# MAPLEWOOD VILLAGE
# FLOOD RISK MANAGEMENT STRATEGY

## FINAL REPORT

Prepared for:

NORTH VANCOUVER
DISTRICT

District of North Vancouver
355 West Queens Road
North Vancouver, BC
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22 September 2016

NHC Ref. No. XXXXXXX

nhc
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# 1 INTRODUCTION

The District of North Vancouver ("the District") retained Northwest Hydraulic Consultants Ltd. (NHC) to carry out an overview level assessment of flood hazards in Maplewood Village, and identify main vulnerabilities in the floodplain. To inform the development of a flood risk management strategy, high-level economic losses caused by flood-damage to buildings are estimated. The report further explores best management practices associated with flood risk mitigation and focuses on strategies feasible for implementation in Maplewood Village. Opportunities and constraints of the various strategies are explored, and a high-level implementation plan for the most promising strategies are developed.

## 1.1 Maplewood Village Centre

Maplewood Village refers to a 35 ha area in the District on the east bank of the lower Seymour River (Figure 1). It is bounded by the Mount Seymour Parkway to the north, Dollarton Highway to the south, the river to the west and approximately Forester Street to the east. The location is attractive from a residential development perspective; in addition to its proximity to the river and foreshore, the area has natural open spaces, small creeks and parkland, including Maplewood Farm.

Development in lower Maplewood began in the 1920's with waterfront sawmills and evolved to other port-related industries, taking advantage of water transport, access to rail and once built, the main highway. More recently, business parks have been developed along the Dollarton Highway, contributing significantly to the District's employment base and economy (DNV, 2011). There is also a residential community of approximately 1,000 people in a mix of older, more affordable rental townhouses and low-rise apartments, as well as old and new single family homes. Modest commercial development is located along Old Dollarton Road.

In 2011, the District developed its Official Community Plan (OCP), in which the Maplewood community was identified as a growth site with plans to create a vibrant village centre. Over the next 20 years, it will accommodate a new mixed use and multi-family development of approximately 1,500 residential units, including significant square footage of commercial space (Figure 2). Figure 3 shows the present state of development in Maplewood Village Centre, including development sites that: 1) are under construction or completed; 2) are in the planning process; and, 3) could have possible applications.

Although most of the Seymour River floodplain lies in the District, the west bank from Mt Seymour Parkway to about Dollarton Highway, is under the jurisdiction of the Squamish Nation.

