided their views on the Adapt alternative for False Creek and Flats. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• Effective as complementary measures along with other options. • Reduces residential risks in event of failure of primary adaptation option. • Promotes recovery after an event. • Improves drainage issues.	• Aesthetics, especially when neighbouring sites are at different elevations or have different treatments of the streetscape. • Implementation challenges. • Equity issues—new and renovated buildings adopt FCLs, but not older buildings. • FCLs do not protect infrastructure, parks, and heritage buildings.

3.3.1.5 Summary of Key Trade-offs Between Alternatives

Figure 18 shows a simplified summary of the trade-offs between the alternatives for False Creek and Flats (full consequence table available in Appendix F). The top half of the table summarizes the differences in anticipated impacts associated with a 0.2% flood event, as well as *king tides* and more *common* flood events, in 2100. The bottom half of the table compares some other key implications associated with implementing a flood-management action (or in the case of the baseline scenario, taking no action). To help clarify communication of the trade-offs, relatively strong-performing alternatives for any given row are shaded blue, and relatively worse-performing alternatives are shaded orange, with deeper colours indicating a bigger impact.

False Creek

		Baseline	Sea Barrier	Raised Seawall	Partial Dike	Adapt
Flood protection (PER EVENT)						
Impacts of a 0.2% flood event in 2100	Economic	\$76M in damages \$76M in lost inventory \$3M in emergency response	Full protection	Full protection	100% of baseline losses	70% of baseline losses
	Social	4000 people displaced	Full protection	Full protection	95% of baseline	70% of baseline
	Parks	0.3 km^2	Full protection	Full protection	50% of baseline	As baseline
	Sites with possible contaminants	No protection	Full protection	Full protection	Partial protection	Sites would need to be cleaned
Impacts of King Tides and common flood events		Gradual periodic inundation of low-lying areas, accelerating after 2050-2070	Full protection	Full protection	Full Protection of Flats No protection for other areas	
Implications of the Management Action (or Inaction)						
Direct implementation costs		None	\$500 - \$850 M	\$200 - \$300 M	\$10 M	\$338 M
People permanently displaced		>1000 people forced out by SLR	None	None	>1000 people forced out by SLR	>250 people forced out by SLR
Loss of land opportunity by 2100		2.6 km^2	None	None	0.9 km^2	N/A
Aesthetics		None	Likely negative relative to today	Likely negative relative to today	Likely negative relative to today	Possibly low impact
Environmental		None	Potential to impede water movement	None	None	None
Adaptability (Ability to change direction later)		High	Low	Potential to implement in stages	Potential to implement in stages	Potential to implement in stages

Legend
Worst impacts
Neutral
Best impacts

Figure 18. Summary consequence table for False Creek and Flats

From the top half of the table we can see the baseline condition (no further actions to reduce flood impacts) would likely suffer a range of damage to economic, social, and environmental assets per flood event. The sea barrier and raised seawall alternatives, designed appropriately, should provide full protection from these impacts for the entire zone. The partial dike option alone would provide little or no protection to economic and social assets relative to baseline, but could protect two-thirds of current parkland. We estimate that the Adapt alternative could be somewhat effective in protecting economic and social asset losses, but relatively ineffective at protecting parks and sites with potential contaminants as they currently exist (though at-risk parks could be made less vulnerable to saltwater incursions perhaps through the use of saltwater-tolerant plants, for example, and sites with contaminants could be remediated or protected).

Outside of periods when flood events are experienced (the bottom half of the table), the baseline condition would see some displacement of people as the result of sea level rise, but would otherwise be preferred. The sea barrier and raised seawall would prevent these displacements of people, but both come with significant downsides. Both would require considerable capital outlay (further engineering design work is required to estimate these costs more accurately), and would be controversial from an aesthetic perspective. A raised seawall would negatively affect access to the water and views for many residents. It would face significant challenges in terms of space constraints and equity concerns (e.g., which sections of seawall should be raised first?). A sea barrier would offer fewer challenges in this respect, but would have its own issues: it may have associated environmental concerns if it impedes flow movement in False Creek. Further, a barrier is inherently less adaptable—typically an all-or-nothing solution that has limited adaptive capacity over time. A seawall could, in theory, be incrementally increased in height over time.

The partial dike and Adapt alternatives mitigate some of the baseline impacts only marginally, and may still have high associated capital costs, although they would both be good complementary alternatives to the engineered structures.

When a preferred solution is selected (see below for discussion of timing), further iterations of these alternatives could improve their performance. For example, the basic sea barrier alternative scores poorly on aesthetics and environmental measures, but this could be improved through good design (perhaps at a higher dollar cost).

3.3.1.6 Summary of Trade-off Evaluation Discussions

Stakeholders and City staff reiterated the view that False Creek and Flats is an asset-dense zone that should be protected. Initial discussions appeared to indicate a general preference for undertaking further investigation into, primarily, a sea barrier and, secondarily, a raised seawall. Participants expressed interest in the use of the partial dike option as a possible secondary backup to a sea barrier approach.

Participants in general thought that while planning options and adaptive measures could provide complementary flood protection and reduce the risk of flooding should a primary protection measure fail, these are not appropriate as complete primary protection measures in themselves. A sea barrier or raised seawall could serve as a first line of defence, with a partial dike and/or other adaptation options added as redundant protection measures.

3.3.1.7 Conclusions and Recommendations

The False Creek and Flats zone contains a large number of important locations and infrastructure assets that are potentially at risk from sea level rise, as well as a large residential population, and protecting these assets is both important and feasible, though with a high capital outlay. That said, although a small proportion of False Creek, particularly Granville Island, may be subject to flooding during *very rare* to *rare* events over the coming few decades, urgent engineering action to protect False Creek and Flats does not appear to be justified at the present time. Simply, with regards to the large engineering responses (a sea barrier, a continuous raised seawall), there is no urgency to make a decision today. It makes sense to wait several decades before re-evaluating—at that point, the City will have much more certainty in the flood risk, through better climate and sea level rise estimates, as well as a better understanding of the city development and vulnerabilities. However, these strategies need to be preserved, in that we should not take away the option of building a barrier, a seawall, or a partial dike by allowing development on the potential future footprints. There is, however, a need to address some issues in the False Creek and Flats zone in the short term.

Based on discussions with invited external stakeholders and City staff, specific recommendations that meet the overall objective of preserving options and of reducing short-term flood risk for this zone include:

Short-Term (to 2020) Recommendations for False Creek and Flats

1. Granville Island has been identified as a key economic centre that is at risk today, and in fact is already subject to minor flooding (through the storm-sewer network) in the winter at *king tides*. The Island is currently owned and operated by CMHC, but it is a significant tourist destination and economic centre for the City of Vancouver. In the short term, we recommend that the City continue to share all available information with CMHC to make them aware of the present-day and future flood hazards. Granville Island will require management action in a shorter term than the rest of False Creek**,** and we recommend that Granville Island (CMHC) begin exploring a stand-alone project in the short term.
2. Both the sea barrier and the raised seawall were seen as viable alternatives, however, for this project, both were assessed based on basic design assumptions. Therefore, we recommend that the City conduct a feasibility study and generate more refined cost estimates for a sea barrier and raised seawall including:
    - Identifying upgradable and adaptable designs.
    - Scoping-level design of sea barrier options and costs.
    - Scoping-level design of seawall raising options and costs, including sections and elevations of five or six different typologies that could be used.

   The purpose of this study would be first to establish if either of these approaches is not technically feasible, and second to ensure that, if they are feasible, planning and development decisions are made to ensure that these alternatives are preserved for the future.
3. Although not identified as a preferred standalone alternative, some value was seen by stakeholders in the strategy of a partial dike at the eastern edge of False Creek. This should not be considered a priority; however, given the planned redevelopment in this area, there may be an opportunity to have a dike constructed by developers as a community amenity.
4. The City should continue to employ and enforce the amended the Flood Plain Standards and Requirements.
5. The City should avoid placing any additional critical infrastructure in the floodplain.
6. Any public infrastructure or assets built on the floodplain should be designed in a flood-resilient manner. Ideally, any new City buildings should be built as models to showcase resilient and innovative design.
7. Ongoing planning processes for projects in the area including the False Creek Flats and Northeast False Creek should continue to be kept abreast of the outcomes of this study. This will enable the City's ability to preserve options into the future. All of the four alternatives presented above were deemed viable given what we understand of our present-day flood risk and our assumptions about our future flood risk. These planning studies should ensure that the alternatives are preserved by maintaining right-of-ways along the seawall (with accommodation for the widening that may be required to allow for the raising of the pathway) and acquisition of additional rights-of-way along the proposed partial-dike alignment.
8. Similar to the previous recommendation, given that stakeholders we spoke to preferred the sea barrier option, we recommend that the opportunity to build this type of structure be preserved. Specifically, the potential footprint of the structure on either side of False Creek should be maintained in public hands, and if the Aquatic Centre site is redeveloped in the next few decades, it should be designed to accommodate a future sea barrier.

Medium-Term Recommendations (to 2050) for False Creek and Flats

9. Updated information for False Creek and Flats should be evaluated within the context of an Adaptive Management plan as outlined in Section 4.
10. Given the high capital requirements of the Protect strategies, financial planning for the design and implementation of a sea barrier or raised seawall should be conducted.

3.3.2 Fraser River Foreshore

3.3.2.1 Zone Summary

Key assets in zone:

- Rail corridor
- FortisBC (formerly Terasen) gas facility
- BC Hydro substation
- Manitoba Works Yard
- Translink bus yard
- Several multi-family dwellings
- Industrial lands and businesses

The Fraser River Foreshore zone lies at the southern edge of the city along the northern banks of the Fraser River. It extends east to the Burnaby border and west to the edge of Fraser River Park. Hydraulically, this zone is different than the zones that border Burrard Inlet; it lies along a river and is subjected to riverine forces, for example, high velocities parallel to the riverbank. It isn't, however, subjected to the coastal waves that would be seen in other areas as it is relatively sheltered. In addition to being at risk of flooding during winter storms from tides and surge that push back up the river, this zone is at a small risk of spring freshet flooding when the Fraser River swells. Freshet flooding and its impacts have not been specifically addressed in this report, however, the adaptation alternatives presented and discussed would reduce both types of flood hazard.

This zone has two distinct areas (and was in fact initially studied as two zones; these were amalgamated when the adaptation solutions required a single response for both areas in order to work). The eastern portion of the zone is characterised by newer multi-family residences and some newer amenities, such as a seawall and restaurant. There are also two City parks. A rail corridor runs parallel to the river through the residential district and through to the more industrial portion of the zone. The western portion of the zone is a largely industrial area with many businesses that historically used the Fraser River for boat access and the rail corridor for land transportation. It is now a diverse industrial and commercial area.

3.3.2.2 Flood Extents and Assets Affected

The Fraser River Foreshore zone is at risk of flooding today under a *king tide* or *common* flood event. Should a 0.2% (*very rare*) flood event occur today, we would expect to see 2.1 km^2 inundated to some degree, affecting 70 buildings, 380 businesses (with almost 3000 employees), and two identified sites with critical infrastructure (BC Hydro Substation, and the Manitoba Works Yard—see Figure 20.) In future, with sea level rise, the extent of flooding will not change significantly as this floodplain is constrained by topography, but the depth of flooding will be greater. Deeper water results in greater long-term damage to buildings and infrastructure.

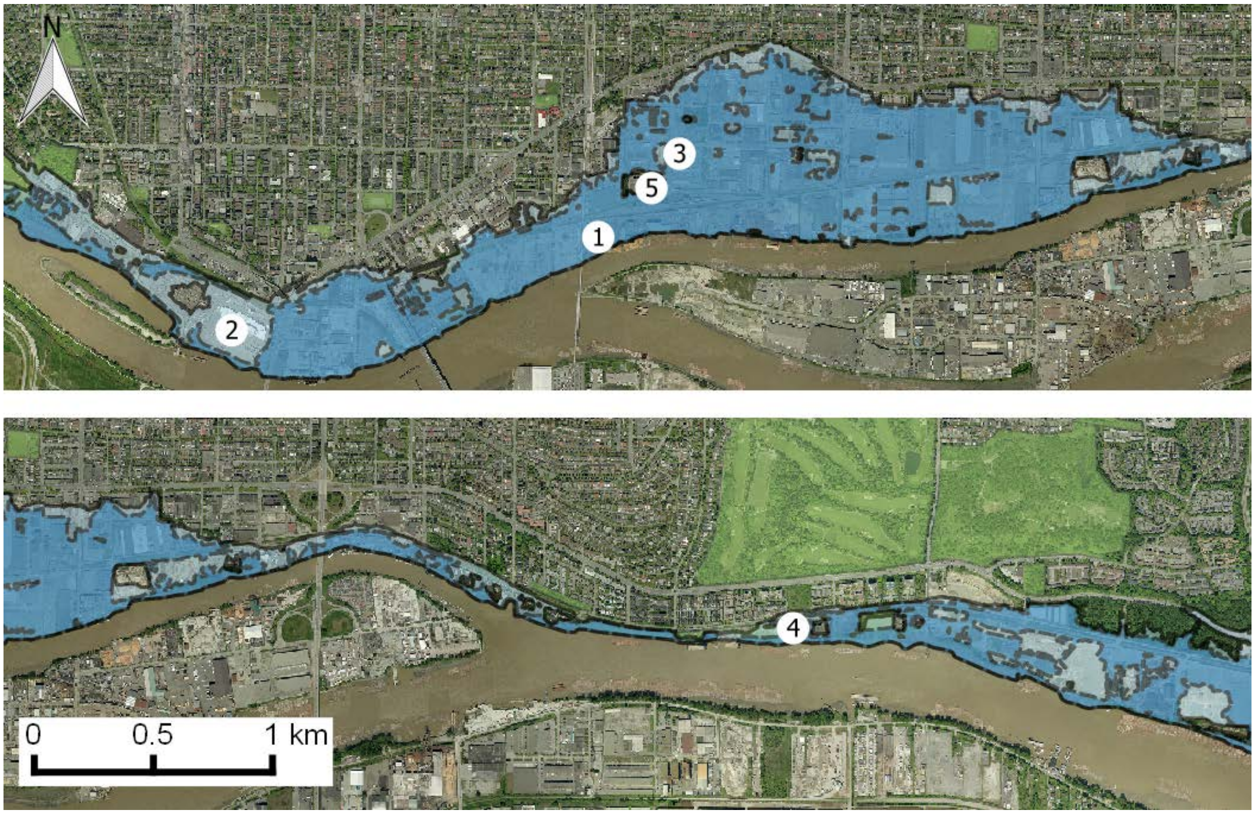


Figure 19. Flood-extent map for Fraser River Foreshore

Flood extent (with freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. The two panels are part of a continuous reach, where the top panel shows the western part of the zone, and the lower panel shows the eastern part. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.3.2.3 Flood Probability, Magnitude, and Timing

Flood probability curves (with freeboard) for a range of representative locations in the Fraser River Foreshore zone are shown in Figure 20. The curves provide some insight into when the probability of specific city assets flooding might be considered too high, thereby requiring some form of action. For example, the curves below (along with the mapping provided above in Figure 19) show two major pieces of critical infrastructure are at significant risk of flooding today - the BC Hydro Substation is at risk of flooding today under *common* events, while the City's Manitoba Works Yard is at risk under *rare* flood events. Toward the end of the century, the Vancouver Transit Centre, FortisBC Gas (formerly Terasen) site, and Vancouver South Transfer Station are at risk from *rare* to *common* flood events and will be flooded even more frequently over time. Also, in the mid- and late-century time horizons, the depth and frequency of flooding across the whole floodplain would be expected to increase, which will cause significant disruption and damage.

This insight into the timing and probability of events, along with the consequences of each of these assets getting wet helps define priorities and timing for adaptation interventions.

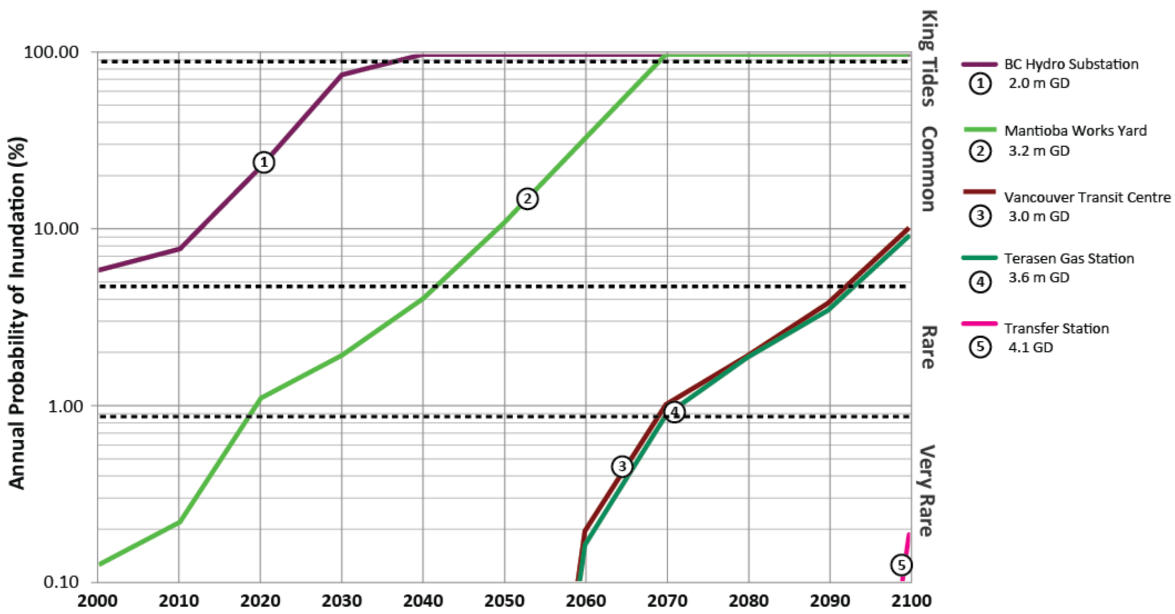


Figure 20. Annual probability of inundation for representative locations in Fraser River Foreshore

3.3.2.4 Alternatives Considered

As discussed in the Approach section (Section 2) above, a wide variety of ways of minimizing harm to Fraser River Foreshore assets over time were considered. Shortlisted alternatives for the Fraser River Foreshore zone are as follows:

Strategy	Alternative	Key features
Protect	Shoreline dike	A protective barrier (dike) predominantly along the Fraser River between Angus Road and Boundary Road.
	Inland dike	As above, in the vicinity of the Arthur Laing Bridge, the dike is moved inland to avoid impact to existing commercial and industrial facilities.
Adapt	Adaptation with multiple tools	Infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding.

Protect with shoreline dike

This alternative involves building a protective barrier (dike) predominantly along the Fraser River between Angus Road and Boundary Road (from Southlands to southeast Vancouver). Some sections of this dike, where space permits, would have a traditional dike cross-section. However, other sections of the dike, where space is an issue, would have a configuration that more closely resembles an engineered wall. Being aligned along the edge of the river would require that the dike be designed to withstand river forces, using rip-rap for example. For the purposes of this study, we assumed that the dike would be built to the current seismic standards.

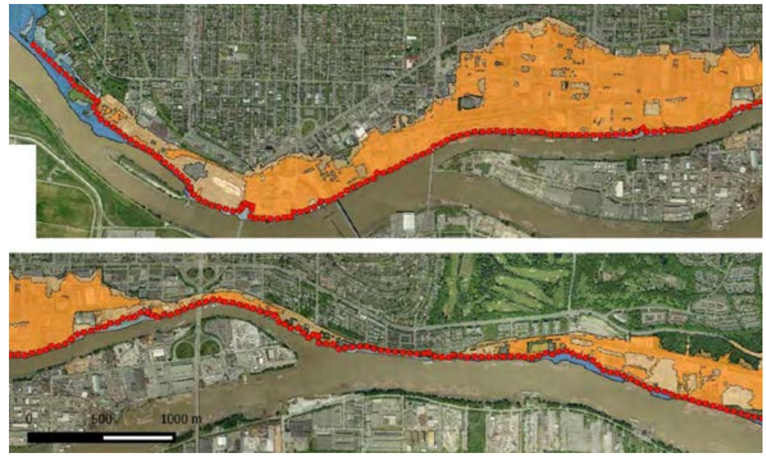


Figure 21. Flood protection for Fraser River Foreshore provided by a shoreline dike

Location of the dike is indicated in red, protected floodplain is indicated in orange.

This alignment would protect most of the floodplain from *common*, *rare*, and *very rare* flood events as soon as it is built.

As part of the SDM process, stakeholders provided their views on the shoreline dike alternative for the Fraser River Foreshore zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• Co-benefit as cycling/walking path. • Protects everything.	• City currently does not have statutory right-of-way along whole length of alignment. • Meeting seismic requirements will be difficult and costly. • This may not be technically feasible given seismic constraints. • Might impede water access for some businesses.

Protect with inland dike

This alternative involves building a protective barrier (dike) predominantly along the Fraser River between Angus Road and Boundary Road (from Southlands to South East Vancouver).

However, in the vicinity of the Arthur Laing Bridge, the dike is moved inland to avoid impact to existing commercial and industrial facilities. In addition, to capitalize on public rights-of-way, a significant portion involves raising South Kent Road. Some sections of this dike, where there is room to build it, would have a traditional dike cross-section. However, in other sections of the dike where space is an issue, engineered walls might be required. For the purposes of this study, we assumed that the dike would be built to the current seismic standards.

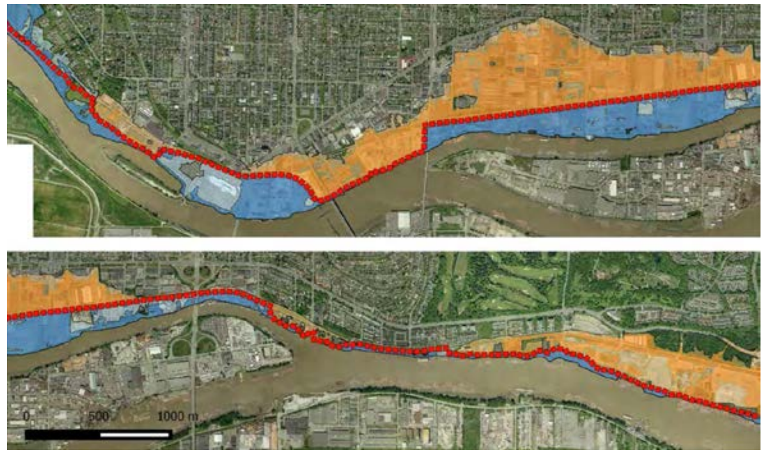


Figure 22. Flood protection for Fraser River Foreshore provided by an inland dike

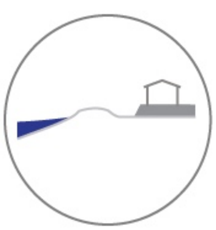
Location of the dike is indicated in red, protected floodplain is indicated in orange.

This alignment would protect part of the floodplain from *common*, *rare* and *very rare* inundation events as soon as it is built. Areas riverside of the dike would remain unprotected under all conditions and timelines.

As part of the SDM process, stakeholders provided their views on the inland dike alternative for the Fraser River Foreshore zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• City has right-of-way. • Soils assumed reasonable and therefore potentially a good alignment for a seismic dike.	• Engineering challenges tying into existing infrastructure. • Does not protect foreshore properties.

Adapt



This alternative works with the idea that coastal communities can accommodate occasional flooding. In this alternative, infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding. This alternative can include a broad base of educational, planning, and building options; more detailed information and examples are provided in Appendix D. Specific components of the alternative used in this study included:

- Bylaws requiring no new critical infrastructure in floodplain.
- Raising of city services (roads, water, etc.) over time.

- Flood-resilient design adjustments to building code along with the development of options and incentives to help residents and businesses improve property-level protection. There may be variability in the City's risk tolerance, where higher risk is deemed acceptable for older industrial areas. Variable building code requirements will be applied in keeping with the City's risk tolerance for different zoning.
- Education of property owners on individual structural responses for flood-proofing (flood gates, flood barriers, stop-valves, etc.). This strategy also includes an incentive program to encourage individuals to flood-proof their homes and businesses.
- A requirement for sub-division and density approvals in floodplains. This aims to keep the number of people at risk of flooding from increasing in the future.
- The development and continued support for a warning system that will warn residents and business owners of impending high river levels, allowing them to minimize damage at an individual property level.

This alternative provides more distributed protection from flooding, as it will increase flood resiliency in areas where the policies are adopted and buildings are turned over. It can be implemented quickly and will slowly improve flood resiliency over time. Depending on which components are adopted by individual building parcels, flood protection can be realized for *common*, *rare,* and *very rare* events today and with 1 m of sea level rise.

As part of the SDM process, stakeholders provided their views on the Adapt alternative for the Fraser River Foreshore zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	**Cons**
• Effective as complementary measures along with other options. • Promotes recovery after an event. • Will continue to allow boat and river access.	• Implementation challenges. • FCLs do not protect infrastructure, parks, and heritage buildings. • Expensive.

3.3.2.5 Summary of Key Trade-offs Between Alternatives

Figure 23 shows a simplified summary of the trade-offs between the alternatives for Fraser River Foreshore (full consequence table available in Appendix F). The top half of the table indicates that in the baseline condition the area is potentially exposed to a variety of economic, social, and environmental damages associated with flood events between now and 2100. A shoreline dike would be expected to provide full protection to all these assets. An inland dike would provide protection from the majority of economic losses and adequate protection for social and environmental assets. The Adapt alternative in this case may reduce economic losses by around 30%, relative to baseline. The majority of people displaced in the baseline condition would also be displaced by this alternative, though environmental assets would be protected.

The bottom half of the table indicates that in the baseline condition more than 1000 people may be forced to move permanently due to sea level rise alone, and one-third of a square kilometre of unprotected land would be permanently flooded (at least with *king tides*). A shoreline dike could prevent these losses and would be reasonably adaptable in terms of form and configurations over time. The most basic configuration for such dike would cost in the range of $150M. An inland dike would have a similar scale of cost, and would be similarly adaptable. The Adapt alternative could be extremely costly if the City were to buy out current landowners and restore the land to a more natural condition; however, the City's legal obligation to do this in these circumstances is unclear. Whether compensated or not, more than 800 people would need to be moved under this alternative, due to sea level rise alone.

Fraser River Foreshore

		Baseline	Shoreline Dike	Inland Dike	Adapt
Flood protection (PER EVENT)					
Impacts of a 0.2% flood event in 2100	Economic	$35M in damages $169M in lost inventory $1.6M in emergency response	Full protection	40% of baseline losses	70% of baseline losses
	Social	>2300 people displaced	Full protection	Full protection	>600 people displaced
	Sites with possible contaminants	No protection of large # of sites with contaminants	Full protection	Some sites with contaminants protected	Sites would need to be cleaned
	Parks	0.6 km^2 inundated	0.02 km^2 inundated	0.02 km^2 inundated	0.6 km^2 inundated
Impacts of King Tides and common flood events			Full protection	Substantial protection	Some protection
Implications of the Management Action (or Inaction)					
Direct implementation costs		None	$157 M	$152 M	$405 M
People permanently displaced		>1100 people forced out by SLR	No displacement	No displacement	>300 people forced out by SLR
Loss of land opportunity by 2100		2.8 km^2	0.2 km^2	1.0 km^2	2.8 km^2
Aesthetics		None	Likely negative relative to today	Likely negative relative to today	Likely negative relative to today
Environmental			High	Moderate	Naturalized
Adaptability (Ability to change direction later)		Moderate	Moderate	Moderate	Moderate

Worst impacts
Neutral
Best impacts

Figure 23. Summary consequence table for Fraser River Foreshore

3.3.2.6 Summary of Trade-off Evaluation Discussions

During the engagement workshops, stakeholders and City staff expressed the view that a shoreline dike could potentially offer full protection from flooding events and sea level rise to all at-risk assets. An inland dike would protect only half of the economic assets for a similar cost. However, it may not be technically feasible to construct a dike along the shoreline, given today's seismic guidelines and dike-building technology. The Adapt alternative provides some improvement over the baseline condition during a flood event, but fares worse on a range of performance measures compared to the two types of dikes. It also costs more than the dikes; raising all existing city infrastructure to meet the FCL will be expensive. However, raising new construction to the FCL has a low marginal cost, and this requirement has been implemented for newly constructed multi-family housing on the eastern edge of the zone.

3.3.2.7 Conclusions and Recommendations

The Fraser River Foreshore zone is at risk of flooding today, making it a priority area within the city for flood mitigation. The residential area east of Argyle Street is for the most part, relatively new and built to an appropriate elevation and therefore the flood risk is mostly mitigated. For the remaining industrial area west of Argyle Street a dike alternative appears to be appropriate, although more detailed engineering design is required to clarify technical and timing issues. An Adapt option may be prohibitively expensive because significant lengths of existing city infrastructure (roads, water utilities, etc.) would have to be raised. Next steps for this zone include:

Short-Term (to 2020) Recommendations for Fraser River Foreshore

1. It is imperative to protect the residents, businesses, and other assets in this zone in the short term, prior to the construction of any other protection strategies. A flood forecast and warning system should be considered for this area. A flood-response plan should be prepared by the City, and ideally, individual citizens and businesses in this area should be encouraged to prepare their own response and business-continuity plans. The City Emergency Management Team should spearhead or be very involved in this process.
2. Given that the dike solutions were preferred by stakeholders invited to this process, additional information should be sourced on these two alternatives in the very near future. Specifically, more detailed design and assessment for both alignments should be conducted within the next couple of years. Of special interest are the soil conditions along each alignment that might render them technically infeasible as well as impacts and retrofit requirements associated with existing infrastructure along the proposed alignment.
3. The City should seek community feedback for this area with regards to a preferred alternative.
4. If a dike option is pursued, discussions should be conducted among affected stakeholders to determine funding sources and dike ownership.
5. The City should begin to consider how it will acquire a right-of-way along the preferred alignment. In the meantime, no new construction should be allowed along these proposed alignments.
6. The failure of critical infrastructure in the floodplain of the Fraser River Foreshore zone would have significant negative impacts on the city and the region beyond the floodplain. The City should continue to make the asset owners (BC Hydro, FortisBC (formerly Terasen), Translink, Rail, and others) aware of the hazard.
7. Additional critical infrastructure should be identified by the City Emergency Management Team. We suspect that there may be telecommunications hubs in this area.
8. The City should avoid placing any additional critical infrastructure in the floodplain. Any public infrastructure or assets built on the floodplain should be designed in a flood-resilient manner. Ideally, any new City buildings should be built as models to showcase resilient and innovative design.

Medium- and Long-Term (2020 to 2100) Recommendations for Fraser River Foreshore

9. The design and implementation of an adaptation alternative in this zone should occur.

3.3.3 Southlands

3.3.3.1 Zone Summary

Key assets at risk in zone:
- More than 300 homes
- Three golf courses
- Stables and hobby farms
- Two City storm outfalls
- City parks

The Southlands zone is a primarily residential area that borders the Fraser River. For this project, we have defined the zone as extending from Angus Drive in the east to the border with Musqueam lands on the west, and Deering Island is also included. Most of this zone lies within the Agricultural Land Reserve, and this means that development prospects are limited. The zone also includes significant recreational assets with three golf courses (one is City-owned) and several parks. The Fraser River shore also holds some ecological value, as do the riparian corridors along the smaller creeks.

3.3.3.2 Flood Extents and Assets Affected

Southlands is at risk of significant flooding now in any given winter under a *very rare* flood event. Should a 0.2% flood event occur today, we expect to see 3.5 km^2 wetted to some degree with almost 400 damaged buildings, most of which are private residences. This will mean the temporary displacement of more than 2000 people. In the future, with sea level rise, the extent of flooding will not change significantly as this floodplain is constrained by topography, but the depth of flooding will be greater. Deeper water results in greater long-term damage to buildings and infrastructure.

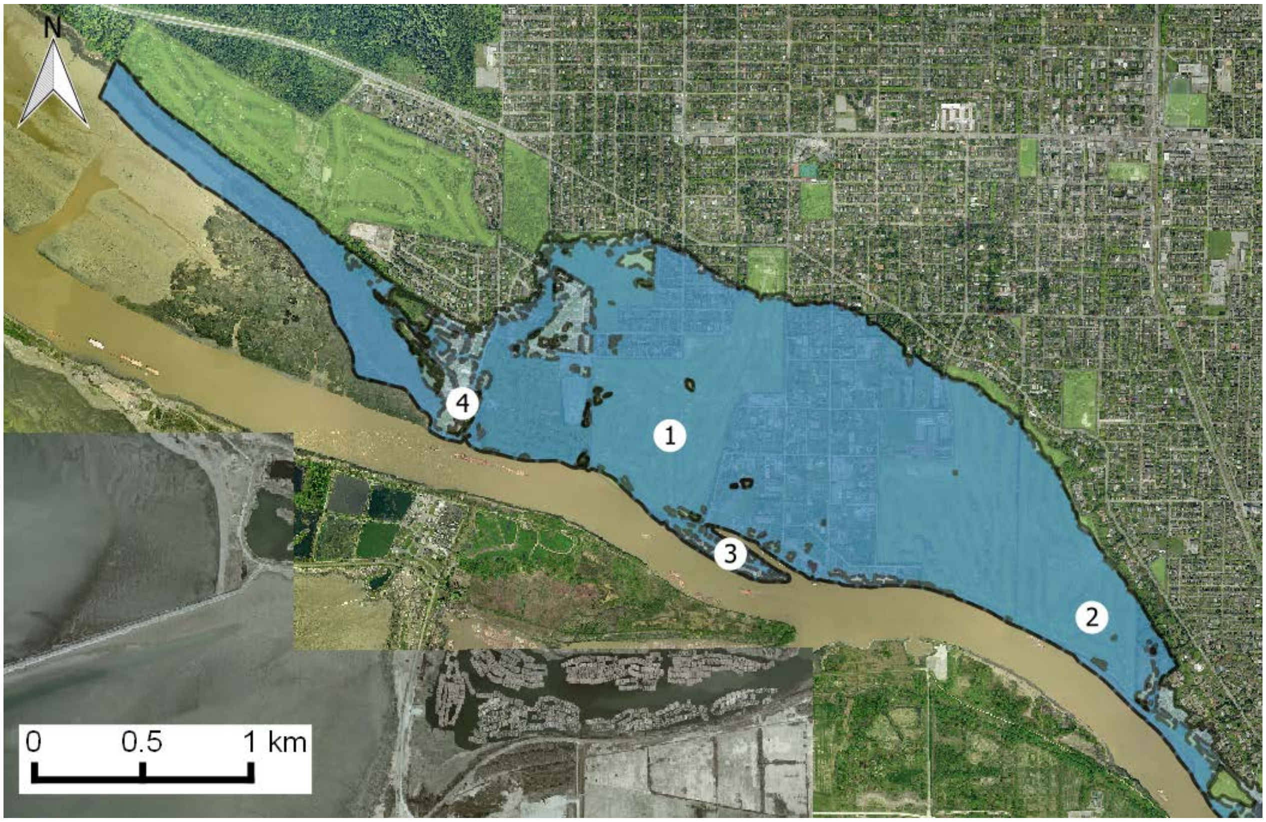


Figure 24. Flood-extent map for Southlands

Flood extent (with freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.3.3.3 Flood Probability, Magnitude, and Timing

Flood probability curves (with freeboard) for a range of representative locations in the Southlands zone are shown in Figure 25. The curves provide some insight into when the probability of major city assets flooding might be considered too high, thereby requiring some form of adaptation. For example, the curves below (along with the mapping provided above in Figure 24) clearly show that there is a high annual probability of flooding for many of the identified assets in the zone today. As we look into the mid- and late century, the depth and frequency of flooding across the whole floodplain would be expected to increase. This will cause significant disruption and damage.

This insight into the timing and probability of events, along with the consequences of each of these assets getting wet helps define priorities and timing for adaptation interventions.

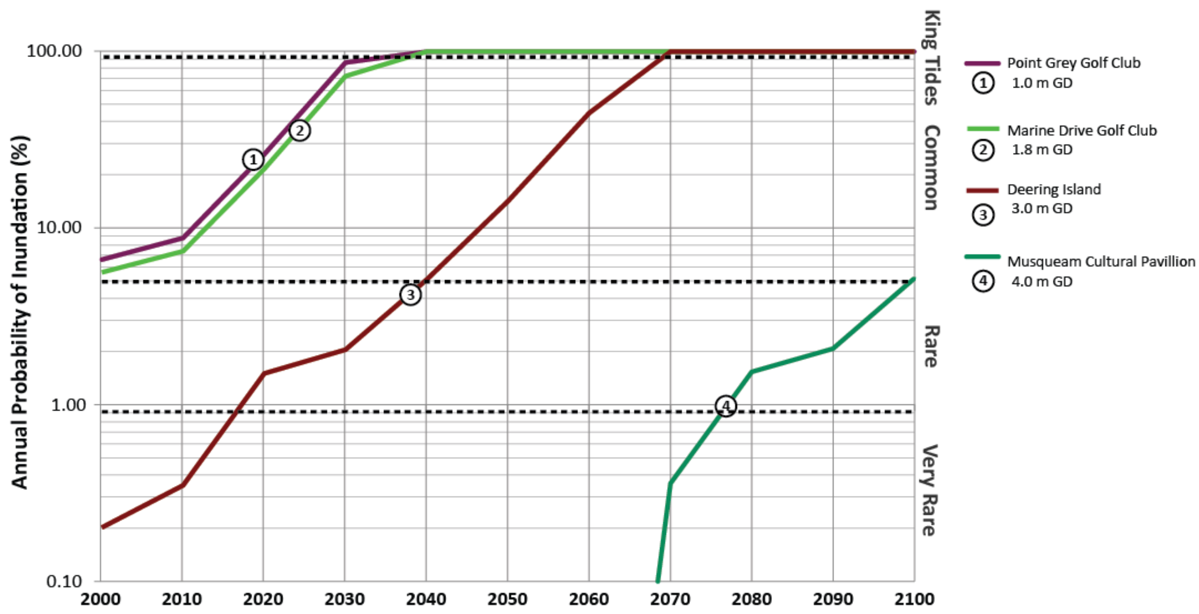


Figure 25. Annual probability of inundation for representative locations in Southlands

3.3.3.4 Alternatives Considered

As discussed in the Approach section (Section 2) above, a wide variety of ways of minimizing harm to Southlands assets over time were considered. Shortlisted alternatives for the Southlands zone are as follows:

Strategy	Alternative	Key features
Protect	Dike	A 6.5 km dike along the foreshore, raising the existing trail by 1.3 m to 3 m to meet the flood construction level of 4.6 m GD.
Adapt	Adaptation with multiple tools	Infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding.
Retreat	Managed retreat	Gradually relocate people and vulnerable assets from the floodplain.

<u>Protect with dike</u>

This alternative involves diking the foreshore of Southlands. A 6.5 km dike would be constructed along the alignment shown in Figure 25. The concept would be to raise the existing trail by 1.3 m to 3 m to meet the flood construction level of 4.6 m GD. This dike is assumed to be designed to meet seismic standards and was costed to include some drainage infrastructure (ditches, floodboxes, and pump stations). For this alternative, a simple dike is assumed with no co-benefit features, such as a recreational trail or habitat enhancement. This alignment would protect the floodplain from *common*, *rare* and *very rare* flood events as soon as it is built. Areas riverside of the dike, including Deering Island, would remain unprotected under all conditions and timelines.

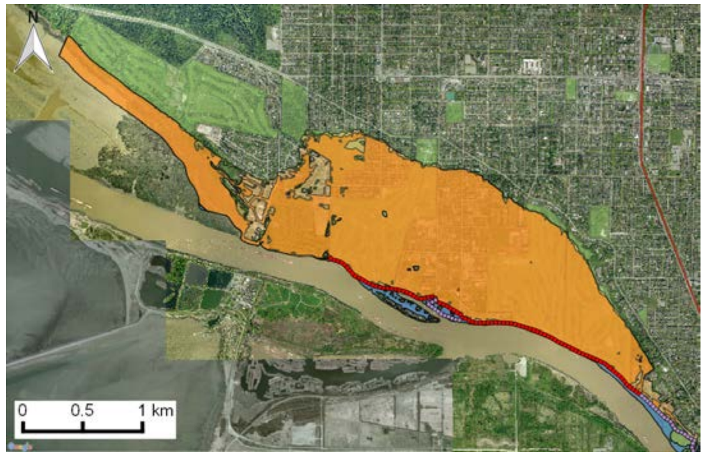


Figure 26. Flood protection for Southlands provided by a dike

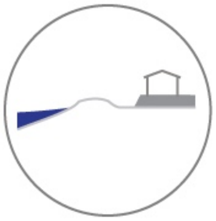
Location of the dike is indicated in red, protected floodplain is indicated in orange.

The dike alignment shown above assumes co-operation with the Musqueam First Nation, as the shore west of the City border would also have to be protected. Various configurations for this were considered, and costs for additional lengths of dike are included as modifications to this alternative.

As part of the SDM process, stakeholders provided their views on the dike option for the Southlands zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	**Cons**
• Will protect people and land, keeping and possibly increasing the tax base. • Lots of opportunity for co-benefits (recreation and environment). • The City already has right-of-way or ownership of much of the alignment. • Will require co-operation with the Musqueam First Nation, which is an opportunity to engage.	• Will require significant drainage infrastructure. • Could be technically unviable due to soils and seismic concerns. • If co-operation with the Musqueam First Nation does not result in the ability to build a continuous dike, additional diking on a north-south alignment will be required. • Could pose a jurisdictional challenge since lands below high-tide mark are the Port's jurisdiction. • The alignment does not protect Deering Island. • Views from first row of houses will be severely affected.