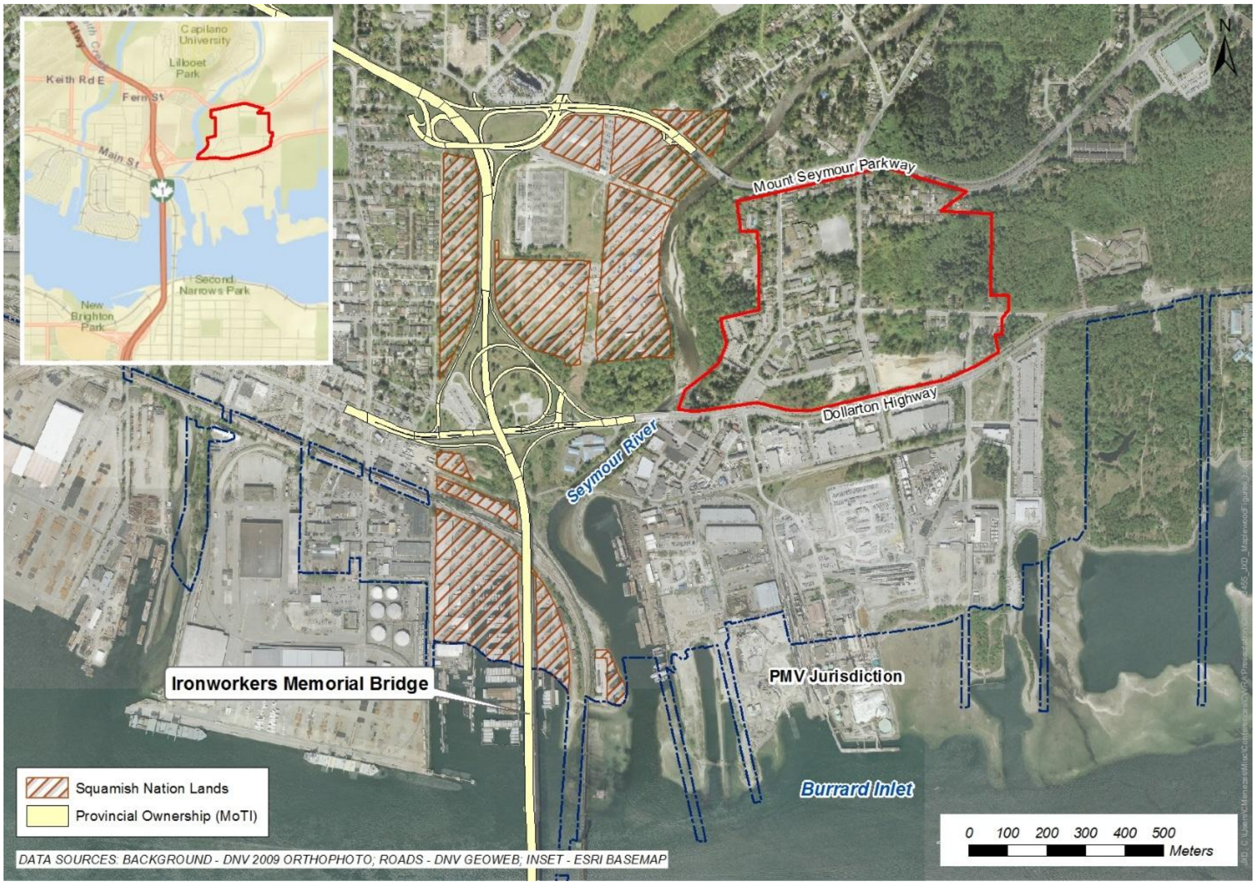



**Figure 1. Location Map of Maplewood Village Centre in the District of North Vancouver.**

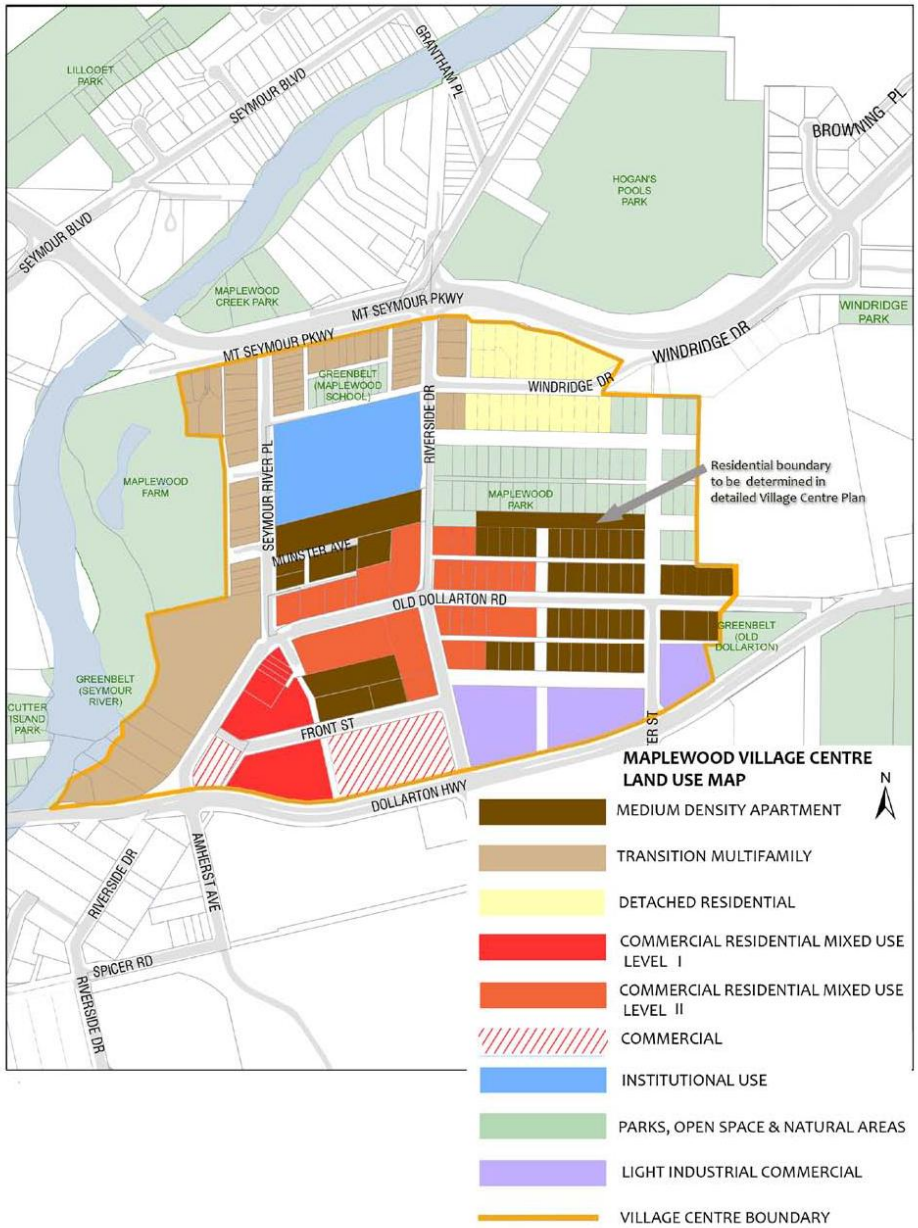



**Figure 2. Maplewood Village Centre Land Use Map from OCP (DNV, 2011).**

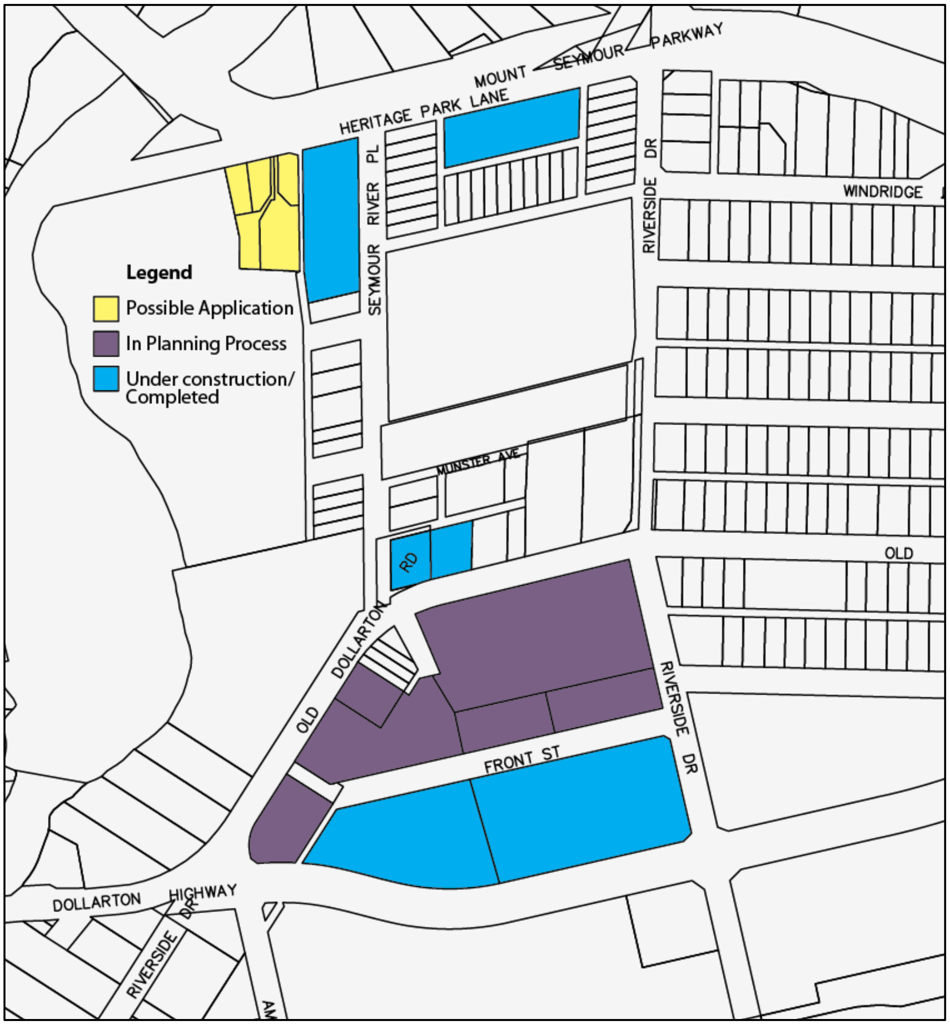



**Figure 3. State of development applications in Maplewood Village.**

## 1.2 Project Understanding

The District, situated in a natural landscape with a number of rivers and creeks, is bordered by the coastal waters of Burrard Inlet to the south and east. The present extent of floodplain is expected to increase over time, in response to sea level rise, increased precipitation caused by climate change and higher runoff caused by development intensification. The District is anticipating an influx of 20,000 people by 2030 which will further increase development pressure on the available lands. Balancing population growth and environmental values is a high priority for the District. New development, typically with a 75 to 100 year lifespan, will need to be designed for future flood conditions and the District recognizes that careful planning of new development is critical.

This forward-thinking outlook is the driving force behind the effort to develop a flood risk strategy for Maplewood Village. A key objective of the strategy is to build resilience through safe development.

Building resilience involves implementing planning-centric measures, minimizing the need for structural measures and achieving a more 'holistic' approach to flood management. The District has been on the forefront of implementing innovative strategies to mitigate risk from natural hazards on a District-wide and site-specific level, and seeks to bring a similar approach to flood mitigation and climate adaptation to Maplewood Village. A secondary objective is to be able to create and showcase this as a flood resilient hub within the District. Maplewood Village would achieve risk reduction without detracting from, and potentially even enhancing, the environmental values of the area, in particular riverine and wetland environments.

In the course of responding to recent development applications, the District has encountered some specific concerns and it is expected that the development of a flood risk strategy will provide guidance on issues such as:

- What are the potential challenges for underground parkades in new multi-family developments in this area?
- What is a safe setback for existing and future development along the river?
- For areas east of Seymour River Place, are there flood hazard concerns that require flood mitigation measures?
- What FCLs should be adopted where grade differences between adjacent properties along a street are significant?

## 1.3 Approach

Risk associated with any natural hazard is the product of the magnitude of the hazard and the degree of vulnerability in the hazard area. In the context of floods, the floodplain extents and flood levels define the hazard, and the vulnerabilities are a function of the assets (people, properties, and infrastructure) within the floodplain. For development planning purposes, it is not only the existing floodplain that should be considered but also the projected future floodplain over the adopted time horizon.

The North Vancouver flood hazard study (KWL, 2014a) provided combined river and coastal flood levels for 2012, 2100 and 2200. The coastal flood levels may be somewhat conservative and should be revisited in view of the Provincial government's preference for adopting a joint probability rather than additive approach in estimating design ocean levels. However, for the purposes of this study, the KWL values were adopted without adjustment. With a focus on development planning, which typically deals with a 100-year maximum building life, the 2100 flood levels were used as the future hazard condition. Year 2200 projections are associated with significant uncertainty and were not utilized in this study.

Using GIS, a broad assessment of community and infrastructure vulnerabilities within the present (2012) and future (2100) floodplains was carried out. The consequences of flooding were assessed using a risk assessment tool, which uses a modelling methodology similar to Hazus[1]. Outputs from this tool are limited to calculating the number of buildings damaged and associated dollar losses, but it nonetheless provides a quantitative indication of the degree of risk posed to a community's assets in a flood event.

The flood vulnerability and consequence assessments identified high risk areas that allowed the targeting of mitigation strategies in particular areas. As part of developing innovative flood risk management strategies, a review of best management practices from other jurisdictions was carried out. These were then screened for their applicability to Maplewood Village and the potential location of each feasible option was mapped.

The options were further assessed based on their approximate costs and benefits. The risk assessment tool informed which areas demand immediate action and was used to drive the implementation plan. Opportunities and constraints associated with the various strategies were explored, including by way of a workshop with District stakeholders. Using consensus regarding the most promising strategies, a high-level implementation plan was developed for the District.

[1] Developed by the Federal Emergency Management Agency (FEMA), Hazards U.S. Multi-Hazard (HAZUS-MH) is a nationally standardized methodology and software program that contains models for estimating potential losses from natural disasters.

# 2 PHYSICAL SETTING

## 2.1 Seymour River and Maplewood Creek

The Seymour River has a drainage area of 188 km$^2$ and flows in a southerly direction from its headwaters in the North Shore Mountains and drains into Burrard Inlet. Since 1961, the upper basin has been regulated by a dam, forming a Metro Vancouver reservoir of limited storage capacity. The Lower Seymour Conservation Reserve (LSCR), also run by Metro Vancouver, is located downstream of the dam. The lower third of the river corridor is largely developed and includes the community of Maplewood, located within the extents of the Seymour River fan on the east bank of the river. Roughly 800 m downstream of Maplewood Village, the river discharges into Burrard Inlet (Figure 4).

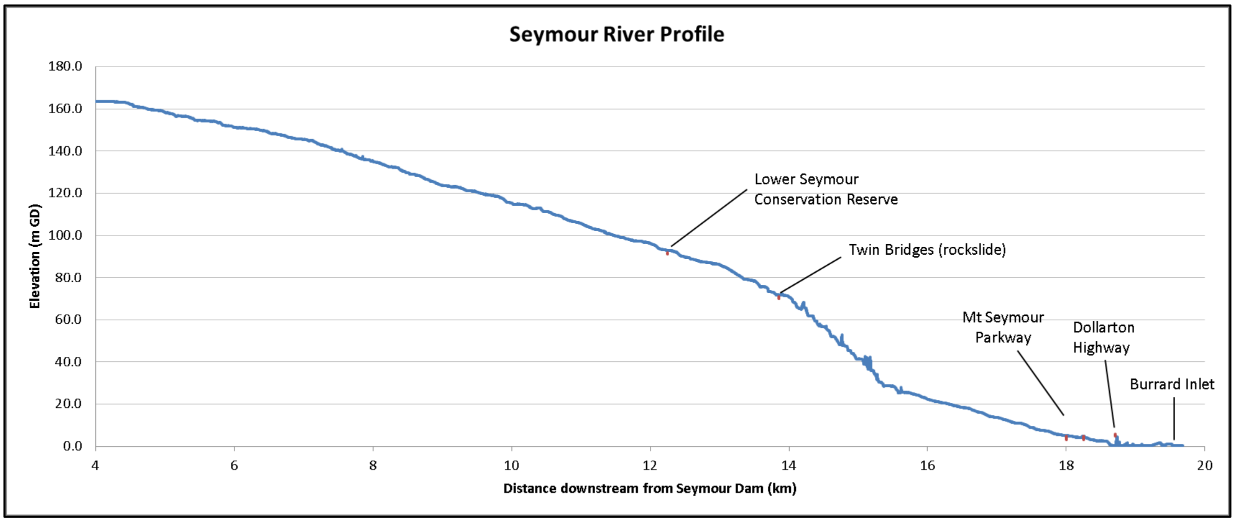



**Figure 4. Seymour River bed elevation profile, extracted from 2014 DNV LiDAR.**

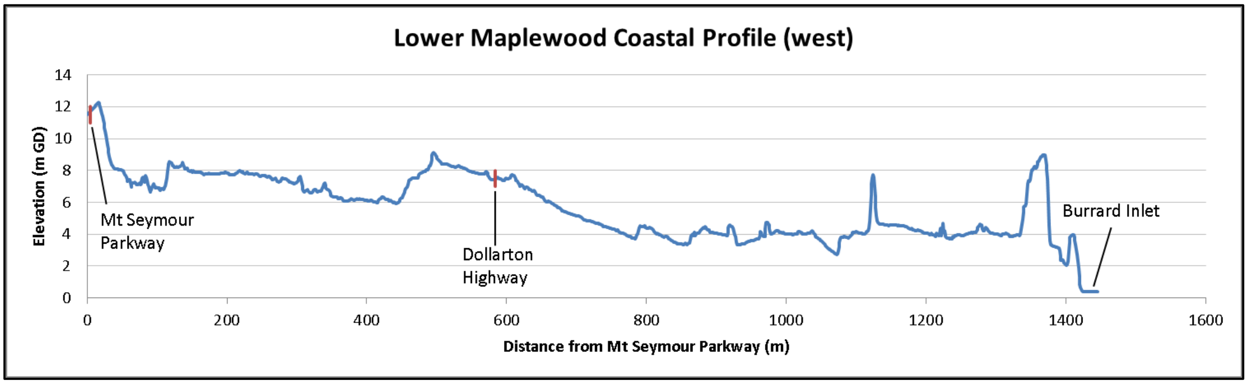
A training berm has been constructed in Seymour River Heritage Park, extending along a portion of the east bank of the river between Mount Seymour Parkway and Dollarton Highway.

Maplewood Creek, the only tributary of the Seymour River downstream of the conservation reserve, traverses the area. The creek flows under Mount Seymour Parkway through a corrugated metal culvert and has a deeply incised channel before entering a pond at Maplewood Farm. Downstream of the pond, the creek is trained with natural armouring, prior to discharging into the Seymour River.

## 2.2 Burrard Inlet Oceanfront

The coastal area south of Maplewood Village is composed of both natural and anthropogenic features. The area used to be natural tidal flats but in the 1950's, fill was added to develop the industrial lands south of Dollarton Highway. At the west end, the area has retained some of its former tidal flat character, including a small spit. Farther east, much of the shoreline is protected by riprap and has some forested foreshore. Other features include dredge cuts to accommodate barge transport and vertical concrete walls next to rail line end points.

Ground elevations along two sections cut through the Maplewood area near the east and west boundaries are shown in Figure 5. The profiles indicate that the ground extending inland from the shoreline is relatively flat at an approximate elevation of 3-4 m GD (Geodetic Datum).



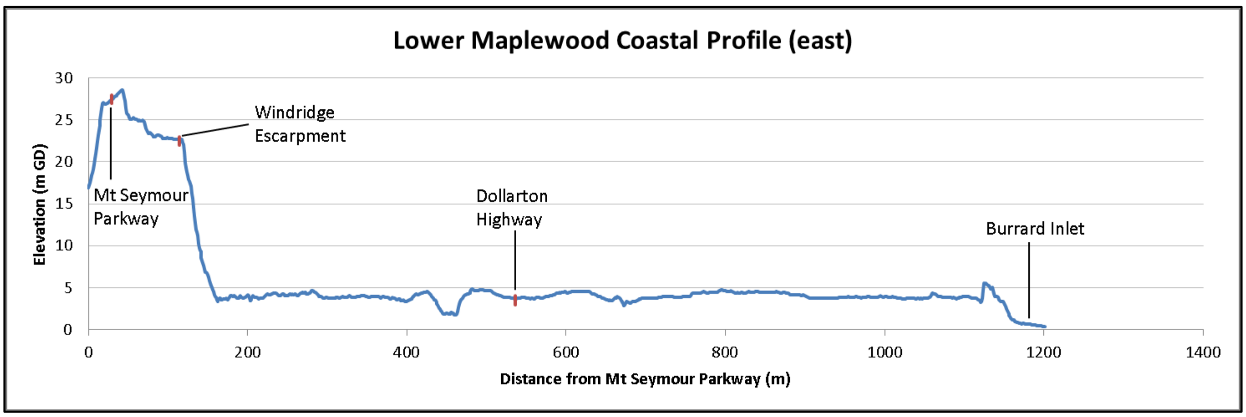




**Figure 5. Ground elevation profiles in the Lower Maplewood coastal area to the Burrard Inlet shoreline, extracted from 2014 DNV LiDAR.**

Windridge escarpment, an elevated landform, lies in the northeast part of the village and slopes down to the west, southwest, and southeast. There is a low-lying, marshy area south of the escarpment and east of Riverside Drive, known as the North Swamp. This area and areas east of it are former gravel pit depressions that have altered the natural drainage patterns and created wetlands (DNV, 2004). Ground elevations in these areas are as low as El. 2-3 m GD, which is lower than some of the coastal fill areas to the south. The surficial geological materials consist mainly of glacial Capilano gravels in the areas above Dollarton Highway.

# 3 FLOOD HAZARDS

Maplewood Village is located on the Seymour River floodplain and the coastal floodplain of Burrard Inlet. According to flows recorded at the upstream Water Survey Canada stream gauge, *Seymour River near North Vancouver 08GA030*, about 80% of the annual peak flows have occurred in the October to January period as a result of heavy rain or rain-on-snow events. The river's flood of record occurred on October 31, 1981. During the event, floodwaters carrying sediment and trees threatened bridges on the Seymour River and properties in the Riverside area (EBA Engineering Consultants Ltd. and KWL, 1999).

Coastal flooding in the region is caused by a combination of high tides, storm surge, wave run-up and wind set-up. To date, major coastal flooding has not been observed in Maplewood Village but during recent December 2012 and 2014 King Tides, water levels were unusually high along the Burrard Inlet shoreline. King Tides and large storm surges typically occur in December and January, indicating there is potential for coinciding coastal and riverine flooding.

## 3.1 Modelled Flood Hazards

KWL (2014a) defined the flood hazard for North Vancouver communities, including Maplewood Village, from both types of flooding under present (2012) and future (2100, 2200) conditions. For simplicity, the study assumed that extreme coastal and riverine flooding would not coincide. Each design event is based on a 200-year return period flood, which has a 0.5% chance of being exceeded in any single year.