Adapt



This alternative works with the idea that coastal communities can accommodate occasional flooding. In this alternative, infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding. This strategy can include a broad base of educational, planning, and building options; more detailed information and examples are provided in Appendix D. Specific components of the strategy used in this study included:

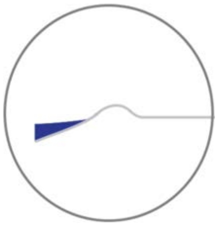
- Bylaws requiring no new critical infrastructure in floodplain.
- Raising of city services (roads, water, etc.) over time.
- Flood-resilient design adjustments to building code along with the development of options and incentives to help residents and businesses improve property-level protection.
- Education of property owners on individual structural responses for flood-proofing (flood gates, flood barriers, stop-valves, etc.). This strategy also includes an incentive program to encourage individuals to flood-proof their homes and businesses.
- A requirement for sub-division and density approvals in floodplains; this aims to keep the number of people at risk of flooding from increasing in future.
- The development and continued support for a warning system that will warn residents and business owners of impending high river levels, allowing them to minimize damage at an individual property level.

This alternative provides more distributed protection from flooding, as it will increase flood-resiliency in areas where the policies are adopted and buildings are turned over. This alternative can be implemented quickly and will slowly improve flood-resiliency over time. Depending on which components are adopted by individual building parcels, flood protection will be realized for *common*, *rare,* and *very rare* events today and with 1 m of sea level rise.

As part of the SDM process, stakeholders provided their views on the Adapt alternative for Southlands. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	**Cons**
• Potential habitat, recreational, and aesthetic gains. • Opportunity to densify if area is protected. • Could be a complementary measure.	• Implementation challenges. • FCLs do not protect infrastructure, parks, and heritage buildings. • Relatively expensive.

Managed retreat



A managed retreat alternative was examined for the Southlands zone. This alternative aims to slowly remove people and vulnerable assets from the floodplain over time. Specifics of the alternative proposed were:

- Opportunistic buyouts as homes/businesses come up for sale for the next 40–60 years.
- More aggressive buyouts 60–90 years from now, which will require enabling legislation.
- Opportunistic removal of roads, other infrastructure, and contaminants, as land is vacated for the next 40–60 years.
- Aggressive re-naturalization around 2070.

As discussed earlier, for the purposes of this exercise we explored the situation where the City would buy out the properties. However, it is by no means clear that the City would be under any legal obligation to do so.

This alternative provides more distributed protection from flooding, as it will increase flood-resiliency in areas where the policies are adopted and properties are acquired. This alternative will provide minimal protection from near-term events, as it will take decades for a significant number of residents to relocate. Towards the end of the century, the risk of flooding in the area will have essentially been removed completely.

As part of the SDM process, stakeholders provided their views on the managed retreat alternative for Southlands. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	**Cons**
• Potential habitat, recreational, and aesthetic gains. • Would reduce risk from seismic hazards (assumed hazard, not specifically addressed in the study). • Population is relatively low in this area. • A long-term strategy that will work regardless of sea level rise rates.	• Implementation challenges. • Relatively expensive. • Loss of land. • Would not be implemented immediately, so would require decades before it is effective. • Musqueam First Nation would also have to adopt this strategy.

3.3.3.5 Summary of Key Trade-offs Between Alternatives

A summary of some of the key impacts associated with flood events under the baseline condition and various alternatives is shown in Figure 27 (full consequence table available in Appendix F). The top half of the table shows that a single *very rare* flood event in 2100 using today's assets could result in over $40M in damages and $60M in lost inventory. More than 2100 people may need to be temporarily evacuated, and over 1.6 km^2 of parkland and several sites with potential contaminants could be flooded.

A shoreline dike should offer complete protection from these events. An Adapt alternative could be expected to reduce social and economic effects by around 30% relative to the baseline condition. A managed retreat alternative could, over time, remove the economic, environmental, and social assets at risk from the area.

With the effects of sea level rise alone (the bottom half of the table), 1600 people could be permanently displaced and 4 km^2 of parkland could be flooded by 2100 under the baseline condition. Almost all of these losses could be prevented by a shoreline dike, however, this could cost in the order of $90M to build, and it runs the risk of changing the character and liveability of the zone.

We anticipate that an Adapt alternative could cost more than $150M (based on raising City infrastructure and incentivising homeowners to implement property-level protections). In this alternative, 1100 people would still be displaced by sea level rise. The main advantage of the Adapt alternative would be to avoid the loss of zone character otherwise associated with a dike option, though this alternative would introduce zone changes of its own, such as access issues as some homes are raised or modified before City services are.

Finally, a managed Retreat alternative could successfully minimize economic and social damages associated with flood events, but only at the considerable expense of moving valuable assets out of the floodplain. Around 4 km^2 of land would gradually be re-naturalized and eventually permanently flooded.

		Baseline	Shoreline Dike	Adapt	Managed Retreat
Flood protection (PER EVENT)					
Impacts of a 0.2% flood event in 2100	Economic	\$40M in damages \$61M in lost inventory \$1.5M in emergency response	Full protection	70% of baseline losses	No damage
	Social	2100 people displaced	Full protection	70% of baseline displaced	No protection needed
	Sites with possible contaminants	No protection of sites with contaminants	Full protection	Full protection	Sites would need to be cleaned
	Parks	1.6 km^2 inundated	Full protection	1.6 km^2 inundated	1.6 km^2 inundated
Impacts of King Tides and common flood events		Expect smaller scale events starting near-term	Full protection	Some minor benefits from adaptation technologies in short term	Most managed retreat benefits come later
Implications of the Management Action (or Inaction)					
Direct implementation costs		None	\$90 M - \$135M	\$150 M - \$200 M	~\$1 Billion if people bought out and land restored
People permanently displaced		1600 people forced out by SLR	No displacement	1100 people forced out by SLR	2100 people bought out by City
Loss of land opportunity by 2100		3.8 km^2	0.15 km^2	-	3.8 km^2
Aesthetics		Change in feel of neighbourhood	Change in feel of shore path	Change in feel of neighbourhood	Naturalized
Environmental		Some naturalization	High-value shoreline disrupted, inland hotspots protected	High-value shoreline maintained, inland hotspots damaged	Naturalized
Adaptability (Ability to change direction later)		Moderate	Low	Moderate	High

Worst impacts
Neutral
Best impacts

Figure 27. Summary consequence table for Southlands

3.3.3.6 Summary of Trade-off Evaluation Discussions

This was one of two zones identified as potentially worth the discussion of a managed Retreat alternative, given the high hazard and relatively low development. After some exploratory discussions, City and external participants generally felt that this would be unlikely to be a preferred approach due to either cost (if property owners were bought out) or equity (if they were not, increasingly frequent floods would gradually reduce property values, forcing a relatively small number people to shoulder a large financial burden). Moreover, some participants felt that the loss of land use *per se* would be a major factor, given that 4 km^2 represents about 3.5% of the land area in the city, which will become ever more valuable as the population grows in decades and centuries to come.

Again, participants thought that the Adapt alternative does not seem to offer good value at this time. Its main benefit appears to be that it would change the nature of the physical interaction with the shoreline in a different and less-obtrusive way than a shoreline dike. The Adapt alternative would create less of a hard edge, but its other downsides may outweigh this advantage.

It may be feasible to soften the negative impacts associated with a dike through creative architectural design. For example, winning entries in SFU RISE competition (November 2014) explored this potential. The degree to which additional capital would be required is undetermined.

3.3.3.7 Conclusions and Recommendations

Action should be taken in the short-term to address the risk of flooding in the Southlands. Discussions with invited external stakeholders and City staff for this zone identified the dike as a possible preferred alternative. Next steps for this zone include:

Short-Term (to 2020) Recommendations for Southlands

1. It is imperative to protect the residents, businesses, and other assets in this area in the short-term, prior to the construction of any other protection options. A flood forecast and warning system should be considered for this area. A flood-response plan should be prepared by the City and ideally, individual citizens and businesses in this area should be encouraged to prepare their own response and business-continuity plans. The City Emergency Management Team should spearhead or be very involved in this process.
2. The City should promulgate regulations to disallow an increase in density in this zone.
3. The City should seek community feedback for this area with regards to a preferred alternative.
4. It is important that additional information be sourced on the dike alternative in the very near future. Specifically, more detailed design and assessment of this alignment should be conducted within the decade. Of special interest are the soil conditions along the alignment that might make a dike technically unfeasible or prohibitively expensive.
5. If the dike option is pursued, discussions should be conducted among affected stakeholders to determine funding sources and dike ownership.
6. The City should begin to consider how it will acquire a right-of-way along the alignment. In the meantime, no new construction should be allowed along the proposed alignment.
7. The City should avoid placing any additional critical infrastructure in the floodplain. Any public infrastructure or assets built on the floodplain should be designed in a flood-resilient manner. Ideally, any new City buildings should be built as models to showcase resilient and innovative design.
8. The City should continue to work with and provide information to the Musqueam First Nation.

Medium-Term (2020 to 2050) Recommendations for Southlands

9. Design and implementation of an adaptation alternative for this area should occur.

3.3.4 Kitsilano

3.3.4.1 Zone Summary

The Kitsilano zone and beach are well-known to Vancouverites as a residential zone and a destination beach and park. For the purposes of this study, we have defined Kitsilano as the area that stretches from Vanier Point to the north and east, over to the far edge of Kitsilano Beach Park to the west. The floodplain within this zone covers all of the beach areas and much of the park. It also stretches into the residential areas.

Key assets at risk in zone:

- Kitsilano Beach
- Kitsilano Pool
- Concessions and restaurant building
- Seawall pathway
- Businesses and more than 40 multi-family dwellings

3.3.4.2 Flood Extents and Assets Affected

Flooding in this zone today under a *common* event would result in much of the beach, the park structures, and some homes getting wet. The City has already seen portions of this area flooded, such as the flooding of Kitsilano Pool in December 2014.

In 2100, a similar storm would result in many additional homes getting flooded by up to 1.5 m of water. The flooding in this area would potentially be exacerbated by waves that would not only increase the depth of water, but also have additional energy that could damage structures. In the short term, the beach and park would be unusable, and the area would also likely suffer longer-term damage and changes to the coastal morphology (i.e., the beach shape and slope will be affected).

Figure 28. Flood-extent map for Kitsilano.

Flood extent (with freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.3.4.3 Flood Probability, Magnitude, and Timing

Flood probability curves (with freeboard) for a range of representative locations in Kitsilano are shown in Figure 29. The curves provide some insight into when the probability of major city assets flooding might be considered too high, thereby requiring some form of adaptation. For example, the curves below (along with the mapping provided in Figure 28 above) show that the Kitsilano Yacht Club, pool, and residential housing along Arbutus Street between Cornwall Avenue and McNichol Avenue are at risk of frequent flooding today with *common* events, whereas flooding of residential buildings as far east as Laburnum Street is possible today with a *very rare* event. The Boathouse Restaurant is at risk of flooding today with *very rare* events, while the Maritime Museum and residential buildings east of Laburnum Street are at risk from *very rare* events by mid-century, and by *common* events later in the century (2100). This insight into the timing and probability of events, along with the consequences of each of these assets getting wet helps define priorities and timing for adaptation interventions.

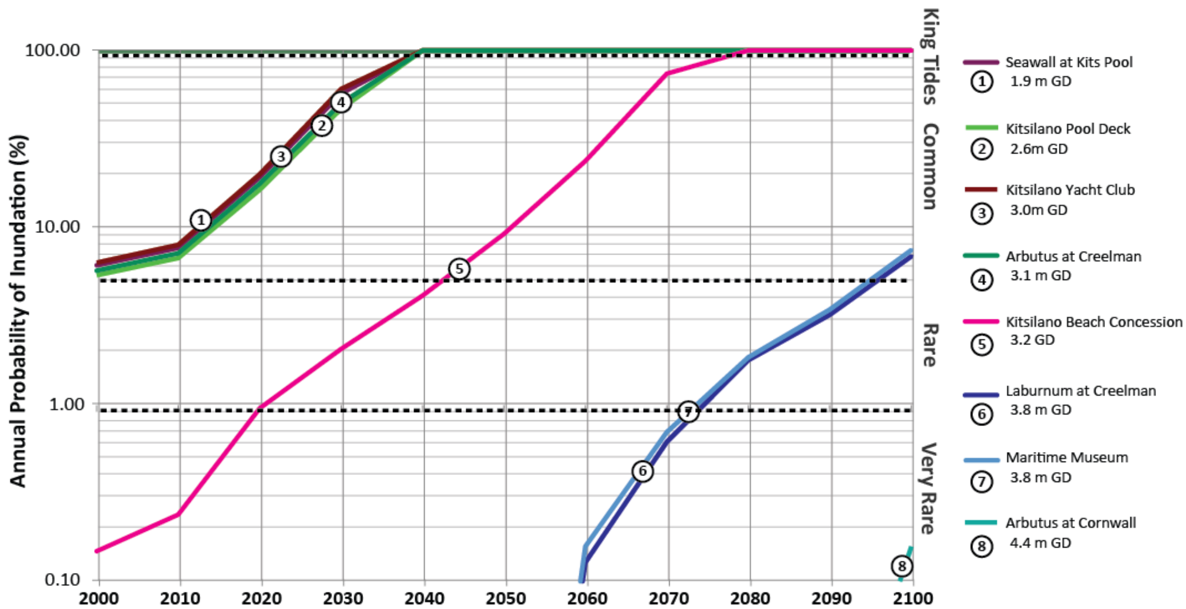


Figure 29. Annual probability of inundation for representative locations in Kitsilano

3.3.4.4 Alternatives Considered

As discussed in the Approach section (Section 2) above, a wide variety of ways of minimizing harm to Kitsilano assets over time were considered. Shortlisted alternatives for the Kitsilano zone are as follows:

Strategy	Alternative	Key features
Protect	Park dike	A 700 m dike along an established trail, on average 1.4 m higher than the existing pathway.
	Road dike	Raising approximately 600 m of established roadways (Arbutus Street and Cornwall Avenue) by 1.4 m with the use of retaining walls in some areas.
Adapt	Adapt with multiple tools	Infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding.

Protect with park dike

This alternative involves the construction of approximately 700 m of dike along an established trail. The dike would be on average 1.4 m higher than the existing pathway, and was assumed to meet seismic standards and to include appurtenant drainage structures. As with all the alternatives evaluated as part of this process, a simple “no-frills” design was used for comparison with other alternatives, and weaknesses of this approach as compared to the defined measures were identified. There would be an opportunity to improve this design with recreational, habitat, or other landscape features that would visually integrate the dike within the park.

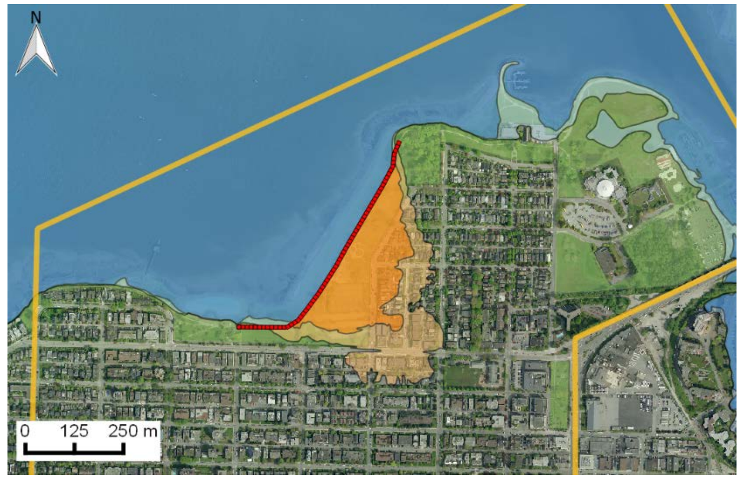


Figure 30. Flood protection for Kitsilano provided by a park dike

Location of the dike is indicated in red, protected floodplain is indicated in orange.

This alternative protects most of the assets at risk both today and in the future. However, the beach would be situated shoreward of the dike. It is expected that over time the dike would look more like a seawall, as the beach is overcome and washed away. This could likely be mitigated with aggressive beach nourishment or other coastal engineering alternatives.

As part of the SDM process, stakeholders provided their views on the park dike option for the Kitsilano zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	**Cons**
• No displacement of people. • Protection of green spaces. • Opportunity to improve the design for aesthetics, recreation, habitat, etc. • Adaptable to higher sea levels (beyond 1 m).	• Aesthetic issues with dike itself and blocking of views. • Loss of beach. • Pool is not protected with this alignment.

Protect with road dike

This alternative involves the raising of approximately 600 m of established roadways (Arbutus Street and Cornwall Avenue), with the use of retaining walls in some areas. The dike would be on average 1.4 m higher than the existing grade, and was assumed to meet seismic standards and to include appurtenant drainage structures. Some impacts to existing infrastructure are assumed. As with all the alternatives evaluated as part of this process, a simple "no-frills" design was used for comparison with other alternatives, and weaknesses of this approach as compared to the defined measures were identified. There would be an opportunity to improve this design with architectural features.

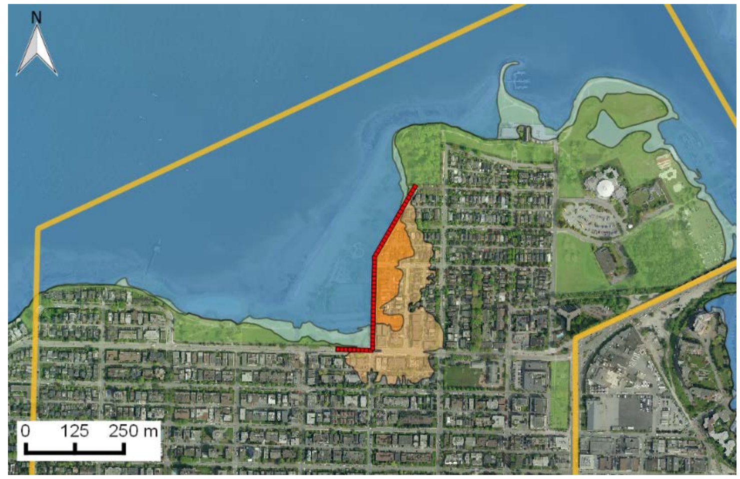


Figure 31. Flood protection for Kitsilano provided by a road dike

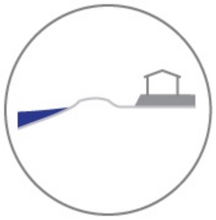
Location of the dike is indicated in red, protected floodplain is indicated in orange.

This alternative protects most of the infrastructure at risk both today and in the future. However, the beach and park would be shoreward of the dike. It is expected that over time the dike would look more like a seawall, as the beach is overcome and washed away. This could likely be mitigated with aggressive beach nourishment or other coastal engineering alternatives. In this alternative, most of the park space and major park amenities are not protected from *rare* floods today or *common* ones in future.

As part of the SDM process, stakeholders provided their views on the road dike alternative for the Kitsilano zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• Could possibly allow for more natural beach (with shallow slope) to continue to exist. • Direct adverse impacts (of walls and loss of land) would only be felt by a few homeowners.	• Leaves some recognized assets/facilities unprotected. • Loss of parks and recreational areas in addition to beach. • Technically challenging. • Not a lot of opportunity to add value to the structure (recreational trails, habitat, etc.). • Not very adaptable to a greater than expected rise in sea level.

<u>Adapt</u>



This alternative works with the idea that coastal communities can accommodate occasional flooding. In this alternative, infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding. This alternative can include a broad base of educational, planning, and building options; more detailed information and examples are provided in Appendix D. Specific components of the alternative used in this study included:

- Bylaws requiring no new critical infrastructure in floodplain.
- Raising of city services (roads, water, etc.) over time.
- Flood-resilient design adjustments to building code along with the development of options and incentives to help residents and businesses improve property-level protection.
- Education of property owners on individual structural responses for flood-proofing (flood gates, personal flood barriers, stop-valves, etc.). This strategy also includes an incentive program to encourage individuals to flood-proof their homes and businesses.
- A requirement for sub-division and density approvals in floodplains; this aims keep the number of people at risk of flooding from increasing in the future.
- The development and continued support for a warning system that will warn residents and business owners of impending high ocean levels, allowing them to minimize damage at an individual property level.

This alternative provides more distributed protection from flooding, as it will increase flood-resiliency in areas where the policies are adopted and buildings are turned over. It can be implemented quickly and will slowly improve flood-resiliency over time. Depending on which components are adopted by individual building parcels, flood protection will be realized for *very rare* to *common* events today and into the future.

As part of the SDM process, stakeholders provided their views on the Adapt alternative for the Kitsilano. zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	**Cons**
• Effective as complementary measures along with other options. • Adaptable to changing sea level rise in future.	• Loss of iconic area and recreational values. • Expensive.

3.3.4.5 Summary of Key Trade-offs Between Alternatives

A summary of some of the key impacts associated with flood events under the baseline condition and various alternatives is shown in Figure 32 (full consequence table available in Appendix F). The top half of the table shows that the direct economic, social, and environmental losses associated with baseline-level flooding in this area are relatively minor compared to other locations discussed. Nevertheless, a *very rare* flood event could result in 720 people being temporarily displaced and $4M of direct damages.

Over time, taking no action to prevent damages from sea level rise (the bottom half of the table) could see a small number of people permanently displaced. Perhaps most significantly, given the primary use of this area, the main trade-off issues concern the relative availability of beach and park area. In the unmitigated case, we would expect current areas of parkland to be replaced over time with beach, essentially shifting the shoreline inwards.