The impact of climate change on both riverine and coastal flooding was incorporated. Based on climate analysis of other North Vancouver watersheds, KWL (2014a) assumed that peak river flows on the Seymour River will increase by 6% by the 2080s as a result of projected increases in short-duration rainfall and changes in snowmelt contributions caused by climate change. For the coastal hazard, Provincial guidelines recommend that a 1 m sea level rise increase for the year 2000 to 2100 time horizon and a 2 m allowance for 2000 to 2200 be adopted. Based on previous NHC investigations for the Lower Mainland, an approximate rise in the order of only 5 mm was observed from year 2000 to 2015, but annual rates are expected to increase over time.

Model results by KWL (2014a) were available for both the 200-year return period flood event on the Seymour River and for the 200-year ocean event. NHC adopted the Japanese national standard for depth categorization with some modification for the flood mapping (**Error! Reference source not found.** and **Error! Reference source not found.**). Depth map colours were also based on the Japanese Flood Control Division, River Bureau, Ministry of Land, Infrastructure and Transport (MLIT) standard, which uses shades of yellow-green-blue-purple.

During a 200-year return period river flood under present conditions (**Error! Reference source not found.**), overbank flooding will occur. Floodwaters will generally be contained at Mount Seymour Parkway but cause backwater flooding in many parts of Seymour River Heritage Park and in the downstream multi-family development. Downstream of the Dollarton Highway crossing, flooding will occur on both sides of the river. The Dollarton Highway bridge cross-section opening cannot convey the entire design flow, resulting in water levels above the low chord of the bridge.[2] Squamish Nation lands along the west bank are expected to flood extensively. Sea level rise and increased river discharge are expected to exacerbate these conditions (**Error! Reference source not found.**). Modelled flood depths are in the order of 0.1-0.5 m in Maplewood Village, under both present and future time horizons.

During a 200-year ocean event, flooding is currently expected in the area around the mouth of the Seymour River (Seymour IR No. 2 and Spicer Road) and potentially at isolated areas on the east side of Maplewood Village (**Error! Reference source not found.**). With a 1 m sea level rise, large low-lying areas south of Dollarton Highway and east of Riverside Drive are expected to be inundated (**Error! Reference source not found.**). Modelled flood depths of 0.1-0.5 m under 2012 conditions increase to as much as 1.0-2.0 m by year 2100.

[2] NHC (2004) identified that there would be capacity issues at the proposed replacement bridge. The abutments of the old bridge were retained, which did not allow the bridge opening to be widened. The vertical alignments of the approach roads and proximity of the intersection and interchanges limited the amount of freeboard that could be provided at the replacement bridge, now constructed. As a result, only a 0.5 m allowance above the estimated 200-yr water level at the bridge could be provided for model uncertainty, sedimentation and debris clearance, which is less than the typical 1.5 m allowance. In lieu of the costs that would be required to provide more freeboard, the District was made aware that it would have to assume some risk of surcharging at the bridge.

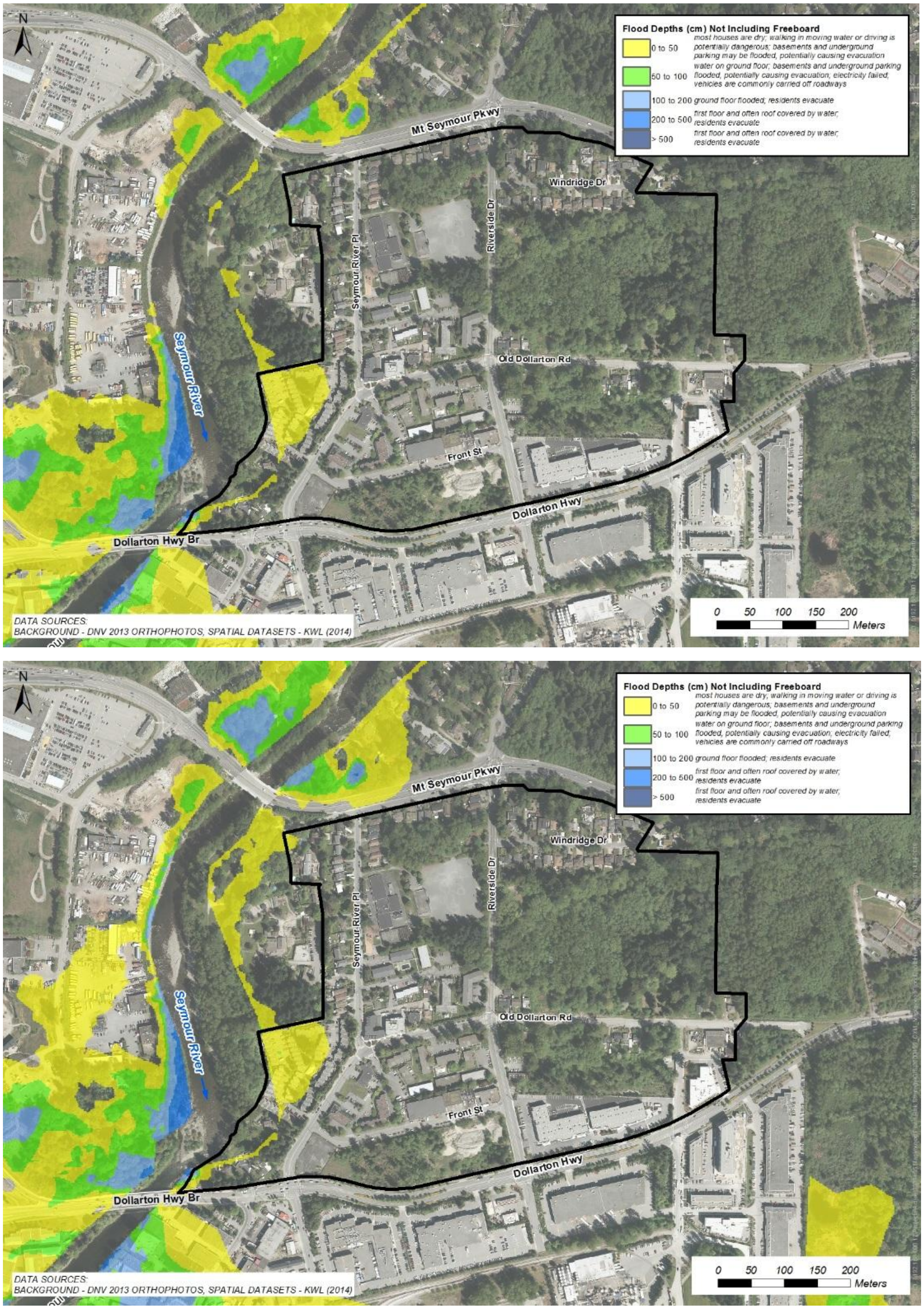



**Figure 6. Maximum flood depths from a river flood in 2012 (top) and 2100 (bottom) (adapted from KWL, 2014a).**

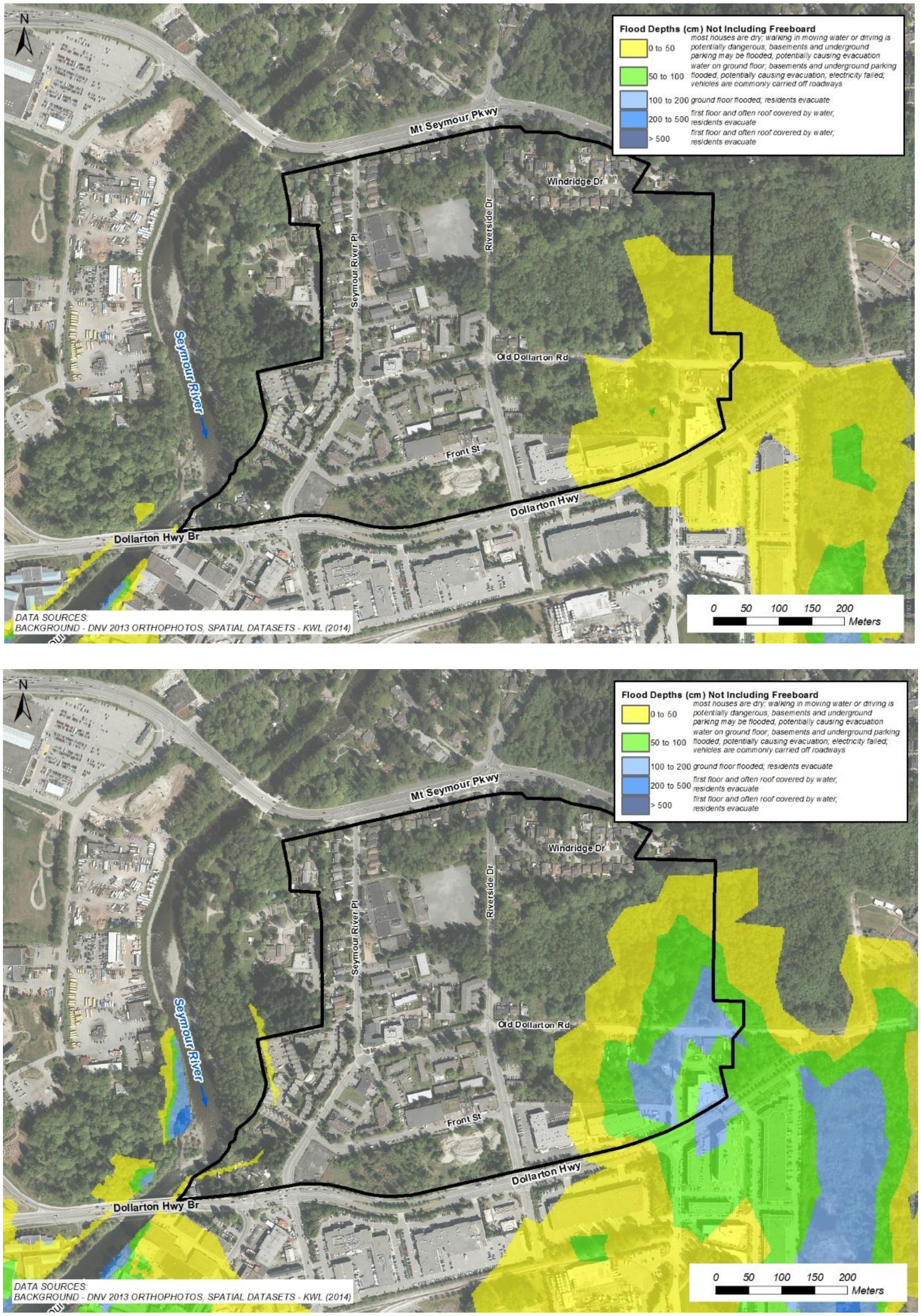



**Figure 7. Maximum flood depths from a coastal flood in 2012 (top) and 2100 (bottom) (adapted from KWL, 2014a).**

Modelled flood extents, including freeboard, are shown on Figure 8. For consistency, these modelled flood extents should be used to update the District's Creek Hazard Development Permit Area (DPA) extents. The current extents of the District's Creek Hazard DPA at Maplewood Village are based on the previously approximated Seymour River flood extent boundaries (BGC, 2011). As water levels simulated within the channel were extended across the floodplain without addressing floodplain flow or attenuation, those results are potentially conservative, particularly in the eastern area along Old Dollarton Road.

## 3.2 Channel Stability

Located on Seymour River Fan, the river has historically undergone significant geomorphic change in the lower reach between Mount Seymour Parkway and Dollarton Highway. In addition, development in the late 1950's and early 1960's reduced the active bankfull width in the reach by an estimated 40%. The reach coincides with the limit of tidal influence and has been an area of gravel deposition. Gravel accumulations during the 1981 and 1990 floods shifted the thalweg and destabilized the east bank upstream and downstream of the Dollarton bridge (KWL, 2003). In response, riprap protection was installed along these reaches of the river after 1981 and more recently upgraded.

A large rockslide occurred in early December 2014 that partially blocked the Seymour River approximately 3 km upstream of Maplewood Village. Hydrotechnical and geomorphic specialists have since determined that the slide deposit is relatively stable and unlikely to fail en masse (NHC, 2015). The feature impedes the recruitment of gravel to lower reaches and will do so for the foreseeable future, which reduces the likelihood of future channel destabilization adjacent to Maplewood Village caused by large accumulations.

The District's Creek Hazard DPA is intended to identify areas adjacent to creeks and rivers that are at a potential risk from floods as well as from debris flows and debris floods. Nearly two-thirds of the Maplewood Village area lies within the extents of the Creek Hazard DPA. However, the flood hazard area within Maplewood Village is based on the Seymour River clear-water flood extent boundaries from an earlier scoping study (NHC, 2010) and does not account for sediment-laden hazards. Nor do results from the KWL (2014) study include such hazards.

## 3.3 Maplewood Creek

Based on Maplewood Creek's drainage area, low gradient and flow depths, the creek would unlikely cause flood hazards more severe than the Seymour River (NHC, 2012). Properties at the western end of Heritage Park Lane (formerly Mt Seymour Parkway Frontage Road) would be primarily affected by Seymour River backwatering up Maplewood Creek, with low flow velocities and water depths anticipated (NHC, 2012).

Maplewood Creek is conveyed under Mount Seymour Parkway and Heritage Lane through a 44.1 m long 1000 mm x 750 mm CSP oval culvert. The culvert was found to be under-sized based on the 200-year design event (ISL, 2016), and particularly in the event of a blockage, upstream ponding may occur. Two upgrade options to meet capacity requirements were assessed, with the option to line the culvert with a HDPE pipe and creating an overflow channel being recommended (ISL, 2016).

## 3.4 Flood Construction Levels

The Flood Construction Level (FCL) is the design flood level plus a freeboard allowance and is used to establish the elevation of the underside of a wooden floor system or top of concrete slab for habitable buildings (MWLAP, 2004).

Maplewood Village FCLs in areas within the year 2100 flood extents were derived from the maximum of peak river and extreme coastal flood levels plus 0.6 m freeboard (KWL, 2014b). In the river floodplain of Maplewood Village, the FCL ranges from 5.7 m GD at the downstream portion of the reach to 6.9 m GD in the middle reach of the study area. Generally in a coastal setting, the design flood level is comprised of several components: tide, storm surge, wind and wave effects, plus a sea level rise allowance. Using an additive approach, the FCL for the coastal floodplain in Maplewood Village is 4.7 m GD (KWL, 2014b). Within both the river and coastal floodplain, the FCL ranges from 0.5 m to 1.0 m above existing ground elevation, depending on location. FCLs in non-inundated areas are set at 0.6 m above surrounding grade because of the location on a creek fan (KWL, 2014b), where the possibility of avulsion means that flood hazards may not be limited to the existing channel.

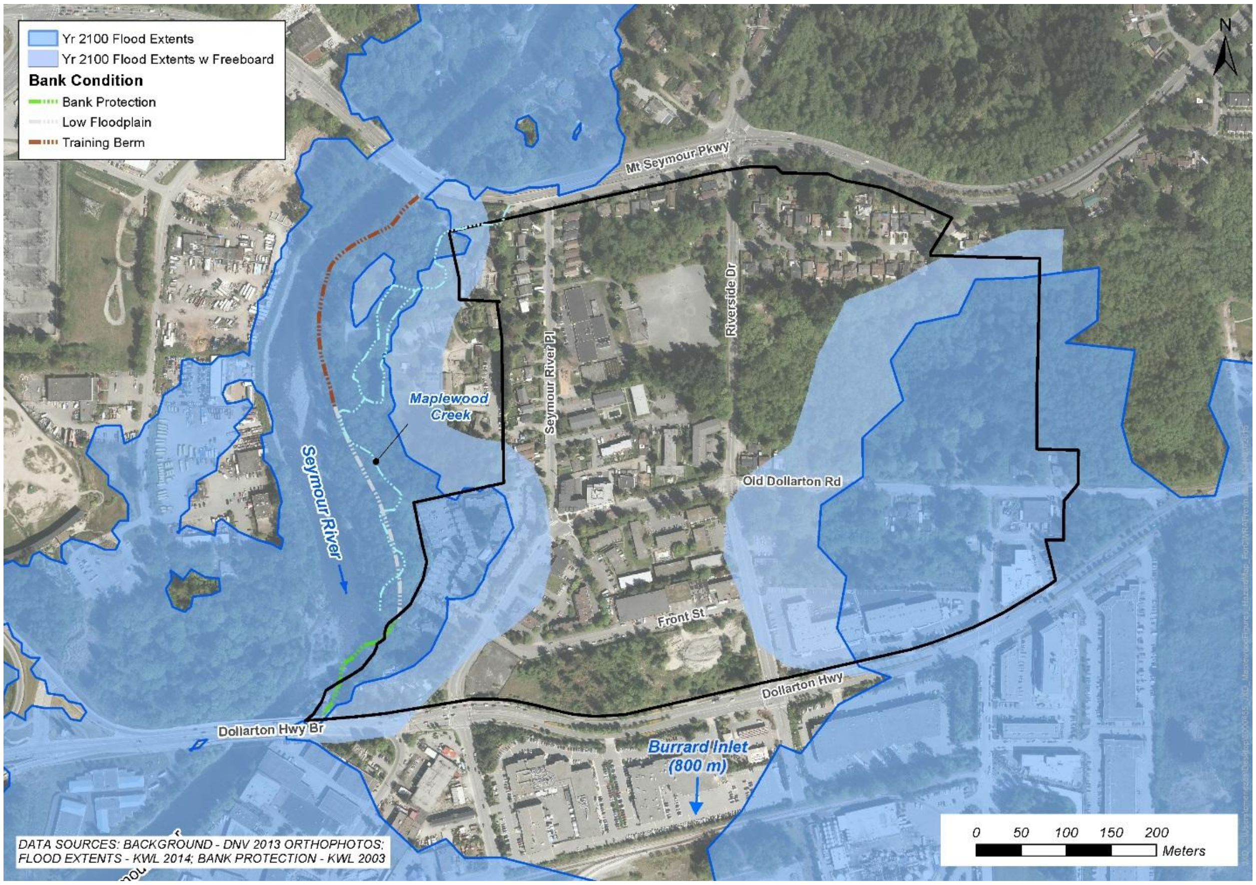



**Figure 8. Summary map of the flood and flood-related hazards in Maplewood Village.**

# 4 FLOOD VULNERABILITIES

The community, environment, economy and infrastructure elements vulnerable to present and future flooding were identified by overlaying flood extents with community data layers in GIS. Table 1 summarizes the vulnerabilities to flooding, and their key features as discussed below.