A park dike could prevent most of the direct damages associated with flood events and sea level rise, but would protect the park area at the expense of the beach. The road dike alternative would see a smaller fraction of the area protected, with the unprotected area converting to beach over time. Finally, an Adapt alternative would focus resources instead at reducing the sensitivity of various assets to flooding.

Kitsilano

		Baseline	Park Dike	Road Dike	Adapt
Flood protection (PER EVENT)					
Impacts of a 0.2% flood event in 2100	Economic	$4M in damages $10M in lost inventory $0.5M in emergency response	Minimal damage	65% of baseline losses	70% of baseline losses
	Social	720 people displaced	200 people displaced	530 people displaced	190 people displaced
	Sites with possible contaminants	No protection of sites with contaminants	Most sites with contaminants protected	Most sites with contaminants protected	Full protection
	Parks	0.2 km^2 inundated	0.01 km^2 inundated	0.05 km^2 inundated	0.2 km^2 inundated
Impacts of King Tides and common flood events		Expect smaller scale events starting now	Minor damage to park infrastructure outside dike, Kits Pool	Minor damage to park infrastructure including Kits Pool	Minor damage to park infrastructure including Kits Pool
Implications of the Management Action (or Inaction)					
Direct implementation costs		None	$5 - $6 M	$10 - $15 M	$12 M
People permanently displaced		56 people forced out by SLR	49 people forced out by SLR	56 people forced out by SLR	15 people forced out by SLR
Loss of land opportunity by 2100		0.28 km^2	0.1 km^2	0.06 km^2	-
Aesthetics		Gain beach at expense of park	Protect park (but lose beach)	Gain beach at expense of park	Gain beach at expense of park
Environmental		Loss of existing shoreline (in present-state)	Loss of existing shoreline, possibly replaced with hard edge (for simple design of dike)	Loss of existing shoreline (in present-state)	Loss of existing shoreline (in present-state)
Adaptability (Ability to change direction later)		Moderate	Low	Low	High

Worst impacts
Neutral
Best impacts

Figure 32. Summary consequence table for Kitsilano

3.3.4.6 Summary of Trade-off Evaluation Discussions

In this case, absolute impacts are comparatively small, and the City has a wide degree of flexibility to reconfigure the area. Workshop discussions therefore turned to envisioning what kind of beach/park arrangements might be preferred by residents and stakeholders. In this case, the various alternatives might, with further development, be amalgamated into a combined idea. For example, a protective, elevated, landscaped area could be created that protects against *common* to *rare* events, and also creates an interesting shoreline of combined park and beachfront.

3.3.4.7 Conclusions and Recommendations

Considering that a number of assets could be inundated in the near term with *rare* to *common* flood events, the City should commence consultation and planning by 2020 to avoid significant impacts to the beach, park and neighbouring residences. In the meantime, the City should focus on preserving technical options for the future and, over the medium term, engaging with residents to discuss reconfiguration opportunities to protect beach and or park areas. Based on discussions with invited external stakeholders and City staff for this zone, the following actions are recommended:

Short-Term (to 2020) Recommendations for Kitsilano

1. The City should seek community feedback for this area, and begin the process of selecting an alternative by 2020. Given that the biggest trade-off between the presented alternatives was beach versus park, it will be important to better understand what should be protected.
2. The City should avoid placing any additional critical infrastructure in the floodplain as per city-wide recommendations. Any public infrastructure or assets built on the floodplain should be designed in a flood-resilient manner. Ideally, any new City buildings should be built as models to showcase resilient and innovative design.
3. Any park infrastructure that comes up for renewal should be designed with flood-resiliency in mind, and ideally as a model or showcase project.
4. The City should monitor available information on coastal squeeze and the likely morphologic changes to the beach over time as a result of sea level rise.
5. The City should maintain right-of-way along (and beside) proposed dike alignments.
6. The City should continue to monitor sea level rise projections, as well as local changes to the beach.
7. The City should re-evaluate alternatives (including the addition of new options) given new information and technologies.

Medium- and Long-Term (2020 to 2100) Recommendations for Kitsilano

8. The design and implementation of an adaptation alternative in this zone should occur.

3.3.5 Jericho-Spanish Banks

3.3.5.1 Zone Summary

The beaches of Point Grey—Spanish Banks, Locarno, and Jericho—are well-known to residents and visitors alike. For the purposes of this study, we have defined Jericho-Spanish Banks as extending from Alma Street in the east to the city's border with UBC in the west. This zone includes many recreational amenities in addition to the beaches themselves, including multiple concessions, the West Point Grey Community Centre, the Jericho Sailing Centre, and the large event program space (that is currently used annually for the Folk

Key assets at risk in zone:

- Jericho Park, including large program space used for Folk Festival and other events
- Extensive beach areas
- Jericho Sailing Centre
- West Point Grey Community Centre
- Concessions
- Single-family and multi-family residences

Festival). There is also a youth hostel and a theatre, in addition to single-family and multi-family residences. The City also has two storm-sewer outfalls (English Bay and Alma-Discovery) in this zone.

3.3.5.2 Flood Extents and Assets Affected

This zone is expected to see flooding in *rare* and even *common* events today and, although the extent does not increase dramatically because of the relatively steep topography to the south of the floodplain, will see more frequent flood events having greater depths in future. Because of its aspect relative to predominant wind direction and the large fetch of Burrard Inlet that lies to the north, this area is subject to wave action in addition to flood hazard from high ocean levels. The waves will not only increase the local water height to as much as 2 m for the single-family residences along NW Marine Drive, but will also have additional energy. Higher wave energy translates into greater damages.

As sea levels rise, recreational spaces and beaches in this area will be affected, as will the large program space within Jericho Park. This is coupled with impacts to the Jericho Sailing Centre, the West Point Grey Community Centre, and half a dozen residences.

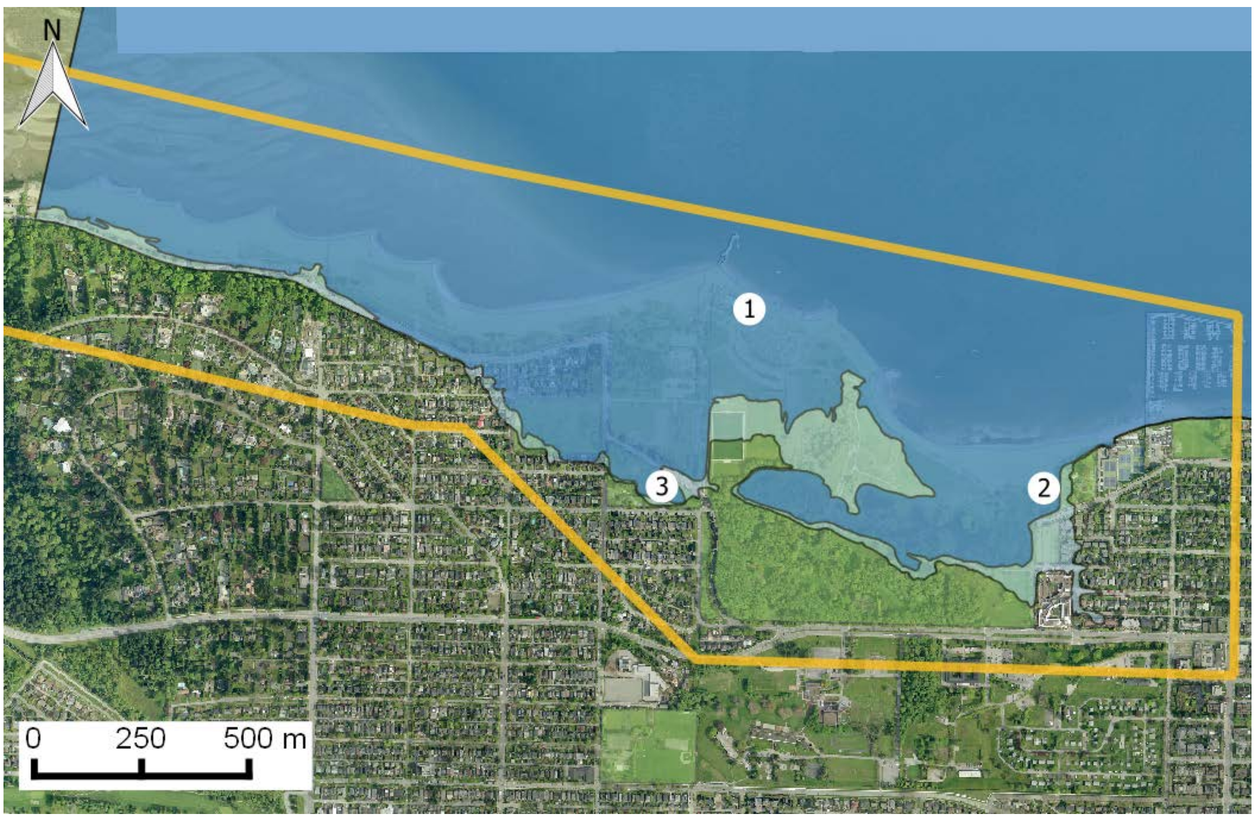


Figure 33. Flood-extent map for Jericho-Spanish Banks.

Flood extent (with freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.3.5.3 Flood Probability, Magnitude, and Timing

Flood probability curves (with freeboard) for a range of representative locations in Jericho-Spanish Banks are shown in Figure 34. The curves provide some insight into when the probability of major city assets flooding might be considered too high, thereby requiring some form of adaptation. For example, the curves below (along with the mapping provided above in Figure 33) show that large parts of this area are at risk of flooding today, with the Jericho Sailing Centre and Jericho Beach Concession being at a significant risk, which is evidenced by water reaching their doors during *common* events. Some of the other major recreational assets are not as at as high a risk today, but could be flooded under a *rare* flood event (e.g., West Point Grey Community Centre). As we look to mid-century, the Sailing Centre and concession may experience wetting annually with *king tides*, and the West Point Grey Community Centre may be flooded in *common* events. This insight into the timing and probability of events, along with the consequences of each of these assets getting wet helps define priorities and timing for adaptation interventions.

Figure 34. Annual probability of inundation for representative locations in Jericho-Spanish Banks

3.3.5.4 Alternatives Considered

Strategy	Alternative	Key features
Protect	Park dike	A 2 km dike along an established trail. The dike would be on average 1.8 m higher than the existing grade.
	Road dike	A 1.7 km dike along established roadways (Marine Drive and Point Grey Road), with the use of retaining walls in some areas. The dike would be on average 1.7 m higher than the existing grade

Adapt	Adapt with multiple tools	Infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding.
Retreat	Managed retreat	Slowly remove people and vulnerable assets from the floodplain over time.

Protect with park dike

This alternative involves the construction of approximately 2 km of dike along an established trail. The dike would be on average 1.8 m higher than the existing pathway, and was assumed to meet seismic standards and to include appurtenant drainage structures. As with all the alternatives evaluated as part of this process, a simple "no-frills" design was used for comparison with other alternatives, and weaknesses of this alternative as compared to the defined measures were identified. There would be an opportunity to substantially improve this design with recreational, habitat, or other landscape features.

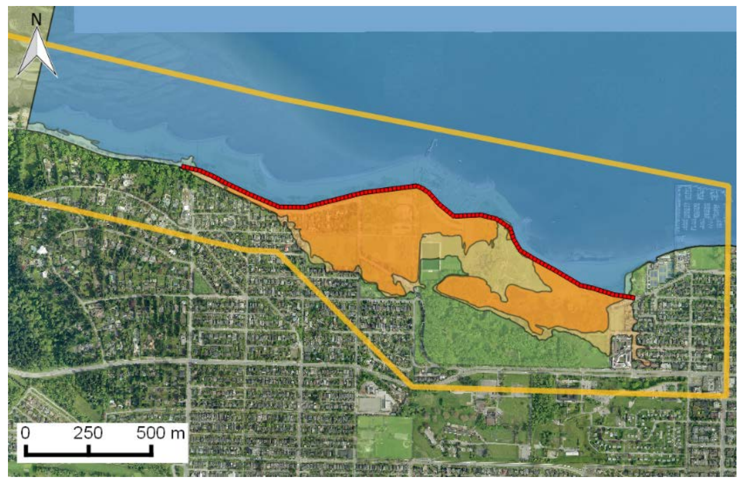


Figure 35. Flood protection for Jericho-Spanish Banks provided by a park dike

Location of the dike is indicated in red, protected floodplain is indicated in orange.

This alternative protects most of the infrastructure at risk both today and in the future. However, the beach would be situated shoreward of the dike. It is expected that over time the dike would look more like a seawall, as the beach is overcome and washed away. This could likely be mitigated with aggressive beach nourishment or other coastal engineering options.

As part of the SDM process, stakeholders provided their views on the park dike alternative for the Jericho-Spanish Banks zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• Protection of green spaces and public land. • Opportunity to improve the design for aesthetics, recreation, habitat, etc. • Adaptable to even higher sea level rise.	• Aesthetic issues with dike itself and blocking of views. • Sacrifices beach for program space. • Limited opportunity for naturalization and habitat enhancement.

Protect with road dike

This alternative involves the raising of approximately 1.7 km of established roadways (Marine Drive and Point Grey Road), with the use of retaining walls in some areas. The dike would be on average 1.7 m higher than the existing grade, and was assumed to meet seismic standards and to include appurtenant drainage structures. As with all the alternatives evaluated as part of this process, a simple "no-frills" design was used for comparison with other alternatives, and weaknesses of this approach as compared to the defined measures were identified. This alternative would directly affect some homes, as the raising would require additional footprint and would make driveway access difficult.

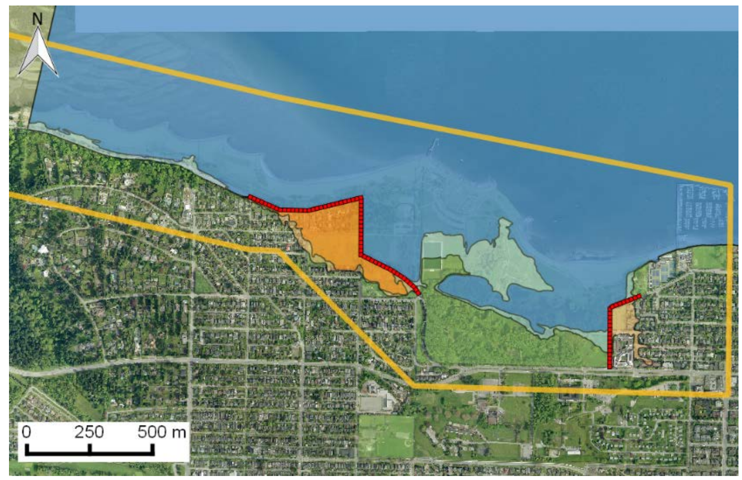


Figure 36. Flood protection for Jericho-Spanish Banks provided by a road dike

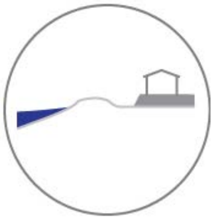
Location of the dike is indicated in red, protected floodplain is indicated in orange.

This alternative protects most of the infrastructure at risk both today and in the future. However, the beach and park would be shoreward of the dike. It is expected that over time the dike would look more like a seawall, as the beach is overcome and washed away. This could likely be mitigated with aggressive beach nourishment or other coastal engineering options. In this strategy, most of the park space and major park amenities are not protected from *rare* to *common* events today or from *common* ones in the future.

As part of the SDM process, stakeholders provided their views on the road dike alternative for the Jericho-Spanish Banks zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• Could possibly allow for more natural beach (with shallow slope) to continue to exist. • Direct adverse effects (of walls and loss of land) would only be felt by a few homeowners. • Economical. • Allows for natural adaptation and the creation of new habitats (e.g., lakes and marshes).	• Loss of parks and recreational areas in addition to beach and especially large program space used for festivals. • Not a lot of opportunity to add value to the structure (recreational trails, habitat, etc.). • Not very adaptable to a greater than expected rise in sea level.

Adapt



This alternative works with the idea that coastal communities can accommodate occasional flooding. In this option, infrastructure, buildings, and communities are retrofitted or slowly changed over the natural building cycle to be more resilient to flooding. This alternative can include a broad base of educational, planning, and building options; more detailed information and examples are provided in Appendix D. Specific components of the strategy used in this study included:

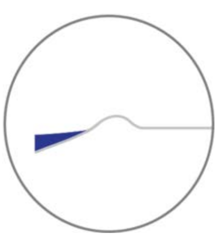
- Bylaws requiring no new critical infrastructure in floodplain.
- Raising of city services (roads, water, etc.) over time.
- Flood-resilient design adjustments to building code along with the development of options and incentives to help residents and businesses improve property-level protection.
- Education of property owners on individual structural responses for flood-proofing (flood gates, personal flood barriers, stop-valves, etc.). This strategy also includes an incentive program to encourage individuals to flood-proof their homes and businesses.
- A requirement for sub-division and density approvals in floodplains; this aims to keep the number of people at risk of flooding from increasing in the future.
- The development and continued support for a warning system that will warn residents and business owners of impending high ocean levels, allowing them to minimize damage at an individual property level.

This alternative provides more distributed protection from flooding, as it will increase flood-resiliency in areas where the policies are adopted and buildings are turned over. This alternative can be implemented quickly and will slowly improve flood-resiliency over time. Depending on which components are adopted by individual building parcels, flood protection will be realized for *very rare* to *common* events today and into the future. There are relatively few structures in the floodplain in the Jericho-Spanish Banks zone, and many of those are older homes that might be expected to be updated in the near future.

As part of the SDM process, stakeholders provided their views on the Adapt alternative for the Jericho-Spanish Banks zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	**Cons**
• People won't have to move. • Beach might be saved.	• Loss of iconic area and recreational values. • Expensive.

Managed retreat



A managed retreat alternative was examined for the Jericho-Spanish Banks zone. This alternative aims to slowly remove people and vulnerable assets from the floodplain over time. Specifics of the strategy proposed were:

- Opportunistic buyouts as homes/businesses come up for sale for the next 40–60 years
- More aggressive buyouts 60–90 years from now, which will require enabling legislation.

- Opportunistic removal of roads, other infrastructure, and contaminants as land is vacated for the next 40–60 years.
- Aggressive re-naturalization around 2070.

This alternative provides more distributed protection from flooding, as it will increase flood-resiliency in areas where the policies are adopted and properties bought up. This alternative will provide minimal protection from near-term events, as it will take decades for all residents to relocate. Towards the end of the century, the risk of flooding in the area will have essentially been removed completely.

As part of the SDM process, stakeholders provided their views on the managed retreat alternative for the Jericho-Spanish Banks zone. These are summarized below. Further details on the stakeholder engagement process are found in Appendix C.

Pros	Cons
• City owns much of the land (leased to others), so it would be relatively easy to move people over time. • Not many people or homeowners are affected.	• Implementation challenges. • Loss of land, especially park and green space.

3.3.5.5 Summary of Key Trade-offs Between Alternatives

Figure 37 shows a simplified summary of the trade-offs between the alternatives for Jericho-Spanish Banks (full consequence table available in Appendix F). From the top half of the table, we can see the baseline condition would likely result in a range of damage to economic, social, and environmental assets per flood event. We estimate that the park dike would reduce economic damages by 55% compared to the baseline, avoid displacement of people, and protect most of the park, at the expense of reduced naturalization of the shoreline. A road dike would reduce economic damages by 40% compared to the baseline; however, a significant portion of the park would be flooded and more than 200 residents of the zone displaced. The Adapt alternative would reduce economic damages by 30% and people displaced by 25% compared to the baseline, but would not protect the park from flooding. Finally, a managed retreat would result in no economic damage or displacement of people due to flooding (all assets and residents would be moved out of the floodplain), but would not protect the park.

Over time, taking no action to prevent damages from sea level rise (bottom half of the table) could see a small number of people permanently displaced, and 0.72 km^2 of land lost in the area, but would otherwise be preferred. A park dike would have an impact on coastal habitat and would not be very adaptable over time, but would protect the greatest land area. A road dike would protect significantly less area, but would have a lesser impact on coastal habitat. Both a park dike and road dike would come at a moderate cost compared to other alternatives considered for this area. The Adapt alternative comes at a higher cost, but is adaptable and would have a low impact on coastal habitat. A managed retreat would result in no protection of land, and require relocating (buying-out) 450+ people at an expense of $350M. However, this alternative would be highly adaptable and have a low impact on habitat.