**Table 1. Summary of identified vulnerabilities to flooding in Maplewood study area.**

| Community | Environment | Economy | Infrastructure |
|---|---|---|---|
| Affordable rental housing | Seymour River | Industrial zone (including business parks) | Stormwater and sewer system |
| Single-family homes | North Swamp wetland | Visitor destinations (Maplewood Farm) | Roads |
| | Maplewood Farm | Commercial services | Buildings (industrial, commercial, residential) |
| | Seymour River Heritage Park | High-value real estate | |
| | Maplewood Park | | |

The only essential facility[3] in Maplewood Village is the Kenneth Gordon Maplewood School, but it lies outside the year 2100 flood boundary and is not vulnerable to flooding (Figure 9). Key vulnerabilities within the floodplain include residential and industrial development. The year of construction is a factor in a buildings' ability to tolerate flooding. Floodplain mapping of the Seymour River was prepared by the BC Ministry of Environment (BC MoE) in 1995. Buildings constructed before this time are particularly vulnerable to flooding because they were likely built to a lower FCL and with less regard for flood resilient design. These older buildings include single-family homes, a townhouse development and industrial buildings (Figure 9). The Riverside Mews townhouses, built in 1973, along the Seymour River

[3] Facilities that provide services to the community and should be functional after a natural disaster (FEMA, 2009).

are vulnerable under both 2012 and 2100 conditions. Only the eastern row of buildings, set back on the lot and closest to Seymour River Place, are outside the modelled year 2100 flood extents.

Newer buildings (post-1995) are largely commercial-residential and townhomes (i.e. multi-family). They were constructed to 200-year flood levels defined by BC MoE. Three industrial buildings along Dollarton Highway were built in 2010-2011. Minimum floor elevations for the Northwoods Business Park buildings were set at 4.3-4.6 m GD (InterCAD, 1999), which is 0.5 m to 0.9 m lower than presently recommended FCLs for the lot (KWL, 2014b). For the recent GWL Northwoods Village mixed-use development, 6.1 m was the proposed minimum floor requirement for the building at the southeast end of the lot, nearest to the coastal hazard (InterCAD, 2013), which is higher than the FCL of 4.78 m (KWL, 2013). For the other buildings to the west on the lot and outside the 2100 flood extents, proposed minimum floor elevations were 7.5 m and 7.8 m (InterCAD, 2013).

The number of properties in the present and future (year 2100) floodplain areas was estimated based on existing building footprints and land uses identified in the OCP (Table 2).

**Table 2. Development characteristics in the present and future floodplains.**

| Number and type of buildings | |
|---|---|
| **Existing in 2013 floodplain (year built)** | **Assumed in 2100 floodplain** |
| 7 townhouse buildings (1973) | 11 townhouse buildings (redeveloped parcels and new townhouses) |
| 9 single-family residential (1940s-1980s) | 18 medium-density apartment buildings (assumed) |
| 1 single-family residential (2012) | 1 commercial-residential mixed-use building |
| 3 light industrial buildings (2010s) | 3 light industrial buildings (2010s) |
| 2 light industrial buildings (~1960) | |

Buildings constructed from 2015 on, will generally be built to 2100 FCLs as supported by recent modelling. However, the increased community resilience afforded by this planning mechanism is only realized once a site is re-developed. The Riverside Mews townhouses are approximately 40 years old and considering a typical 75-year lifespan, are likely to be replaced well before the end of the century. The remaining vulnerable single-family and light industrial buildings in the floodplain are between 50 and 60 years old, and replacement may occur relatively soon. Some lots slated for multi-family re-development are located close to Seymour River and highly vulnerable to flood hazards, for example, lots on the east bank between Riverside Mews and Dollarton Highway. In developing a floodplain area, flood-compatible land uses such as recreation are most appropriate. Residential use may be acceptable if adequate floodproofing is introduced.

Main roads in the study area are also vulnerable to flooding. Mount Seymour Parkway and Dollarton Highway are the main east-west arterials, the latter designated a disaster response route. Mount Seymour Parkway would be impacted in a 200-year river flood whereas transportation along Dollarton Highway is more susceptible to disruption by a coastal flood. However, on the west side of the river, Dollarton Highway would likely experience the most severe inundation during a river flood.

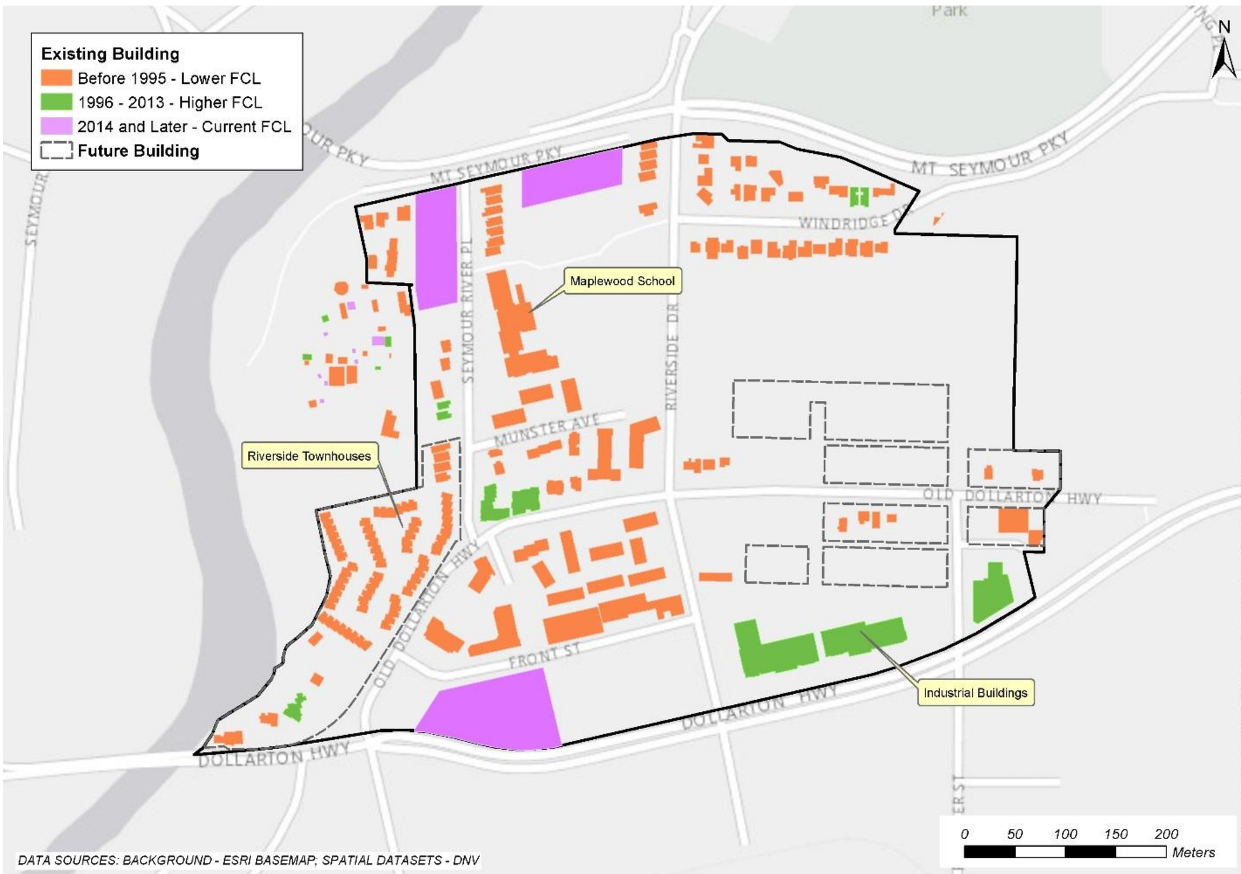



**Figure 9. Buildings vulnerable to flooding in Maplewood Village.**

# 5 FLOOD RISKS

To illustrate the benefits of a flood management strategy for Maplewood Village, present and future economic losses from a 200-year riverine or coastal flood were estimated. By developing an understanding of potential losses, high-risk areas requiring mitigation measures were prioritized.