Jericho

			Baseline	Park Dike	Road Dike	Adapt	Managed Retreat
Flood protection (PER EVENT)							
	Impacts of a 0.2% flood event in 2100	Economic	\$4M in damages \$9.5M in lost inventory \$0.3M in emergency response	45% of baseline losses	65% of baseline losses	30% of baseline losses	No damage
		Social	460 people displaced	0 people displaced	230 people displaced	320 people displaced	0 people displaced
		Environmental		Reduced naturalization	Some naturalization	Some naturalization	Natural shoreline
		Parks	0.6 km^2 of park inundated	0.04 km^2 park inundated	0.3 km^2 park inundated	0.6 km^2 of park inundated	0.6 km^2 of park inundated
	Impacts of King Tides and common flood events		Expect smaller scale events starting in now	No damage. Program park space behind dike useable	No damage. Park space and beaches closed infrequently	Some damage to non-upgraded homes	Retreat unlikely in short term
Implications of the Management Action (or Inaction)							
	Direct implementation costs		None	\$7 - \$25 M	\$10 - \$20 M	\$55 M	\$620 M
	People permanently displaced		Small number* of people forced out by SLR	Small number* of people forced out by SLR	Small number* of people forced out by SLR	Small number* of people forced out by SLR	460 people bought out
	Loss of land opportunity by 2100		0.72 km^2	0.30 km^2	0.62 km^2	Some land use still possible	0.72 km^2
	Aesthetics		Lose beach and park space over time	Protect park (but lose beach)	Gain beach at expense of park	Lose beach and park over time	Beach may move inland
	Environmental		low impact	Medium impact	Medium Impact, opportunity to renaturalise ponds	Low impact, opportunity to renaturalise ponds	Low impact, opportunity to renaturalise ponds
	Adaptability (Ability to change direction later)		Moderate	Low	Low	High	High

* Actual number difficult to establish due to census boundaries

Legend
Worst impacts
Neutral
Best impacts

Figure 37. Summary consequence table for Jericho-Spanish Banks

3.3.5.6 Summary of Trade-off Evaluation Discussions

Stakeholders and City staff expressed the value of this zone as a destination beach and park, and the program space (for the Folk Festival) was considered unique in the city and particularly important. Considering alternatives for Jericho-Spanish Banks, a dike alignment through the park protects some city assets, but it does risk losing the beach over time. There is also significant opportunity to add value to a dike that runs through the park through good design (landscape, amenities, etc.). A dike alignment that runs along the road provides the benefit that the beach could likely be saved, but would most certainly result in the loss of the park space over time. Similarly, the Adapt alternative has the same trade-off (lost park, saved beach). The managed retreat alternative results in significant land losses, as well as some lost residences; the biggest loss possibly being the unique large program space. It does, however, offer an opportunity for a naturalized shoreline (potentially keeping the beach) and creating new biodiversity spaces to compensate for coastal squeeze elsewhere around the city.

3.3.5.7 Conclusions and Recommendations

A key message we heard from stakeholders and City staff was that this is an iconic area of Vancouver and that some parts of it are unique. The city will be at risk of losing many of its destination beaches and parks, and it will be a significant cost to lose them or replace them.

Given the flood extents, depths, and timing, this is an area where decisions will have to be made in the short- to medium-term. Next steps for this zone include:

Short-Term (to 2020) Recommendations for Jericho-Spanish Banks

1. We recommend that the City consider investing in temporary barriers to be deployed for this area during king tide events to protect from flooding until a more permanent solution is in place. Although sandbags continue to be used around the world, better more robust options are available.
2. A city-wide warning system and emergency response plan should also be in place, so that temporary protection can be placed in time to mitigate damages.
3. The City should avoid placing any additional critical infrastructure in the floodplain. Any public infrastructure or assets built on the floodplain should be designed in a flood-resilient manner. Ideally, any new City buildings should be built as models to showcase resilient and innovative design.
4. The City should seek community feedback for this area. Given that the biggest trade-off between the presented options was beach versus park, it will be important to better understand what should be protected.
5. Any park infrastructure that comes up for renewal should be designed with flood-resiliency in mind, and ideally as a model or showcase project.
6. The City should monitor available information on coastal squeeze and the likely morphologic changes to the beach over time as a result of sea level rise. A site-specific coastal geomorphology and coastal biology study for this area should be completed.
7. The City should begin strategic-level planning for this area based on the results of the stakeholder engagement and community values discussion. A design competition or other mechanism could be carried out to ensure that the selected cornerstone option is enhanced with landscape or architectural features that maximize biodiversity and recreational values. This will likely be a more fine-grained solution, where different reaches of the beach could be treated with different design solutions. The City should not go ahead with the basic cornerstone protection options presented.
8. The City should maintain right-of-way along (and beside) proposed dike alignments.

Medium-Term (2020 to 2050) Recommendations for Jericho-Spanish Banks

9. Continue to monitor sea level rise information as well as local changes to the beach.
10. Re-evaluate alternatives (including the addition of new alternatives) given new information and technologies.
11. The design and implementation of an adaptation alternative in this zone should occur.

Long-term (2050 to 2100) Recommendations for Jericho-Spanish Banks

12. Monitor sea level rise and adequacy of implemented adaptation response.

3.4 Zone-by-Zone Analysis: High-Level Assessment Zones

The first five zones were studied in detail. However, given resource and time constraints, the same level of effort could not be employed for the entire length of the City of Vancouver coastline. Furthermore, some zones are simpler and have more obvious adaptation alternatives, making a detailed trade-off assessment unnecessary. For these zones, an assessment of hazard and major vulnerabilities was completed as for the priority zones, but a more basic level of analysis of alternatives was undertaken.

The six zones that underwent this basic adaptation assessment include:

- Coal Harbour

- Waterfront
- Port Lands
- Brighton Beach
- Stanley Park
- Point Grey Road

The following provides an overview of the zones, hazard and vulnerabilities, proposed adaptation alternatives, and recommended next steps.

3.4.1 Coal Harbour

3.4.1.1 Zone Summary

Coal Harbour consists of the coastal area along Burrard Inlet bounded by Denman Street to the northwest and Thurlow Street to the southeast. This zone is home to high-end condominiums, waterfront businesses and parkland, Coal Harbour Community Centre, and a hotel and conference centre. Dense commercial and residential buildings abut the seawall. Dense development limits the range of adaptation alternatives given the limited waterfront area available.

Key assets at risk in zone

- A hotel
- A small number of condominiums and waterfront businesses
- Harbour Green Park

Figure 38. Flood-extent map for Coal Harbour

Flood extent (with 0.6 m freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.4.1.2 Flood Probability, Magnitude, and Timing

The overall probability and extent of flooding in this area is relatively contained compared to other areas in the city, with impacts generally limited to the hotel, parkland, and a small number of businesses and residences along the waterfront. While the potential for flooding in Coal Harbour in the present day is minimal, the seawall and parts of the hotel property may be affected in a very rare flood event at today's sea level. By mid-century, the hotel and some businesses and residences along the waterfront may experience flooding with a common flood event (5–10% chance of occurring in any given year). Flooding will increase in frequency and depth by the end of the century when flood events are expected annually with king tides, and common events will bring floods with depths greater than 0.6 m to the hotel. A flood probability curve for the hotel, as a representative location for Coal Harbour, is shown in Figure 39.

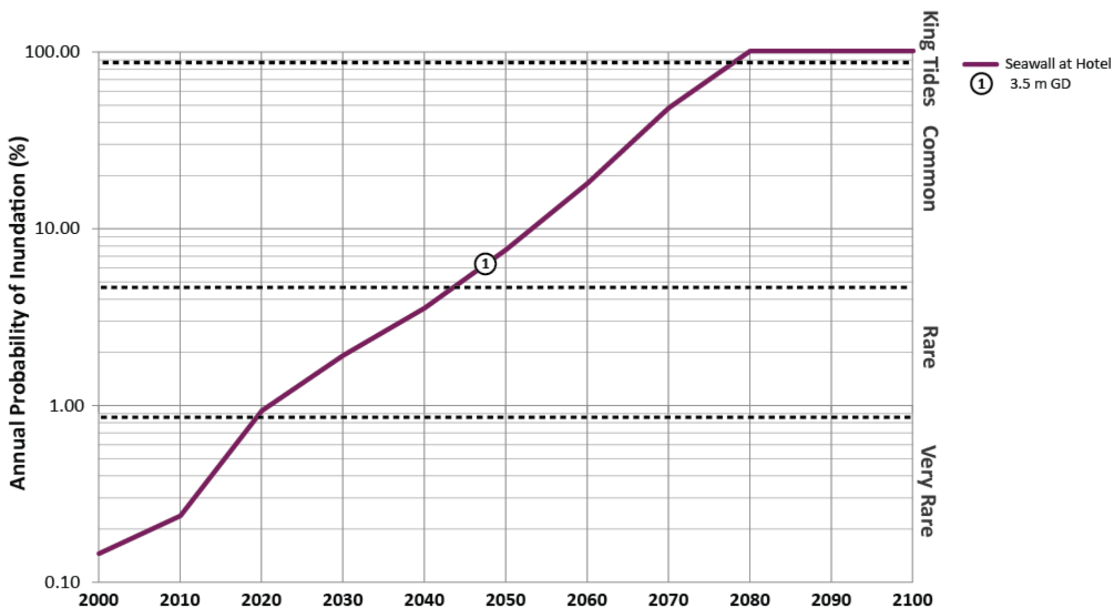
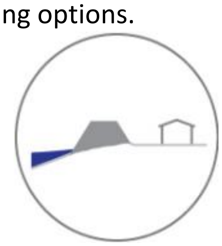


Figure 39. Annual probability of inundation for the hotel in Coal Harbour

3.4.1.3 Alternatives Considered

Three alternatives for protecting the Coal Harbour zone were identified: i) protecting with a raised seawall, ii) protecting with a structured wall, and iii) adapting to accommodate occasional flooding using planning options.



Protect
With Raised Seawall

Protect
With Structured Wall

Adapt
With Planning Options

Detailed designs were not developed for Coal Harbour at this stage, though workshop participants agreed in principle that these three alternatives should be considered further. The two Protect alternatives are very similar, in that a physical structure (raised seawall or structured wall—potentially a temporary barrier) would nominally run along the existing alignment of the seawall. The raised seawall approach requires space to allow for gentle sloping, whereas a structured wall could be accommodated in tighter spaces. The raised seawall approach would have recreational and aesthetic benefits, in that the current user experience of walking or cycling along the seawall would remain virtually the same. A structured wall might impede views and access to the water. Both Protect alternatives will likely affect the views from existing ground-floor residences and businesses. The Adapt alternative is a viable one for this area, as only one building is severely affected. In this case, assuming the existing structure remains as is for the next 50 years, then retrofits to the building that create property-level barriers could be an effective option. Should the property turn over or undergo significant re-design, the property should be designed for flood-resiliency (either by raising the main structure, a sacrificial first floor, or temporary dry flood-proofing barriers as described for the retrofit scenario).

3.4.1.4 Conclusions and Recommendations

Coal Harbour contains a number of businesses, residences, and parks that are subject to significant flooding from mid-century onward, and will need to be protected. Immediate action in this area is not required given the limited extent of flooding in the near term. However, flood protection at the hotel will be required in the coming decades.

In order to make an informed decision when developing an adaptation strategy for this area, we recommend:

Short-Term (to 2020) Recommendations for Coal Harbour

1. The City should immediately provide the current owners of the hotel with information relating to their existing hazard (i.e., this report).

Medium-Term Recommendations (to 2050) for Coal Harbour

2. A similar study to this one should be completed using new sea level rise projections as well as updated information on development patterns within Coal Harbour. If a raised seawall path or structured wall is recommended at this point, plans should be in place to implement it by 2050.

Long-Term Recommendations (to 2100) for Coal Harbour

3. Continue to monitor sea level rise.

3.4.2 Waterfront

3.4.2.1 Zone Summary

Key assets at risk in zone:

- Vancouver Convention Centre
- Canada Place
- Translink SeaBus Terminal
- Rail yard
- Crab Park
- Port Metro Vancouver

This zone consists of the north downtown waterfront along Waterfront Road from Thurlow Street to Main Street. The Vancouver Convention Centre and Canada Place occupy a large portion of the waterfront to the west with large structures, as well as complex underground roads and building entrances. Flood risks underneath these structures are not well-understood given a lack of information on sub-structure elevations (for roads, walkways, the Canada Line Station, and rail lines) and potential points of entry for water. A low-lying stretch of Waterfront Road immediately to the east of Canada Place poses a potential entry point for water, with present-day *king tide* events nearly breaching the top-of-bank. Adaptation alternatives have not been considered in detail for this area to date because of the complicated inter-jurisdictional concerns. However, Port Metro Vancouver has been involved in the CFRA process and is aware of the immediate concerns. They have provided some design concepts to protect the area in the short term (Figure 41).

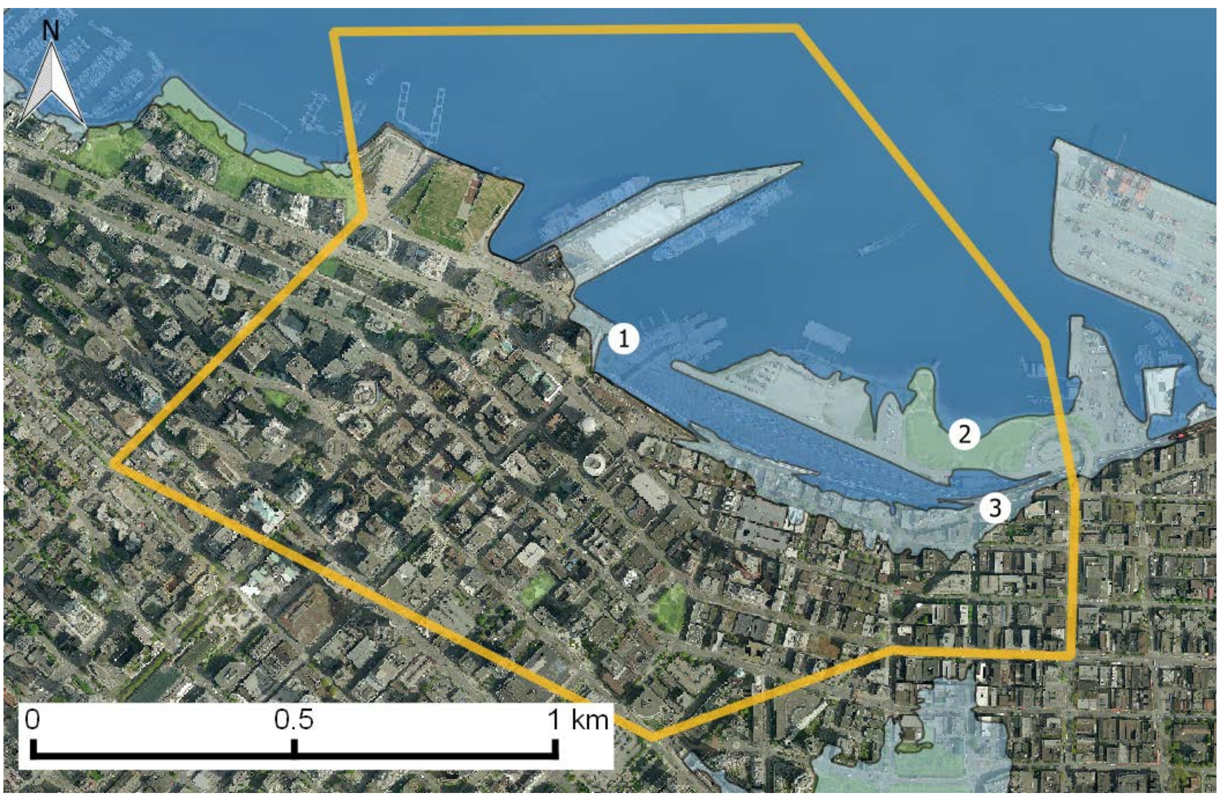


Figure 40. Flood-extent map for Waterfront

Flood extent (with 0.6 m freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

a) b)

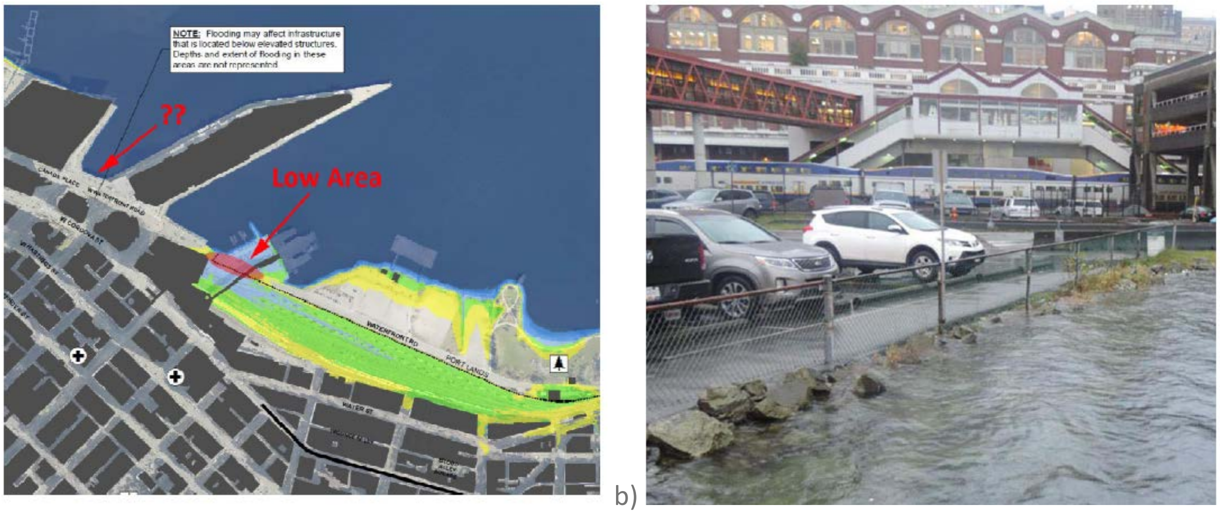


Figure 41. Low-lying stretch along Waterfront Road

a) Location of the low-lying section (red) and potential flood extents in the area (green and yellow), b) Photo taken from 2014 king tide event in front of the low-lying area. Concept from Sean Smith, Port Metro Vancouver

3.4.2.2 Flood Probability, Magnitude, and Timing

Analysis of the probability and extent of flooding in this area suggests that the low-lying portion of Waterfront Road to the east of Canada Place, as well as potential water entry points underneath these structures, pose a significant threat of flooding today for Canada Place, the Vancouver Convention Centre, the SeaBus Terminal, and potentially the Canada Line station and rail lines (Figure 42). Crab Park and the Port Metro Vancouver loading docks could also flood today in *very rare* flood events. By mid-century, the low-lying area of Waterfront Road may be flooded annually with increasing flood depths, while Crab Park may flood with *common* flood events. Flooding will increase in frequency and depth by the end of the century, with annual or multiple floods per year for Crab Park, and the low-lying stretch of Waterfront Road, which could reach 1.5 m or more in depth.

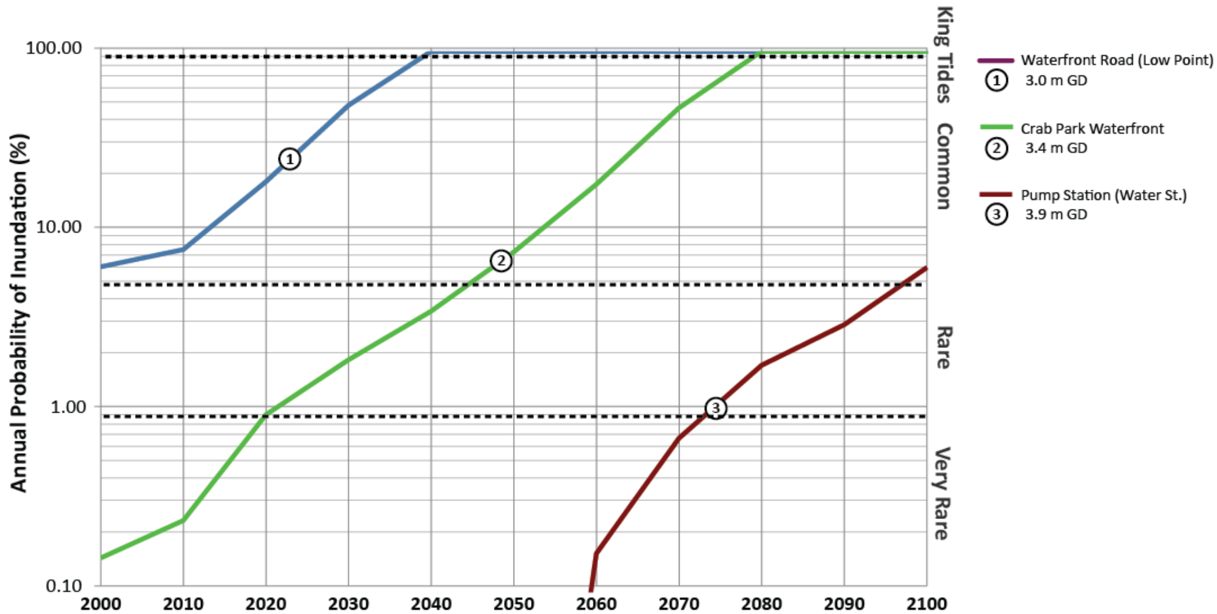


Figure 42. Annual probability of inundation for representative locations in Waterfront

3.4.2.3 Conclusions and Recommendations

The Waterfront zone is a hub for the city. It contains the terminus for multiple transportation networks as well as the Convention Centre, Canada Place, and the cruise ship terminal. It is crucial that the City and other stakeholders work together to reduce flood risk in this zone.

Due to a lack of information on elevations and potential points of water entry underneath the Convention Centre and Canada Place (not within City Jurisdiction), it is difficult to assess flood risks for these structures. Flood risks assessed at the low-lying stretch of Waterfront Road may serve as a proxy until more information is collected. Specific recommendations include:

Short-Term (to 2020) Recommendations for Waterfront

1. Considering that water levels with annual *king tide* events may breach the roadway west of the SeaBus Terminal at today's sea level, it should be an urgent priority for action by the City. We recommend that the City form a committee with other affected parties (Port Metro Vancouver, PavCo, Translink, railways) to investigate available options for raising this stretch of road in the next few years, or alternately building a wall to block the water.
2. In addition, we recommend that the Waterfront Road stakeholders consider investing in temporary barriers to be deployed for this area during *king tide* events to protect from flooding until a more permanent solution is in place. Although sandbags continue to be used around the world, better more robust options are available.
3. A city-wide warning system and emergency response plan should also be in place, so that temporary protection can be placed in time to mitigate damages.
4. In order to make an informed decision with developing a broader adaptation strategy for the Waterfront zone, we recommend that the City convene a broad stakeholder committee to:

- Collect elevation profile data and survey the waterfront underneath these structures to identify potential points of water entry.
- Review flood risks underneath the Convention Centre and Canada Place.
- Identify and assess potential protection and adaptation options for the location.

3.4.3 Port Lands

3.4.3.1 Zone Summary

This zone comprises the coastal lands east of Main Street to the edge of New Brighton Park. The mapped floodplain (today and in the future) lies entirely within the bounds of Port Metro Vancouver (PMV). The rail lines are largely outside the floodplain in this zone, although some of the spur lines are at risk of *rare* flooding today and in the future.

Key assets at risk in zone:

- Port Metro Vancouver assets including:
  - Ballantyne Pier
  - CenTerm
  - VanTerm
  - Alliance Grain Terminals
  - Maintenance Yards

The impact of flooding in this area would directly affect PMV operations, and the cascading effects of this in terms of goods movement and economic losses would be significant for the region and country.

The floodplain in this area is not within the jurisdiction of the City of Vancouver, and therefore no adaptation alternatives are presented as part of this report.

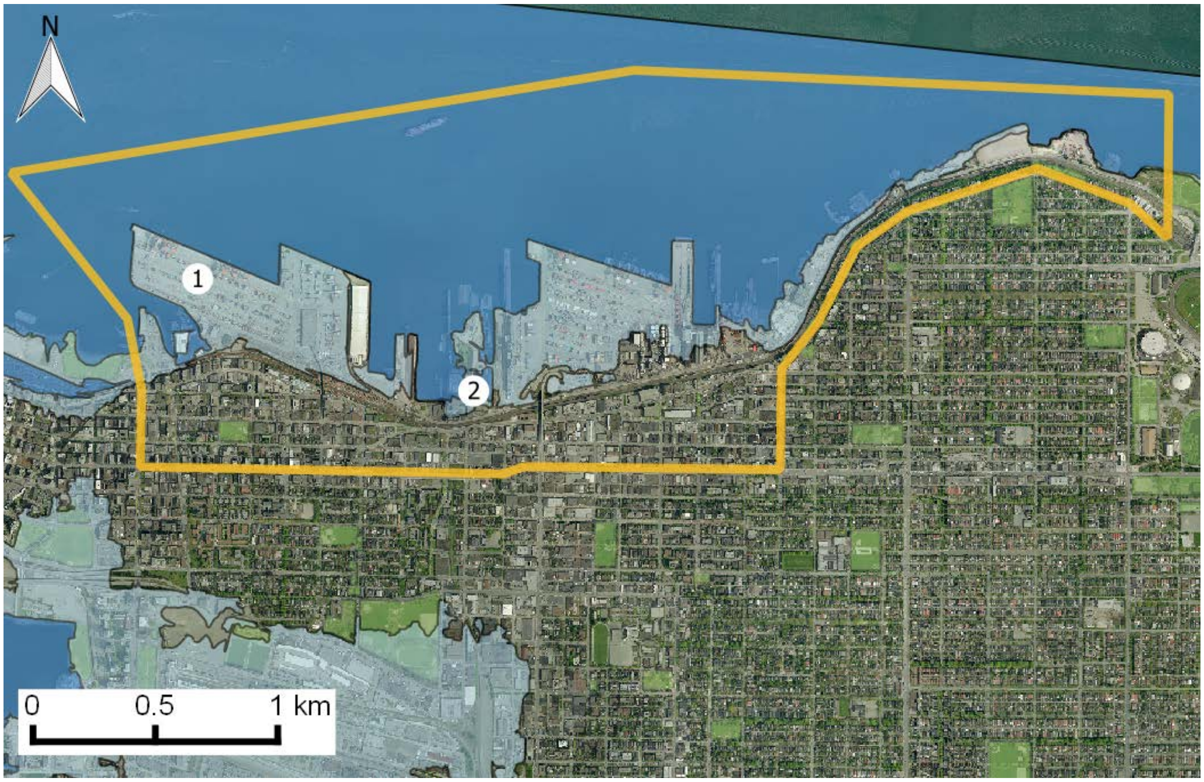


Figure 43. Flood-extent map for Port Lands

Flood extent (with 0.6 m freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.4.3.2 Flood Probability, Magnitude, and Timing

Analysis of the probability and extent of flooding in this area suggests that the low-lying portions of Port Lands are at risk of flooding in a *very rare* event today (Figure 44). Flooding will increase in frequency and depth by the end of the century, with annual flooding or multiple floods per year.

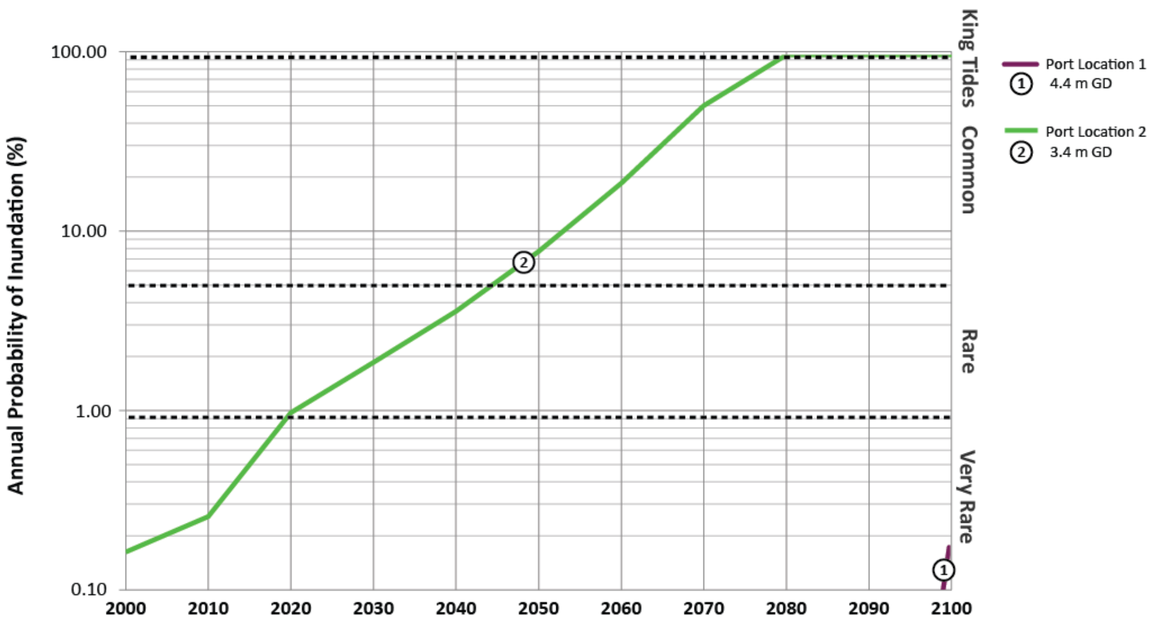


Figure 44. Annual probability of inundation for representative locations in Port Lands

3.4.3.3 Conclusions and Recommendations

Port Metro Vancouver is an economic driver for the city. Although outside the direct jurisdiction of the City of Vancouver, it is important that the City inform PMV of their risk so that they can work to mitigate it over time.

Short-Term (to 2020) Recommendations for Port Lands

1. Immediate action is not needed to protect this area, though we recommend that the City continue a conversation with Port Metro Vancouver to review flood risks and adaptation options available.

3.4.4 Brighton Beach

3.4.4.1 Zone Summary

The Brighton Beach zone consists of New Brighton Park and the terminal to the west of Second Narrows Bridge, and Bates Park and the westernmost section of Montrose Park to the east of the Bridge. Much of the area along the waterfront to the west of the bridge is low-lying land. Impacts from flood events and adaptation alternatives have not been explored in detail for this zone.

Key assets at risk in zone:

- New Brighton Pool and field house
- Port terminal building

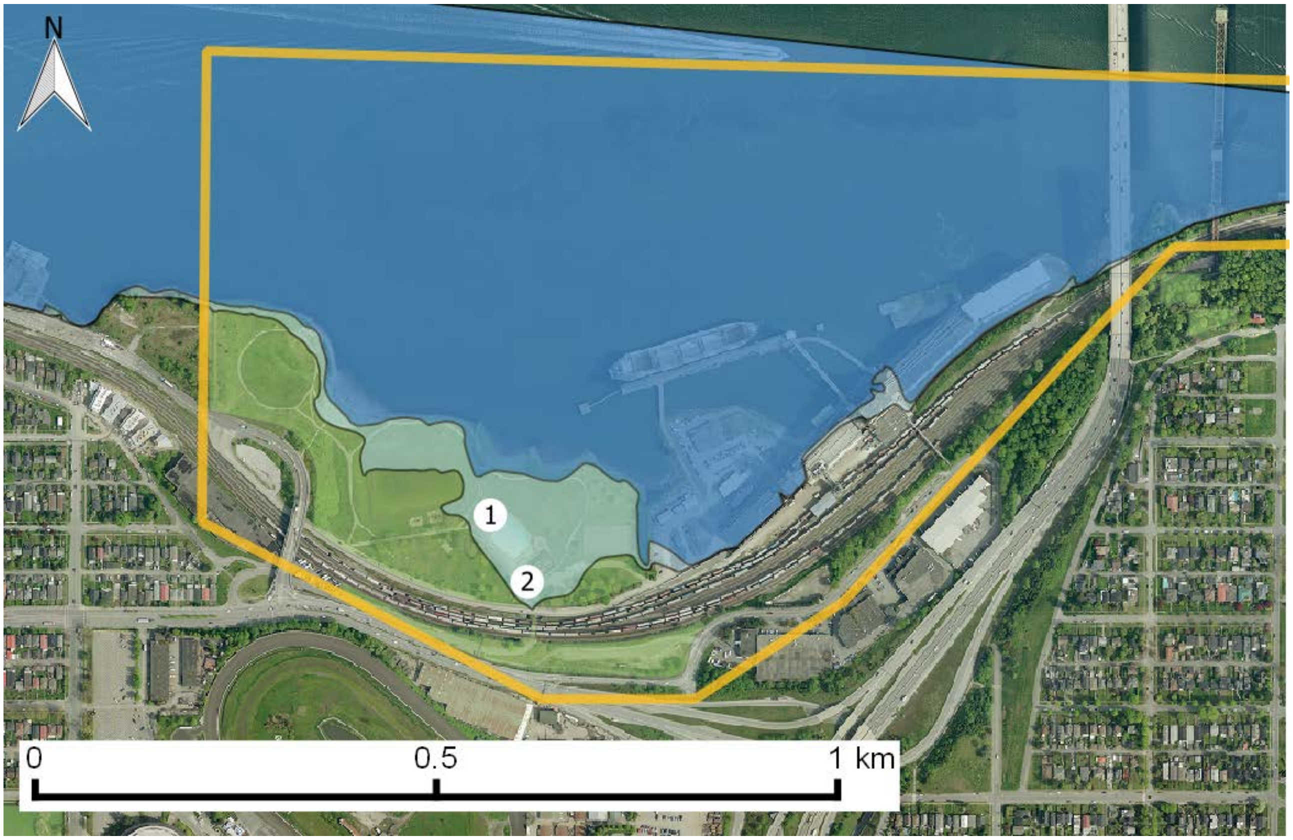


Figure 45. Flood-extent map for Brighton Beach

Flood extent (with 0.6 m freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.4.4.2 Flood Probability, Magnitude, and Timing

The probability of flooding in the area of the terminal today is high given the low-lying land. The terminal may flood today under a *rare* to *common* flood event, while New Brighton Park is protected given its relatively higher elevation (Figure 46). By mid-century, the terminal may be flooded annually with *king tides*, while the pool and field house in the park may flood with *rare* events. The frequency and depth of flooding will increase by the end of the century with the terminal flooding once or more annually, and the park flooding with *common* events.

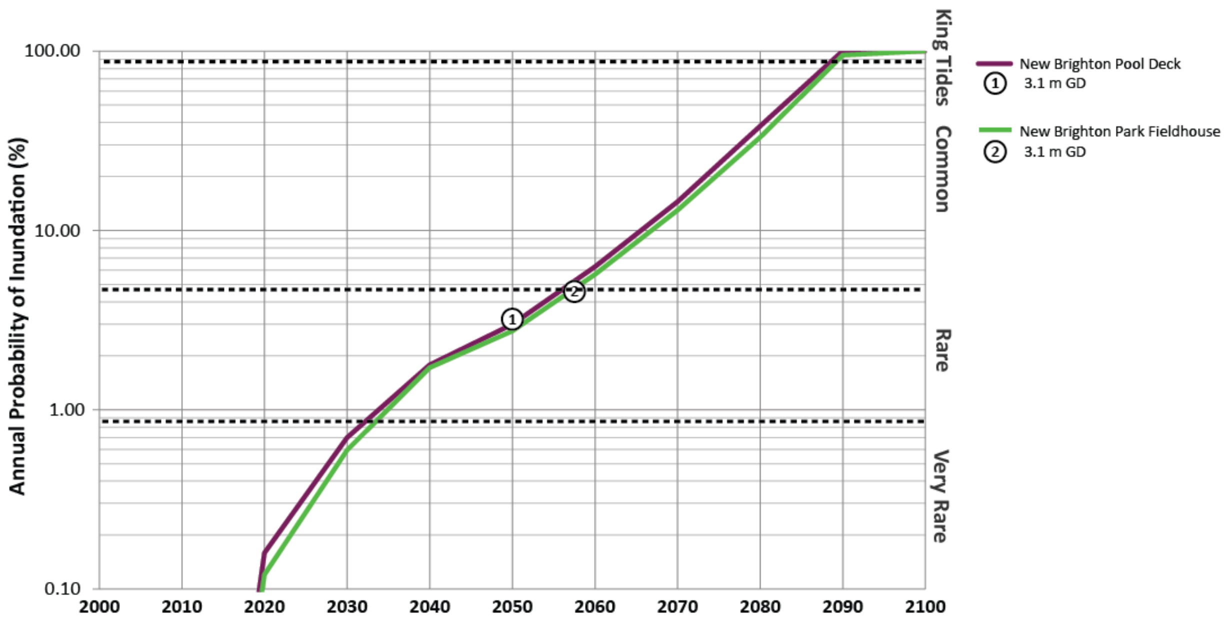
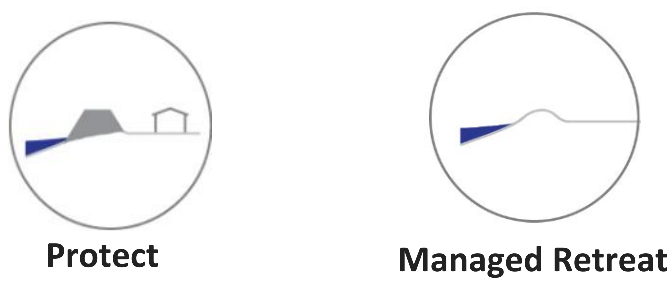


Figure 46. Annual probability of inundation for representative locations in Brighton Beach

3.4.4.3 Alternatives Considered

Two alternatives for protecting the Brighton Beach zone were identified, including i) protecting with a dike, and ii) managed retreat. Detailed designs were not developed for this zone, though workshop participants agreed in principle that these alternatives should be considered further.



3.4.4.4 Conclusions and Recommendations

While immediate action is not required for this area, the port terminal is at risk of significant flooding at current sea levels, and action should be taken in the near future (the next 5–10 years) to explore adaptation alternatives. We recommend the City inform affected stakeholders in the area. They can then further explore flood risks and identify potential adaptation options to protect the infrastructure.

New Brighton Park is not expected to flood in the near future, but will experience increased flood risks by mid-century. We recommend that the City convene a committee to further explore risks and adaptation options for New Brighton Park in the next decade or two to protect facilities from flood damage. A managed retreat alternative offers significant potential for habitat enhancement in this area, which may align with the Parks Board vision for this area.

3.4.5 Stanley Park

3.4.5.1 Zone Summary

This zone consists primarily of beaches, seawall, parkland, and park facilities, as well as residences and small businesses northwest of Denman Street and along Beach Avenue from Stanley Park to Burrard Bridge. The zone is characterized by relatively steep grades that constrain flood risks to areas close to the waterfront, most of which lie within City of Vancouver parks and are therefore under the jurisdiction of the Parks Board. Relatively few structural assets lie in the floodplains compared to other areas and therefore flood impacts were not analyzed in detail for this zone, and adaptation alternatives have not yet been developed.

Key assets at risk in zone:

- Deadman's Island, HMCS Discovery
- A yacht Club
- A rowing Club
- Seawall and park waterfrontroadways
- Causeway
- Second Beach Pool and concession
- Sunset Beach concession

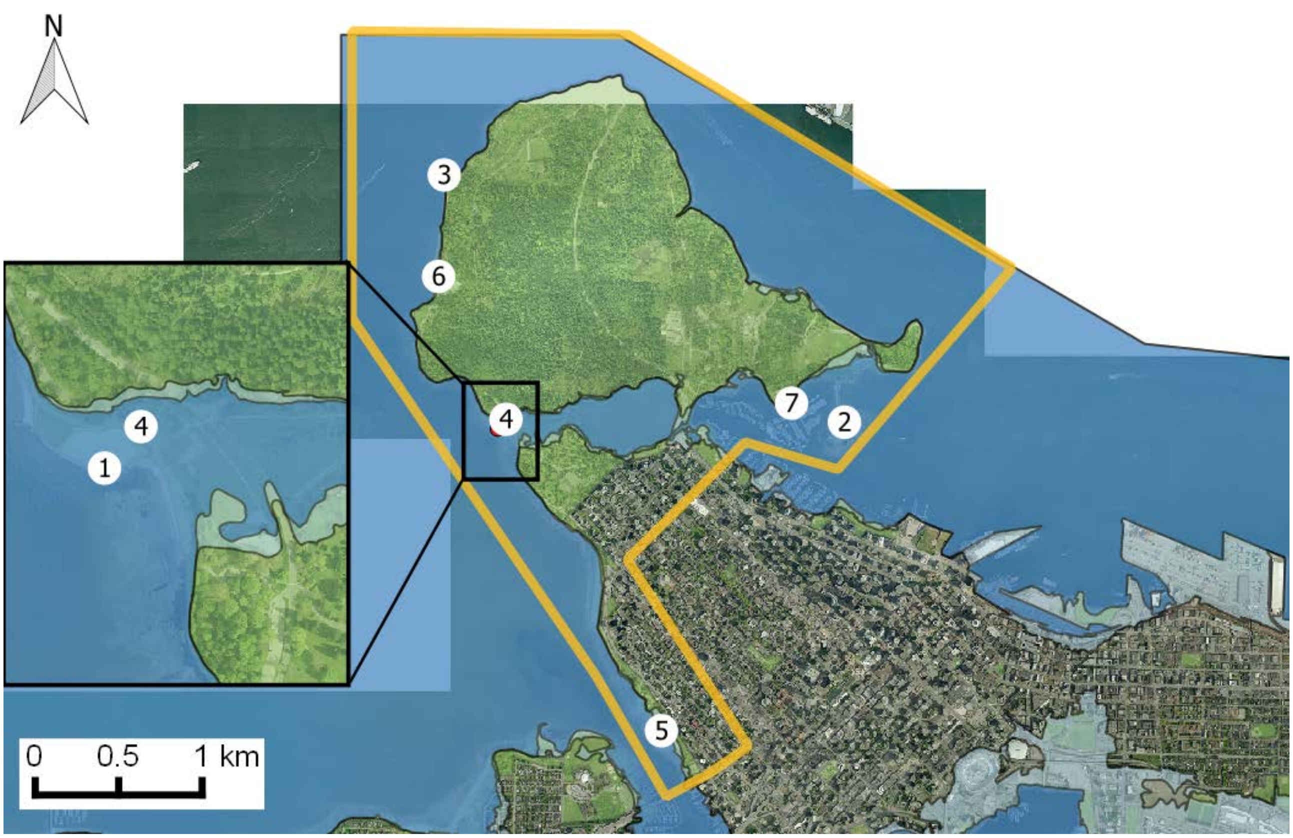


Figure 47. Flood-extent map for Stanley Park

Flood extent (with 0.6 m freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue. White numbered circles indicate representative locations where annual probability of inundation curves are calculated, as illustrated below.