## 5.1 Risk Assessment Methodology

The Canadian version of the Hazus flood risk software was recently introduced by NRCan. It uses BC Census data to estimate losses for the present degree of development. Considering the objective of this study was to not only estimate present losses but also project losses for future development, a spreadsheet tool recently developed by the Flood Hazard and Risk Assessment Research Group at the University of New Brunswick was adopted for the analysis. It utilizes the same functions as Hazus to calculate exposure and damages to building stock. It does not consider economic losses to infrastructure such as bridges and utilities.

Direct physical damage to buildings is estimated using depth-damage curves, which calculate building damage based on water depth. These are translated into direct economic losses, comprising of costs associated with structural repair and replacement, and those related to damage of contents. Indirect economic losses resulting from business disruption and emergency response are not accounted for, and neither are intangibles, such as loss of life, health problems, environmental damage and social losses (Messner and Volker, 2005).

### 5.1.1 Model Inputs

The tool estimates potential losses for different building occupancy types. The key data inputs are:

1) Percent of area inundated
2) Development characteristics
   a) Number of buildings
   b) Building occupancy type
   c) Building foundation
   d) Average year built
   e) Number of stories
   f) Presence of basement or garage

Relevant spatial datasets were obtained from the District's GeoWeb application or supplied by District GIS staff. Depth mapping associated with river and coastal flooding in 2012 and 2100 was used (KWL, 2014a) to calculate the percent area inundated. For development characteristics, key datasets that were used included Buildings and Parcels layers and the Official Community Plan from DNV. Older buildings in the floodplain were entered as having a slab-on-grade foundation, while the newer and future buildings were assumed to be built on fill. Multi-dwellings with 50+ units were recorded as having three or more stories; multi-dwellings with 10-19 units and newer light industrial as two stories; and retail trade, older light industrial, and single family dwellings as one storey. Basements and garages were assumed to be limited to older single family homes away from the river and future multi-dwellings with 50+ units.

### 5.1.2 Model Calculations

The spreadsheet uses underlying Hazus tables and depth-damage functions. Key parameters for exposure calculations are: building foundation type, height of the first floor, and age of the structure. When converting exposure to monetary values of damage, attributes such as building occupancy classes, square footage, valuation, construction class, number of stories, and age are used (McGrath and Stefanakis, 2014). Replacement costs per square foot come from Hazus Canada and are based on RS Means 2006 values for each occupancy type.

Sensitivity tests completed as part of the tool's development compared spreadsheet and Hazus outputs for the same area. The results suggest that the multi-occupancy loss estimates from the spreadsheet are within 1% of Hazus estimates. However, it should be noted that both methods are approximate, and actual losses may vary significantly from those estimated.

## 5.2 Risk Assessment Results

The spreadsheet tool provides a summary of flood exposure of buildings and direct losses to buildings, by building occupancy. Values are high-level estimates only and meant to inform relative losses from current and future flooding.

Under the 2012 flood scenario, multi-family townhomes incur the greatest combined structure and contents losses, followed by light industrial buildings (both older 1-storey and newer two-storey) and then detached residential properties (Figure 10). The total estimated damages (structures and contents) from a 2012 flood are about $11.3 million.

For the year 2100 flood scenario, total building losses were estimated to be $42.2 million (present value). The majority of the losses would stem from the medium-density apartments, having high structure and contents values (Figure 10). Multi-family townhomes, i.e. those along Seymour River, are almost equally at risk in a 2012 flood scenario as they would be in the year 2100. Light industrial buildings and commercial uses are also at risk, particularly with respect to contents.

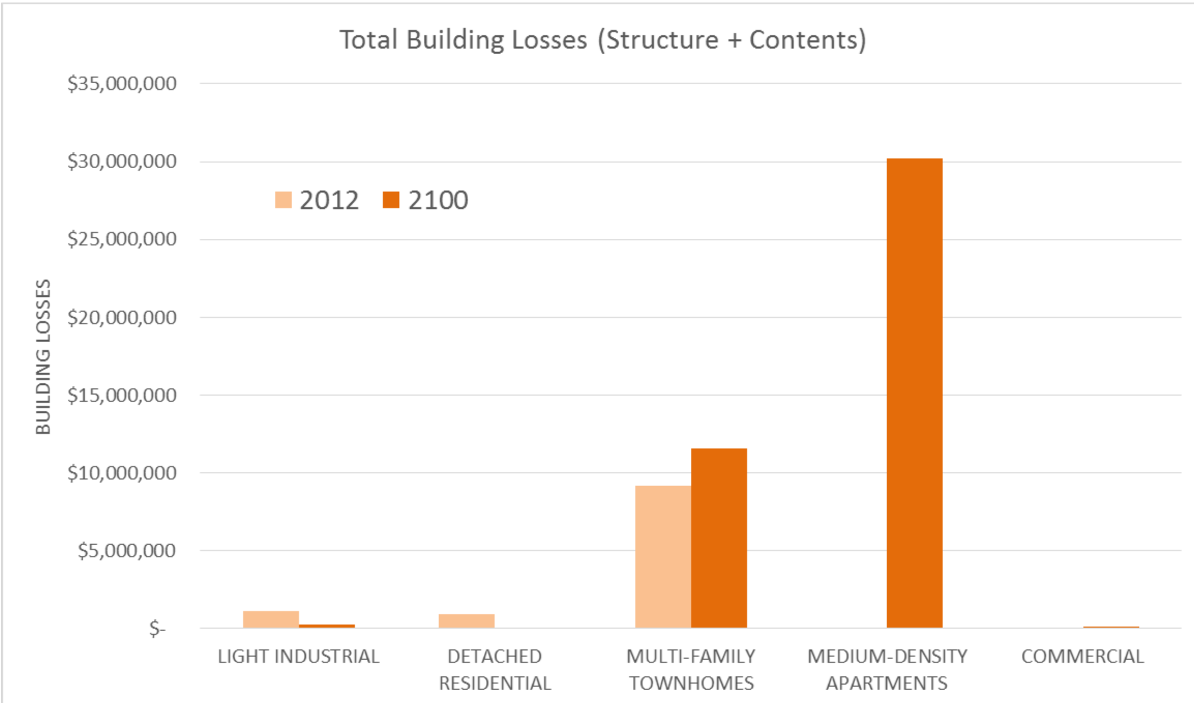



**Figure 10. Direct building losses by building occupancy type for 2012 and 2100 flood scenarios.**

## 5.3 Assumptions

The tool provides an overview level assessment of exposure and losses, and results are considered approximate. Flood loss estimation relies on a combination of components: flood levels, inventory of the built environment, and pre-selected vulnerability parameters such as depth-damage functions, all of which have large associated uncertainties (McGrath, 2014). A number of simplifying assumptions include:

- Flood damage and losses are computed based on a flood-depth grid; damage due to flow velocity, wave forces, flood duration, sediment/debris and erosion is not accounted for.
- The flood depth information is averaged over the floodplain area. The tool uses percent area inundated at different depth ranges rather than comparing site-specific flood depths to habitable floor elevations of buildings.
- The Hazus default depth-damage curves per occupancy type are applicable across Canada, discounting regional differences.
- The valuation of buildings is based on 2006 census mean values for each occupancy type. It does not account for difference in urban/suburban environments or differences between cities. The total estimate of damage only accounts for damage to the structure and contents, but does not include inventory loss, which can be significant in commercial and industrial occupancies, or indirect losses.

# 6 FLOOD RISK MANAGEMENT STRATEGIES

The KWL (2014b) flood hazard study proposed preliminary adaptation measures for Maplewood Village. It primarily focused on raising the road along Spicer Road for protection against coastal flooding and providing a standard dike along Seymour River as a riverine measure. To develop a range of broader solutions, NHC reviewed flood management strategies from different parts of the world as summarized in Appendix A. There is an emerging trend of not relying on one isolated tool for flood defense but to combine hard infrastructure (like dikes) with soft infrastructure (like parks). This combined approach is well-suited for Maplewood Village, where a close relationship with the river/ocean is to be maintained while protecting against river floods, high tides and storm surges. Key flood mitigation measures and their applicability for various flood, site and building characteristics are summarized in Table 3.

A discussion of strategies applicable to Maplewood Village is provided, along with the locations in Maplewood Village where they apply (**Error! Reference source not found.**). Although strategies to minimize stormwater flooding are beyond the focus of this study, they are briefly mentioned. For further detail, refer to the Maplewood Environmental Strategy (Dillon, 2012).