3.4.5.2 Flood Probability, Magnitude, and Timing

The probability of flooding in this zone at today's sea level is high along the seawall, with *king tides* flooding some locations annually, *common* events expected to flood the Second Beach Pool and elevated portions of the seawall, and *very rare* events expected to flood the Second Beach and Sunset Beach concessions (Figure 48). By mid-century, annual flooding or multiple floods per year can be expected along much of the seawall and at the Second Beach Pool, with *common* flood events inundating Second Beach and Sunset Beach concessions, the Stanley Park Causeway at Lost Lagoon, and Deadman's Island. By 2100, flooding is expected once or more per year along the seawall, causeway, and concessions. It is unclear to what extent the Royal Vancouver Yacht Club and Vancouver Rowing Club would be affected by sea level rise and flood events over the next century; individual assessments of these structures with detailed floor elevations could be conducted to improve on this analysis.

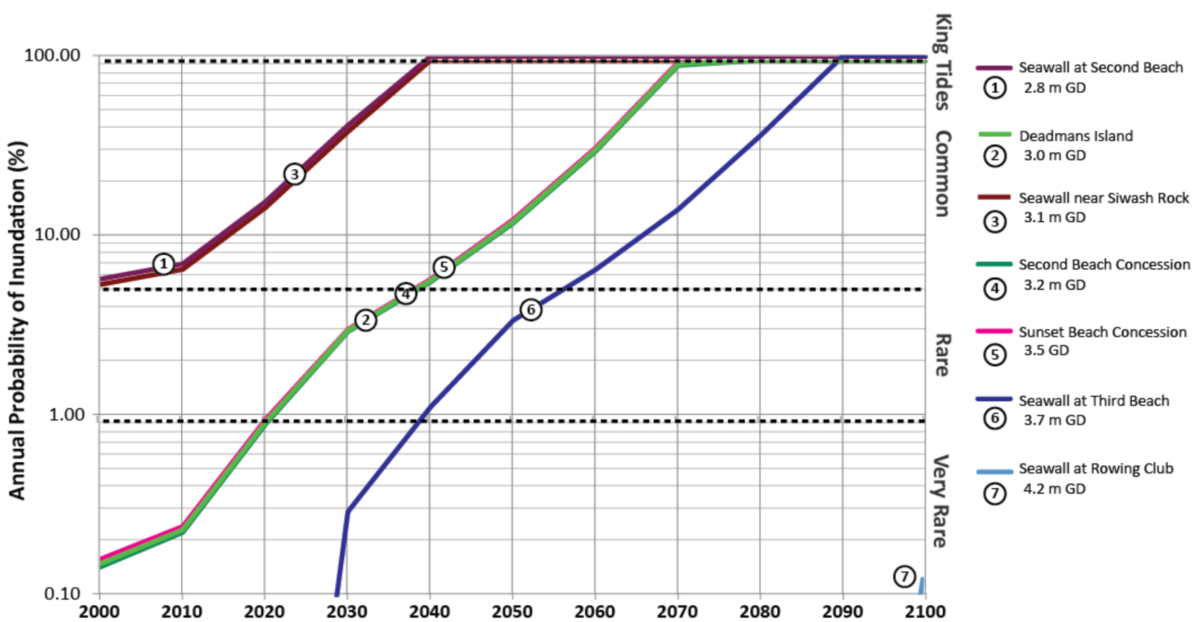


Figure 48. Annual probability of inundation for representative locations in Stanley Park

3.4.5.3 Conclusions and Recommendations

While flood risks for a number of structures in this area will increase over time, immediate action is not required given the limited extent of flooding and relatively few locations that will experience damage in the near-term. We recommend that the City work with the Parks Board in the next decade to further investigate flood risks and adaptation alternatives for beaches, parkland, and structures including Second Beach Pool and concession, Sunset Beach concession, Royal Vancouver Yacht Club, Vancouver Rowing Club, and the Stanley Park Causeway at Lost Lagoon. Specific recommendations include:

Short-Term (to 2020) Recommendations for Stanley Park

1. The City should continue to inform the Parks Board of the hazards and risk, and help them understand the implications of these.

2. Any park infrastructure that comes up for renewal should be designed with flood-resiliency in mind, and, ideally, as a model or showcase project.
3. Given that the raising of the seawall over time (especially west of Denman) might be a preferred protection strategy in the future, a right-of-way should be established along this alignment so that no structures are placed within the potential footprint of a raised walkway.
4. The City should monitor available information on coastal squeeze and the likely morphologic changes to the beaches over time as a result of sea level rise.
5. The City should investigate the value of allowing flooding to reconnect Lost Lagoon to the ocean.

Medium-Term (2020 to 2050) Recommendations for Stanley Park

6. Continue to monitor sea level rise projections as well as local changes to the beach.
7. Re-evaluate options (including the addition of new options) given new information and technologies.

Long-term (2050 to 2100) Recommendations for Stanley Park

8. Design and implement a solution.

3.4.6 Point Grey Road

3.4.6.1 Zone Summary

The Point Grey Road zone consists of the stretch of waterfront west of Kitsilano between Trafalgar and Alma Streets. It is characterized by steep topography with low flood risk to properties well into the future. No residential properties or businesses are within the floodplain, though the shoreline is prone to wave attack and associated erosion.

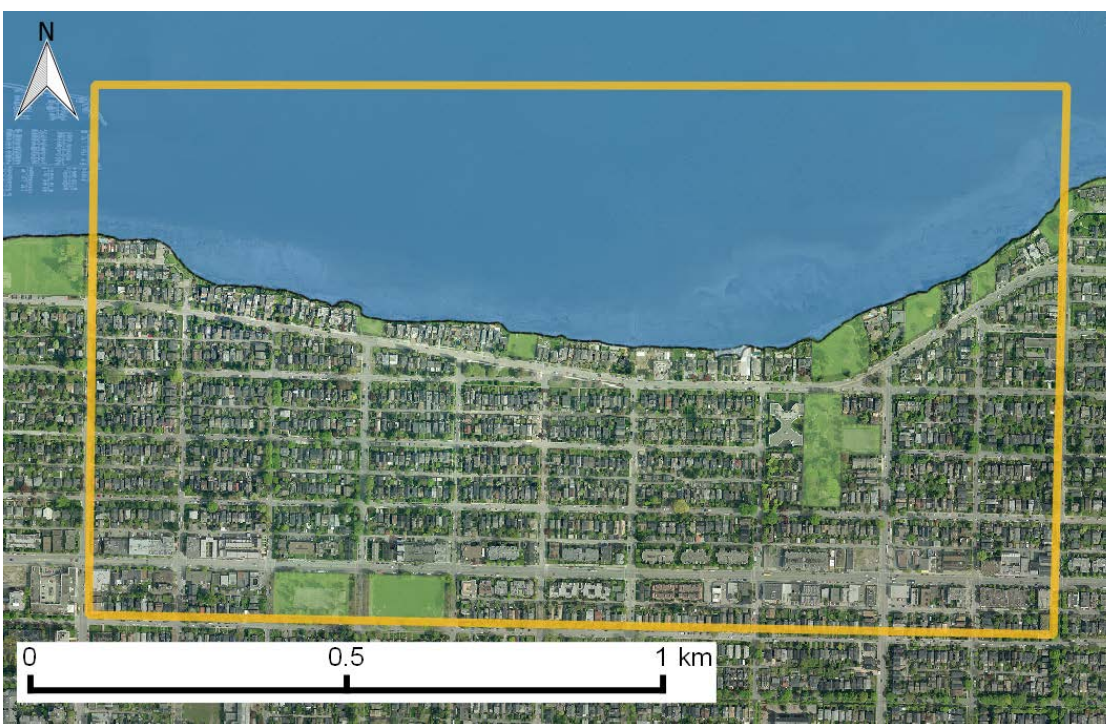


Figure 49. Flood-extent map for Point Grey Road

Flood extent (with 0.6 m freeboard) for i) a 0.2% flood today (0 m SLR) or high tide in 2100 (1 m SLR) is indicated in dark blue, and ii) a 0.2% flood in 2100 (1 m SLR) is in light blue.

3.4.6.2 Alternatives Considered

Protect
With Armouring

Given that impacts are generally limited to erosion, workshop participants agreed in principle that the City should consider protecting the zone with armouring.

3.4.6.3 Conclusions and Recommendations

The topography and morphology of this zone suggest a low overall flood risk. However, should storms strengthen over time in conjunction with sea level rise, increased erosion of the shore could be expected at this site. Specific recommendations to protect this area include:

Short-Term (to 2020) Recommendations for Point Grey Road

1. The City should monitor available information on coastal squeeze and the likely morphologic changes and erosion of the shoreline over time as a result of sea level rise.

Medium-Term (2020 to 2050) Recommendations for Point Grey Road

2. Continue to monitor sea level rise information as well as local changes to the beach and shoreline.
3. Re-evaluate options (including the addition of new options) given new information and technologies.

Long-term (2050 to 2100) Recommendations for Point Grey Road

4. Design and implement a solution.

3.5 City-Wide Recommendations

In addition to the zone-specific recommendations described above, city-wide recommendations are provided. Some of these are also re-confirmed in each of the zones. These include a mix of strategic planning initiatives, as well as tangible short-term actions:

1. In 2014, the City updated its Building Bylaw to include floodplain standards and requirements for floodplain areas. The City should continue to actively enforce these standards.
2. To support residents' and others' compliance with the updated regulations we recommend that the City work with higher-level governments and industry bodies to develop a toolbox and potentially an incentive program for property-level protection. A model of such a toolbox is the UK Homeowner's Guide to Flood Resilience[13]. No known incentive programs (other than through reduced insurance premiums, which is not applicable) were found as models.
3. Many of the recommended actions require that warning systems be in place. Therefore, we recommend the City work with other stakeholders to develop/support a flood warning system. The BC Storm Surge Forecasting Program, which provides storm surge forecasts, is not funded beyond March 2016.
4. The City Emergency Management Team should develop a flood-specific strategic response plan. Focus areas in the short term should be Fraser River Foreshore, Southlands, Waterfront, and Jericho-Spanish Banks.
5. The City should purchase temporary flood barriers to be deployed as appropriate (based on warnings—see recommendation 3 above). Sandbags, which are used currently, are an outdated technology prone to failure.
6. The City should avoid placing any additional critical infrastructure in the floodplain.
7. Any public infrastructure or assets built on the floodplain should be designed in a flood-resilient manner. Ideally, any new City or Parks Board buildings should be built as models to showcase resilient and innovative design.
8. The City should develop public and stakeholder engagement and education strategies at a city level as well as at a zone level (as discussed above).
9. The City should continue to work with and provide information to the Musqueam and Squamish First Nations.
10. The City should design and implement an Adaptive Management Plan (similar to the one proposed in Section 4). This will include monitoring activities, including the monitoring of actual local sea level rise rates and forecasts, and the monitoring of success/failure of implemented adaptation actions.
11. The City should continue to work with higher-level governments to develop better tools for future risk assessments. In particular, the City should recommend that the Federal Government collect

[13] UK Homeowner's Guide to Flood Resilience:
http://www.knowyourfloodrisk.co.uk/sites/default/files/FloodGuide_ForHomeowners.pdf

data on damage and losses for flood events in Canada. This will allow for a vastly improved Canadian Disaster Database, which can be used to improve the estimates presented in this report.

4 Adaptive Management Plan – A Proposal

Planning for sea level rise is an inherently complex problem, in great part because of the uncertainty of the timing and nature of climate change itself. In this report, we have made a number of recommendations that the City should consider for implementation now or in the near future—these are recommendations that deal with areas that are at risk of flooding today or that preserve options for adaptation in areas that will only be affected by floods in future. We also recommend a series of actions that will help monitor sea level rise and the changing flood risk.

Making recommendations beyond a horizon of about twenty years for specific actions does not make good sense; we do not have the information we need today to make robust decisions for the longer-term future. In fact, committing to decisions now about concerns that do not need to be addressed for decades could actually lead to bad outcomes—major infrastructure investments might be made several decades before being needed. Also, alternatives that seem inferior now might be rejected and options lost when in the future such alternatives might be viewed more favourably as situations and public values change over time. Based on Phases I and II of this Coastal Flood Risk Assessment, we know enough to develop a rational, systematic plan to address *near- to medium-term risks*, to preserve options for future decision making on *medium-* to *long-term risk*s, and to implement monitoring to help revise our path as we learn more. However, we do not (and cannot) know enough about the future to recommend specific solutions now to those *longer-term* challenges.

Applying the principles adopted early on in this planning process of seeking *flexible, adaptable, and robust solutions*, we suggest the development of a formal Coastal Flood Adaptive Management Plan for the City. Such an “AM Plan”, which would integrate closely with the Climate Change Adaptation Strategy, could perform the following main functions:

- Organize and keep track of the status of sea level rise and of each zone.
- Formalize the value judgements of City staff and (optionally) external stakeholders about the best time to make decisions to commit to a specific solution or solutions in each zone.
- Allow for adaptability, flexibility, and robustness in management actions and changing public values about choices.
- Provide a long-term blueprint to communicate what is known on an ongoing basis.

The following sections outline the potential features of such a plan.

4.1 Framework for addressing medium- to long-term risks

Central to the proposed Coastal Flood Adaptive Management Plan would be a framework to aid in determining *when to make a decision* about how to mitigate coastal flood risks in a specific zone (Figure 50). Two key thresholds may explicitly be defined and considered when choosing the timing of when flood risks are “too high” for a zone, and when planning and preparations should begin.

The first threshold concerns the outlook for hazards to each zone and the City’s risk tolerance for accepting the potential for flood damages there. At the present time, for most zones considered in this study, the risk posed by coastal flooding (in terms of *probability* x *consequences*) is low. However, as sea levels rise and zones change and grow, risk will begin to rise, even with the gradual ongoing implementation of adaptation measures such as property-level protection to minimize vulnerability. At some point in time the risk posed to the zone will be deemed by the City to be "unacceptable". This threshold (T_1) defines *the estimated sea level and date at which risk to a zone becomes greater than the City's threshold of acceptable risk*. The City would want to protect the zone by this date, therefore this threshold defines the **required in-service date** for flood protection measures. As discussed further below, the definition of such a threshold is a value judgment, and may differ from zone to zone.

The second threshold takes into consideration the expected **lead time** for the implementation of any of the identified options in a zone. Many of the options identified to date involve infrastructure that, to be built, would require a number of years to pass through the sequence of planning, consultation, financing, design, permitting, building, and commissioning. For some major infrastructure items, this lead time may be 15 years or more. The **zone decision date** (T_2) is the date by which a decision must be made and planning initiated for a zone. T_2 is defined by the *required in-service date* (T_1) *minus the lead time of the option with the longest expected lead time*. This threshold also defines the *mean sea level value*, which can also be used as a decision trigger. Since there is significant uncertainty over sea level rise projections, one strategy may be to decide on a mean sea level trigger rather than a date trigger to account for uncertainties over when a particular risk threshold is exceeded. Once observed mean sea levels reach the T_2 threshold, a decision process would be triggered.

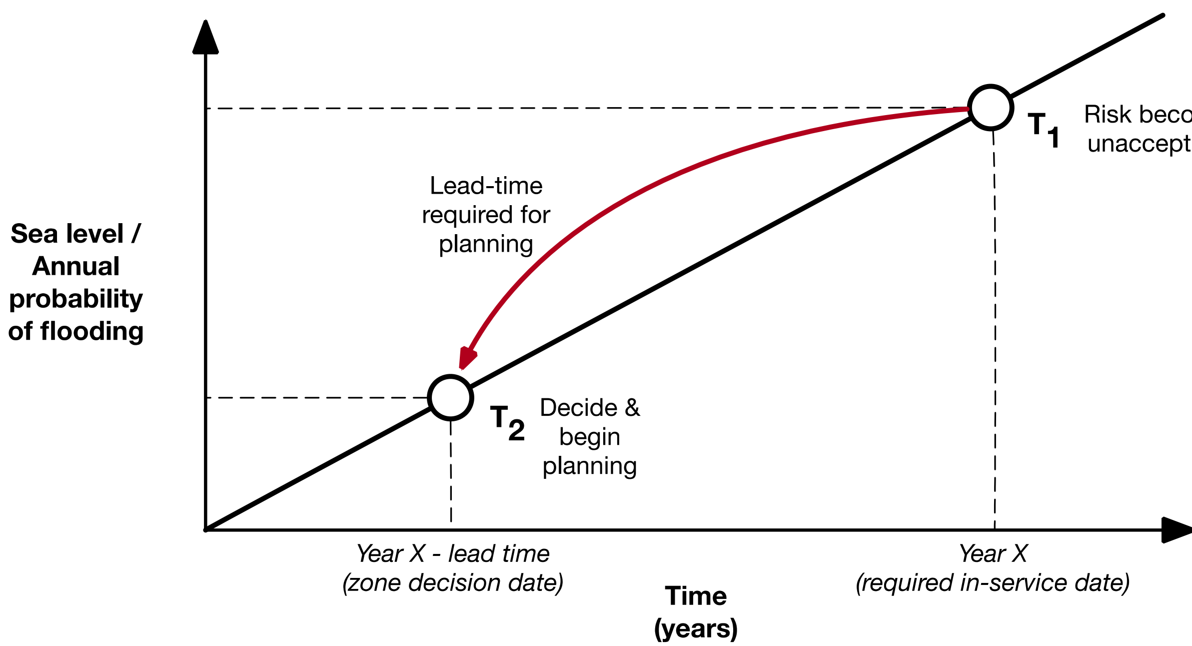


Figure 50. Selection of adaptive management thresholds.

If the risk is predicted to become unacceptable for a location in year X (T_1), and it would take a number of years of planning and preparation to protect that location (lead time, in red), then a decision would need to be made on an option in year X minus the required lead time of the option with the longest expected lead time (T_2).

Within an AM Plan framework (below), estimates for these dates could be updated on a five-year cycle as the City has access to better information on sea level rise rates (the hazard) and city development (the vulnerability). Table 5 shows options and estimated in-service dates, lead times, and decision dates for various options in two zones. *All numbers in this table are illustrative, and would need to be confirmed as* *part of the AM Plan.* For False Creek, the City may determine, for example, that the risk of inundation of key assets in a 5% flood event is unacceptable for the zone, and with rising seas that level of risk is projected to occur around 2045. Of the four options considered for False Creek, if the longest lead time is, say, 20 years, the City would need to make a decision by 2025 to provide enough time to implement an option before the desired 2045 in-service date. The City may choose to closely monitor mean sea levels as a trigger for making a decision (rather than selecting a firm decision date). In this case it may choose to use a mean sea level of, say, 7.3 m GD as a trigger. This mean sea level may be reached before or after the estimated threshold date, depending on how sea levels change over time, providing some ability to account for uncertainties in sea level rise projections.

Zone	Latest decision threshold criteria	Latest estimate of required In-service date	Options	Latest estimated implementation lead time	Conservative estimate of decision date to meet in-service date	Other relevant factors	Latest estimate of zone decision date
False Creek	Key assets at risk of flooding in a 5% event OR Mean sea level reaches 7.3 m GD	2045	Sea barrier	15 years	2030		2025
			Seawall	10 years	2035		
			3rd option	5 years	2030		
			Adapt	20 years	2025		
Fraser River Foreshore	Key assets at risk of flooding in a 0.5% event OR Mean sea level reaches 7.1 m GD	Happens now	Shoreline dike	10 years	2025		
			Inland dike	10 years	2025		

Table 5. Illustrative example of risk thresholds, lead times, and required decision and planning start dates for various zones

4.2 Possible structure of a Coastal Flood Adaptive Management Plan

Once a matrix is developed with key thresholds for unacceptable risk and decision triggers for flood-protection measures, a process could be followed to periodically review developments and decide what actions are necessary. Figure 51 is a proposed decision flow chart for a Coastal Flood Adaptive Management Plan that could be implemented on a five-year cycle during each AM Plan review. This framework involves five key steps, each of which is elaborated upon below.

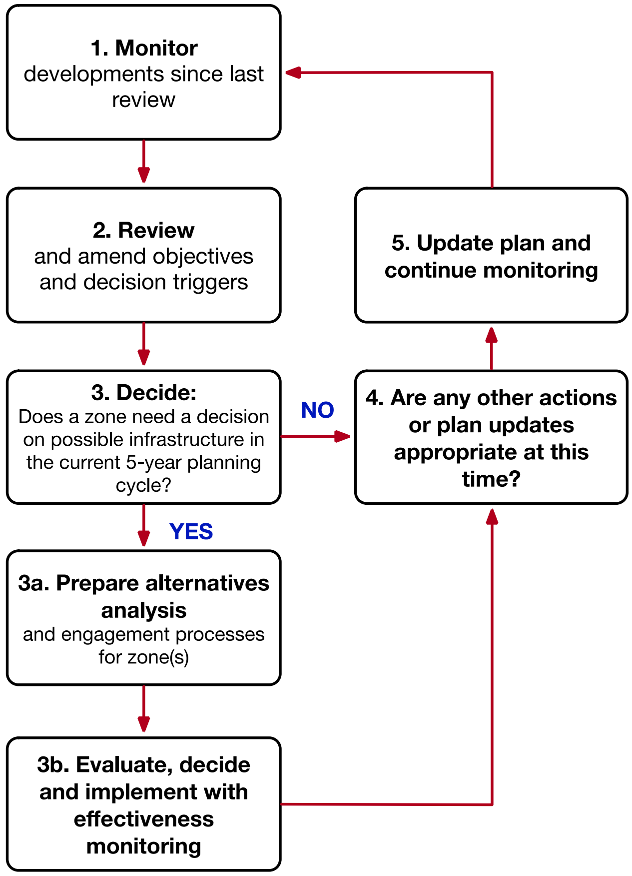


Figure 51. Draft AM Plan decision flow chart (to be undertaken every five years)

5. Monitor

In the first step of each five-year cycle (or in the face of a sudden, significant change in circumstances), the City (potentially with stakeholder input) would review the status of monitoring programs that have been organized under this plan. A report to the City would detail, among other things:

- **Mean sea level rise** – How much has the average sea level actually risen in the previous five years relative to Vancouver? How does this compare with historical forecasts? How does it compare to the water levels estimated in this study? What are the implications for future forecasts?
- **Effectiveness of previously implemented management actions** – What has been learned over the past five years about the efficacy of previously implemented actions (such as a dike or other mitigation option)? Learning about which activities work and which prove ineffective will be a vital role of a structured AM Plan.
- **City vulnerabilities** – How have City vulnerabilities changed over the past five years, and do any of these changes have implications for the risks associated with each zone? The performance measures defined for this project, under the broad categories of People, Economy, Environment and Infrastructure, are a starting point for this assessment. The precise measures should be updated to reflect values of the time (we cannot presume what City residents will care about 50 years from now).

- **Technological developments** – What new technological changes have been made, and do any of them represent opportunities for new options to be considered in any zones?
- **Experiences in other jurisdictions** – Have significant things been learned in other jurisdictions that might have relevance for future decisions in Vancouver?

6. Review and amend objectives and decision triggers

After reviewing this contextual information, the next step should be to review and consider amending summary Table 5. Dates may need to be adjusted to reflect better information on actual sea level rise, planning conditions, new technologies, etc.

A feature of this framework concerns the setting of elevation-based decision triggers for each zone. These could take several forms, but would functionally specify a mean average sea level value that would trigger the need for a decision to be made for each zone. Setting and amending these triggers would be a value-based exercise, ideally developed in partnership with stakeholders, that would take into account which assets or items are at risk at different elevations. In the periods between plan updates, we might expect to see changes in each zone to the number and type of the things that are valued in the area at risk (e.g., new buildings, new parks, higher populations, new transportation infrastructure, etc.). There might also be changes in how vulnerable these things have become—perhaps vulnerability has increased due to increasing numbers of assets at risk, or perhaps it has decreased as a result of the ongoing implementation of adaptation measures over time.

7. Decide: Does a zone need a decision on possible infrastructure in the current planning cycle?

Ultimately, the previous two steps then inform a decision as to whether or not the zone decision date (or sea level threshold) has been reached. If the answer to Step 3 is *yes* for one or more zones, then a parallel process begins for each zone.

If a threshold has not been reached for any zone, then skip to Step 4.

3a. Prepare alternatives analysis and engagement process

Once a zone has been identified as requiring a decision within the present five-year planning cycle, the City might consider reviewing the standard structured decision making steps of:

- **Clarifying the decision context** – Define the scope of the decision: performance requirements, budget constraints, stakeholder engagement process / communications plan, etc.
- **Reviewing objectives and performance measures** – Ensure that relevant city-wide and zone concerns are properly represented in objectives and performance measures. The performance measures defined for this project, under the broad categories of People, Economy, Environment and Infrastructure, are a starting point for this assessment. The precise measures should be updated to reflect values of the time (we cannot presume what City residents will care about 50 years from now).
- Refresh information on **available options**, including partial and full implementation variants, making good use of any new technologies identified during monitoring (Step 1).
- Assemble the options into various alternatives (combinations of options).
- Develop a **consequence table** that shows the expected performance of alternatives on the performance measures.

This may be carried out with stakeholder involvement and public engagement, and may be conducted on a zone-by-zone basis.

3b. Evaluate, decide, and implement with effectiveness monitoring

According to the appropriate engagement strategy developed for the zone, the City may then decide on a preferred alternative and initiate steps to implement it with appropriate effectiveness monitoring.

8. ***Are any other actions or plan updates appropriate at this time?***

AM Plans are living, dynamic strategy documents and all aspects of them require maintenance and rejuvenation. In this step, the City should consider issues including:

- Are monitoring efforts working (and if not, how might they be improved)?
- Are previously implemented flood-management actions working effectively (and if not, how might they be improved)?
- Are new monitoring efforts needed because there are new things we care about?
- Do new options exist that need to be preserved?
- Are any old options clearly no longer appropriate and should be released from consideration?

9. ***Update the plan and continue monitoring***

After considering these questions, changes should then be made and the monitoring phase re-started.

5 Summary Recommendations

The process used for this study resulted in some specific recommendations on a zone-by-zone basis, but also includes some broad city-wide ideas. For ease-of-use, we have summarized all of these in this section.

The recommendations in this section are grouped into the following categories:

- **Preserve** future options
- **Refine** engineering design of specific short-term and/or big-ticket options
- **Implement** short-term and “no-regrets” actions
- **Monitor** developments and plan to actively adapt to them
- **Engage** with communities, partners, and other levels of government

These categories are based on natural groupings, but can also be generally used to help define who at the City might take ownership of each of these recommendations. For example, the **preserve** and **engage** recommendations likely fall to the Planners, whereas many of the **refine** and **implement recommendations** will require action by the Engineering, Parks, and Planning Departments. **Monitoring** would likely be led by a co-ordinating project manager within the Sustainability Department.

<u>Key to Summary Tables</u>

Location: City-wide (CW); False Creek and Flats (FC); Fraser River Foreshore (FR); Southlands (SL); Kitsilano (KL); Jericho-Spanish Banks (J-SB); Coal Harbour (CH); Waterfront (WF); Port Lands (PL); Brighton Beach (BB); Stanley Park (SP); Point Grey Road (PG)

Approximate Timeline: 2XXX = Rough approximation of timeline for implementation (subject to AM Plan revision); NOW = Implement as soon as possible, ideally within 5 years; "+" = Once implemented, maintain activity (or function) into the future

City Effort, Cost, and Priority: L = Relatively Low; M = Relatively moderate; H = Relatively High

Note that only recommendations that are in the near future are given values for City effort, cost and priority.

5.1 Preserve future options

For the majority of zones for which immediate decisions are not required at this time, we believe that it is more important to identify and take steps to preserve options that might need to be evaluated perhaps decades into the future. The table summarizes specific suggestions we have on the area of preserving future options.

Location	Approximate Timeline	Description	City Effort	Cost	Priority
CW	NOW+	Avoid placing any additional critical infrastructure in floodplains.	L	L–M	H
FC	NOW+	Maintain/acquire right-of-way for partial dike in False Creek as well as for raised seawall.	M	M	H
FC	NOW+	Maintain potential future footprint of barrier.	L	L	H
SL	NOW+	Enable regulations to maintain existing density (i.e., do not allow increased density or development).	M	L	H
SP	NOW+	Maintain right-of-way along (and beside) existing seawall alignment to allow for future raising if warranted.	L	L	H
KL, J-SB	NOW+	Maintain right-of-way along (and beside) proposed dike alignments.	L	L	H

5.2 Refine engineering design of specific short-term and/or big-ticket options

In addition to dike alignments in Southlands and Fraser River Foreshore, more detailed engineering investigations are necessary in the cases of potentially major infrastructure investments in False Creek and Coal Harbour.

Location	Approximate Timeline	Description	City Effort	Cost	Priority
FC	NOW	Site-level protection strategies for Granville Island (CMHC).	M	H	H

Location	Approximate Timeline	Description	City Effort	Cost	Priority
FR	NOW	Detailed design for dike alignments, specifically looking for technical constraints.	H	M	H
SL	NOW	Detailed design for dike alignment, specifically looking for technical constraints.	M	M	M
J-SB	NOW	Plan for design competition to develop fine-grained adaptation solution.	L	M	M
FC	2020	Scoping-level design for sea barrier and seawall.	M	L	M
WF	2030	Review existing data and potentially acquire more detailed topographic (3D), hazard, and vulnerability information for the Waterfront zone that can be used to develop mitigation solutions.			
SP	2030	Investigate opportunity and consider value of reconnecting Lost Lagoon to open water.			
CH	2040	Revisit structural design solutions using latest information on SLR, development patterns and new technologies.			

5.3 Implementation Actions

The following table summarizes actions that the City should consider implementing. In particular, policy options should be considered that help potentially at-risk zones become less vulnerable to the effects of sea level rise and flood events over the natural course of infrastructure turnover over the coming decades.

Location	Approximate Timeline	Description	City Effort	Cost	Priority
CW	NOW+	Enforce existing Flood Plain Standards and Requirements.[14]	L	L	H
CW	NOW	Develop/support a flood warning system.	M	M	H
CW	NOW	Develop Strategic Flood Response Plan with focus on FR, SL, WF, and J-SB.	M	M	H

[14] http://former.vancouver.ca/commsvcs/guidelines/F014.pdf

Location	Approximate Timeline	Description	City Effort	Cost	Priority
FR	NOW	Plan, with other affected stakeholders, to finance approximately $150M dike construction project in near-term. (See related recommendation under Engagement.)	M	M	H
FR	NOW	Plan to acquire right-of-way along proposed dike alignments, refine best on outcome of detailed design project.	H	L	L
SL	NOW	Plan to finance dike project, with other affected stakeholders, of approximately $90M in near-term.	M	M	H
SL	NOW	Plan to acquire right-of-way along proposed dike alignments, refine based on outcome of detailed design project.	M	L	L
WF	NOW	Raise road or build permanent or temporary barrier to stop water ingress west of SeaBus Terminal.	L	L	H
J-SB, WF, CW	NOW	Purchase temporary barriers to be deployed as appropriate. Sandbags, which are used currently, are an outdated technology prone to failure.	L	M	H
FR	2020	Implement (i.e., build) a dike.	M	H	H
J-SB	2020	Plan to finance adaptation strategy.	L	L	M
KL	2020	Design and plan for implementation of adaptation strategy.			
J-SB	2030	Detailed design and construction of refined adaptation plan.			
CH	2050	Implement adaptation strategy.			
FC	2050	Develop plan to finance large infrastructure (barrier or raised seawall).			
FC	2100	Subject to change based on new information, but a barrier or seawall should be in place by the end of the century.			
SP, PG	2100	Implement adaptation strategy.			

5.4 Monitor developments and plan to actively adapt to them

Predictions on sea level rise are inherently uncertain, as are forecasts of increased frequency and intensities of storm events. We believe it is important that the City design and implement a formal adaptive management plan to help structure the timing and process of decision-making that will need to be made on an ongoing basis. (A proposed approach to adaptive management is presented in Section 4.)

Location	Approximate Timeline	Description	City Effort	Cost	Priority
CW	NOW+	Design and implement an Adaptive Management Plan.	L	L	H
CW	NOW+	Monitor success of implemented projects on variety of measures—using measures defined in this project as a guide.	L	L	M
CW	NOW+	Monitor actual local sea level rise rates, as well as updated forecasts. Review the suitability of the Canadian Hydrographic Gauge at Vancouver Harbour (Station 7735) for local sea level monitoring. If it is not suitable because of local effects (uplift, local hydraulics), then the City should consider investing in a second gauge, possibly in False Creek. This gauge could also be tied into education and engagement if it were designed for public interactions.	M	M	H
KL, J-SB, SP, PG	NOW+	Monitor changes to beach profiles and erosion of cliff faces.	L	L	H

5.5 Engage with communities, partners, and other levels of government

Finally, we urge the City to consider ways in which it can formally engage with communities, partners, and other jurisdictions to coordinate a range of activities and to begin and maintain a wider public dialogue about the often-difficult choices that lie ahead.

Location	Approximate Timeline	Description	City Effort	Cost	Priority
KL, J-SB	NOW	Explore community values, specifically to understand the value of beach versus parklands.	M	L	M
CW	NOW	Work with higher level governments and industry bodies to develop a toolbox and incentive program for retrofit and new-build property-level protection.	M	L	M

Location	Approximate Timeline	Description	City Effort	Cost	Priority
WF	NOW	Form a working group or committee with other stakeholders in this area to further explore risks and options. This would include Port Metro Vancouver, PaVCo, Railways, Translink, etc.	M	L	H
FC	NOW	Provide this report to CMHC.	L	L	H
FC	NOW	Include results of this study in planning process for False Creek Flats and Northeast False Creek.	L	L	H
CW	NOW	Provide report to higher-level governments. Make them aware of resources that will be required in future, especially for large infrastructure projects.	L	L	H
CW	NOW	Work with higher-level governments to improve data and tools for future risk assessments.	L	L	M
FR	NOW	Seek community feedback on the current preferred solutions (shore and inland dikes).	M	M	H
FR, SL	NOW	Discuss funding options for dike implementation with affected stakeholders.	L	L	H
FR	NOW	Provide report and detailed hazard information to owners of critical infrastructure in floodplain (BC Hydro, FortisBC, Translink, Metro Vancouver). Research if any other critical infrastructure is in this reach and inform owners.	L	L	H
SL	NOW	Seek community feedback on the current preferred solution (dike).	M	M	H
SL, FC, J-SB	NOW+	Continue to work with and provide information to Musqueam First Nation.	L	L	H
CW	NOW+	Use new City infrastructure as an opportunity to showcase and model flood-resilient design.	M	L	H
PL	NOW	Provide report and hazard information to Port Metro Vancouver.	L	L	H
SP	NOW	Provide report and hazard information to Parks Board.	L	L	H
BB	2030	Form working group or committee with other stakeholders in this area to further explore risks	L	L	M

Location	Approximate Timeline	Description	City Effort	Cost	Priority
		and options. This would include Parks Board, Port Metro Vancouver, and other stakeholders.			

6 Closing

The City of Vancouver's need to begin planning to adapt to climate change-driven coastal flood risk is a major issue. Over the decades to come, the solutions that will need to be implemented will profoundly shape the nature of many zones and will involve the expenditure of significant sums. The City has made significant progress in coming to terms with this likely reality.

In the Southlands and Fraser River Foreshore zones, the City of Vancouver already faces immediate need for flood protection. Fortunately, decisions in these areas are relatively straightforward since it appears that diking options are clearly a highly competitive option—the question is mostly around the technical feasibilities of potential alignments. However, as sea levels rise, other areas of the City will take their turn as the necessary focus of attention, and in many of these cases, the choices will often be tougher.

This journey is far bigger than one report can fully address. However, this work provides a foundation upon which subsequent work can build. We have developed options for examining in detail the trade-offs that underpin some of the toughest choices laying ahead, and that often need to be tackled at the appropriate time. Using the mapping, baseline consequence assessments, and probability curves, the City can work, through an Adaptive Management Plan, to sequence how and when to address these needs. Furthermore, the interests and perspectives of stakeholders and First Nations can be communicated through the use of consequence tables during consultation and engagement processes.

There are some gaps in our work. Most pressingly, we would like to continue to develop an approach to complement the scenario-based work presented here with a more risk-based, multi-objective approach to estimating consequences (i.e., where the consequences of flood events at different probabilities can be aggregated into an expected value for each objective). This would be another option to help weigh the pros and cons of different forms of intervention at different times. We are concerned that the scenario-based approach presented here (only because we did not have sufficient data or resources to complete a full risk-based assessment) does not adequately address the cumulative impacts of many small flood events. Such an option would also be valuable for a deeper level of stakeholder engagement.

We were fortunate to have access to the many perspectives and viewpoints from the individuals who participated in the various meetings and workshops we undertook for this process. However, moving forward, the conversation should ideally involve more people in order that the broadest possible range of perspectives are brought to bear. Through engagement, the City can learn about its citizens' priorities and preferences, and people can begin to understand and sympathize with the difficult values-based choices that City managers face. Developing these kinds of relationships early could prove invaluable once decisions that require highly controversial or potentially very large-scale interventions (e.g., at False Creek) eventually come to the fore.

We have emphasized the double uncertainties associated with 1) the physical nature of climate change itself, and 2) the changing needs and values of Vancouverites over time. In our view, an Adaptive Management Plan is an ideal vehicle to help balance our understanding of both as they unfold over time and to ensure that decisions are made at the right time. In conjunction with an external stakeholder committee, this could be a powerful means of both educating and engaging people over time. In order for this to work, however, the City needs to invest both in the Plan and in a program of monitoring of the key indicators discussed in Section 4. The staffing and monetary needs for this should be relatively modest.

The journey into the future of rising sea levels is an uncertain one, but one for which prudent, adaptive, flexible, and robust solutions can be made available over the coming decades, providing the City continues to demonstrate leadership in actively looking for them.

Glossary

Adaptation	In human systems, adaptation is the process of adjustment to actual or expected climate change and its effects, in order to moderate harm or exploit beneficial opportunities. With respect to sea level rise, adaptation refers to action taken to prepare for its occurrence.
Adaptation alternative	One or a combination of several adaptation options that collectively could be implemented to reduce the coastal flooding impacts associated with sea level rise.
Adaptive capacity	The ability to adapt in the face of potential flood hazards and risks.
Adaptation option	An isolated activity or tool that could be used as part of an adaption alternative (See Table 2 for list).
Adaptation strategy	A guiding overall philosophy to developing initial adaptation alternatives; alternatives could, in a first iteration, be designed to protect from, adapt to, or retreat from flood risk. More sophisticated alternatives could later be developed that combine these approaches once learning about their effectiveness has occurred.
Coastal squeeze	An environmental situation where the coastal margin is squeezed between the fixed landward boundary (artificial or otherwise) and the rising sea level.
Exposure	Refers to the state of the elements at risk being exposed to contact with something, such as a coastal flood event.
Flood event	An **x% flood event** is one with an x% chance of occurring in a given year, or once in (1/x * 100) years. ***Common* flood event:** High water levels associated with a combination of tide and additional storm components, with a 5% to 99% chance of occurring in any given year. ***Rare* flood event**: High water levels associated with a combination of tide and additional storm components, with a 1% to 5% chance of occurring in any given year. ***Very rare* flood event**: High water levels associated with a combination of tide and additional storm components, with a <1% chance of occurring in any given year. The City of Vancouver flood construction level (FCL) is currently set to the 0.2% event with 1 m of sea level rise. This would be considered a *very rare* flood both in the present-day and in 2100.
Flood hazards	The features of flooding that have adverse impacts on elements at risk such as the depth of water, speed of flow, duration, and water quality.
Freeboard	A freeboard is a safety factor used by engineers and managers to account for uncertainties in the calculation of water levels. In line with convention in BC, the flood extent mapping used here includes a 0.6 m freeboard.

HAZUS	A standardized methodology using Geographic Information System technology to estimate potential physical, economic, and social impacts from floods and other natural disasters. It was developed by the Federal Emergency Management Agency (FEMA) in the USA and is being adapted by Natural Resources Canada.
King tide	A predictable high-tide event without exacerbation from an accompanying storm. This would occur on average once or twice a year.
Likelihood (probability) of Flooding	A general concept relating to the chance of an event occurring. Likelihood is generally expressed as a probability or a frequency of a flood of a given magnitude or severity occurring or being exceeded in any given year. It is based on the average frequency estimated, measured or extrapolated from records over a large number of years and is usually expressed as the chance of a particular flood level being exceeded in any one year. For example, a 1-in-200-year flood would, on average, be expected to occur once in 200 years or with a 0.5% probability in any given year. Similarly, a 1-in-500-year flood would be expected to occur, on average, once in 500 years or with a 0.2% chance each year.
Option	See adaptation option.
Resilience	The capacity to anticipate, prepare for, respond to, and recover from the effects of sea level rise with minimum damage to social well-being, the economy, and the environment.
Risk	The likelihood of a negative event occurring (e.g., flooding due to sea level rise) combined with the magnitude of the potential consequences. Risk = Likelihood (Probability) x Consequence
Sea level rise	A slow increase in sea levels associated with the thermal expansion of warming seas and melting of major stores of land ice, due to climate change.
Storm surge	An increase or decrease in sea level due to atmospheric pressure changes and large-scale wind stress associated with a storm.
Strategy	See adaptation strategy.
Vulnerability	Refers to the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including variability and extremes. It is a function of exposure, sensitivity, and adaptive capacity. Vulnerability = Exposure x Sensitivity x Adaptive Capacity
Wave set-up	An increase in sea level shoreward on the wave-breaking zone due to momentum transferred from breaking waves. The wave-breaking process “pushes” water up the shore causing an increase in sea level. Wave set-up has a static component which is a constant increase in water level and a dynamic component which oscillates and is sometimes known as “surf beat”.

Wind set-up	An increase or decrease in sea level caused by wind stresses on the surface of the water. On-shore winds blowing over shallow water “push” the water up the shore causing an increase in sea level.

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