**Table 3. Applicability of flood mitigation measures based on flood characteristics, site characteristics and building characteristics (✓ indicates potential mitigation, ✗ unsuitable mitigation)**

| FLOOD DAMAGE REDUCTION MATRIX<br>*Adapted from Jha et al. (2012) and USACE (2009)* | MEASURES | *Elevation on Foundation Walls* | *Elevation using Fill* | *Elevation on Piles* | *Managed Retreat* | *Dry floodproofing* [1] | *Wet floodproofing* [2] | *Dikes and walls* | *Channel Diversions* |
|---|---|---|---|---|---|---|---|---|---|
| **Flood Characteristics** | | | | | | | | | |
| Depth | Shallow (<1 m) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Moderate (1-2 m) | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ |
| | Deep (>2 m) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Velocity | Slow (<1 m/s) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Moderate (1-2 m/s) | ✗ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| | Fast (>2 m/s) | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Flash Flooding | Yes | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| | No | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Debris Flows | Yes | ✗ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| | No | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Site Characteristics** | | | | | | | | | |
| Location | Coastal floodplain (interior) | ✓ | ✓ | ✓[3] | ✓ | ✓ | ✓ | ✓ | ✗ |
| | Riverine floodplain | ✓ | ✗[4] | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Soil type | Permeable | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ |
| | Impermeable | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Building Characteristics** | | | | | | | | | |
| Foundation | Slab on Grade | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Basement | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Construction | Concrete / masonry | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Wood | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Condition | Excellent to good | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Fair to poor | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ |

[1] Dry floodproofing involves making a structure watertight below the level that needs flood protection to prevent floodwaters from entering. This can be achieved by sealing the walls with waterproof coatings, impermeable membranes, or a supplemental layer of masonry or concrete.

[2] Wet floodroofing a structure consists of modifying uninhabited portions to allow floodwaters to enter and exit.

[3] In areas with wave effect hazard, buildings should be constructed on open foundation (i.e. piles, posts, piers).

[4] Can shift flood hazard to adjacent areas

## 6.1 Strategies for Maplewood Village

Broad flood management strategies discussed in this section include: land-use planning; building design; flood defences; floodwater storage, conveyance and energy dissipation; sustainable urban drainage systems; infrastructure improvements; and, emergency planning and management. Details related to each strategy are outlined below.

***Land-use planning***

- Retain low-vulnerability recreational uses along the river to accommodate floodwaters. Retain Maplewood Farm and retain the Seymour River greenbelt, which can continue to be used as a trail and pedestrian greenway.
- Consider land acquisition of the rows of Riverside Mews townhouses that lie within the floodplain to minimize existing flood risk. Alternatively, when these buildings reach their end of life, replace them with new buildings that are set back on the lots and allow densification only outside the floodplain.
- Introduce building setbacks for all new buildings on the lots along the river, north of Dollarton Highway. Prescribed setback distances should be large enough to restrict development to areas outside the floodplain boundary. Assuming no dike is installed, approximate setbacks for new development along to the river can be based on unmitigated year 2100 flood extents. Adjacent to Seymour River Place, the lot setback ranges from between 130 m and 180 m relative to the river's edge, as shown on **Error! Reference source not found.**.
- Minimize residential land uses on the coastal floodplain, where the majority of new development is currently planned. Industrial land uses, such as those along Dollarton Highway, have a lower flood vulnerability per unit area than residential uses and should be retained.
- Establish a Coastal Hazard DPA to require site assessments by a qualified professional for new buildings in the coastal floodplain in order to determine the appropriate FCL and to advise on site-specific mitigation.
- Revise the existing Creek Hazard DPA extents to incorporate recent flood hazard modelling, and debris flow hazards as available.

In conjunction with setting building FCLs, adjacent roads, utilities, etc. will need to be raised over time to meet building elevations and ensure that buildings are not cut-off from services during a flood.

***Building design***

- For new development:
  - Require structural elevation of new buildings in the floodplain, including non-residential uses, to meet new FCLs. Elevation of construction in the river floodplain should be achieved using piles rather than fill. In the coastal floodplain, localized fill may be permitted.
  - In both floodplain areas, ensure windows and doors are above the FCL. Require installation of electrical and mechanical systems above FCLs for new development.
  - Avoid underground parking areas in the river floodplain, except in high-density developments protected by a setback dike or set back structures on the lot (in which case the floodplain is not infringed). Underground parking may be permitted in the coastal floodplain; however, its compatibility with groundwater conditions and the wetland environment need to be considered.

- Install scour/foundation protection for buildings in areas near to the river.
- Encourage flood resilient construction, using flood-resilient building materials below FCLs such as brick, concrete, glass or metal. However, specific building materials cannot be required because of the recent 2015 Building Act legislation that unfortunately prevents local building regulation beyond the BC Building Code.
- Grade lots to direct surface drainage away from foundations and footings and prohibit construction of reverse slope driveways.

- For existing development in the floodplain that is not due for replacement, consider incentives for retrofitting such as:
  - Relocate utilities above the FCL. Alternatively, dry-proof critical building systems ensuring structural integrity from hydrostatic pressure. For industrial buildings that cannot be dry-proofed, install pumping systems to ensure positive drainage.
  - Wet floodproof by replacing windows, doors, structure and finishes with flood-resilient construction materials below FCL, and install flood vents at walls and floors to ensure vertical and horizontal water flow.
  - Elevate the structure on a new foundation and fill the basement/cellar to the lowest adjacent grade. The area below the elevated structure can be left open or enclosed and wet floodproofed for use as parking, crawl space, access and storage of goods not sensitive to flooding. Note that vulnerable wood-frame structures may pose constraints on the option of elevating.

  All floodproofing solutions require assessment of the building's structural integrity and implications on neighbouring buildings.

- Parkades for multi-family developments (including electrical/mechanical utilities) located below the FCL in the floodplain should be constructed so that access points are above the FCL and with a minimum of two exits to allow for safe pedestrian egress. Parkades must be designed to withstand hydrostatic pressures.
- Where FCL values vary within a property and between adjacent properties, it is recommended that the maximum FCL from the KWL Floodplain DPA (KWL, 2014b) be used. Landscape design measures can help minimize the grade transition so that streetscape uniformity can be maintained or improved.

***Flood defences***

- Plan to construct a standard dike on the east side of the Seymour River from Mt Seymour Parkway to tie into high ground at Ironworkers Memorial Bridge fill (KWL, 2014a). Set back the dike as far as possible from the river. Privately-owned residential parcels just north of Dollarton Highway along the Seymour River would require a right-of-way to be established for flood protection works. The crest of the dike, including freeboard, would need to be approximately 0.5 m to 1.0 m higher than the surrounding grade based on local FCLs and occupy a footprint width of as much as 10 m[4]. Consider the influence of the dike on Squamish Nation lands on the opposite side of the river and avoid adverse impacts (further discussion provided in Section 7.4).

- Consider a sea dike along Spicer Road for coastal flood protection that uses road or rail alignments to obtain the necessary right-of way (KWL, 2014a). Although detailed study would be required[5], for high-level planning purposes, the crest of the dike would need to be approximately 0.7 m to 1.7 m above surrounding grade based on FCLs, and the dike would occupy a footprint width of about 8.2 m (possibly doubling east of Forester St.), based on dike side slopes of 3H:1V and crest width of 4.0 m. There appears to be sufficient width north of the rail line and along the proposed alignment to the east to accommodate a dike structure. Some acquisition of vegetation corridors and private parking lots along the route would likely be required. Where space is limited, the sea dike could transition into a floodwall. Alternatively, a floodwall could be constructed along the entire alignment.
- Another possible sea dike alignment could be that of Dollarton Highway, which could be raised and engineered for coastal flood protection.
- As an alternative to the sea dike, consider building a raised seawall along the Burrard Inlet shoreline south of Maplewood Village with options to further raise it in the future if necessary. Maintaining boat and rail access to and from the industrial lands of lower Maplewood may limit the viability of this option.

***Floodwater storage, conveyance and energy dissipation***

- Restore natural landforms and habitats similar to work done for the Seymour Estuary restoration project. Retaining vegetation and geomorphic features along the shoreline may have some wave dissipation benefits while maintaining ecological function.
- Maintain the Maplewood Conservation Area to the southeast of the Maplewood study area. With coastal floods posing a hazard to the eastern part of Maplewood Village, preserving this wetland area is important for energy dissipation and attenuation of waves.
- Adapt urban features such as car parks, playing fields, parkland, and industrial areas for temporary storage of river floodwaters, ensuring safe flow routing into and out of these areas. Seymour River Heritage Park already provides this function to some degree and could be enhanced for flood mitigation. An example of this may involve removing the training berm along the bankline in conjunction with other engineered measures to reconnect the river to its floodplain.
- Consider building a floodway or flood diversion channel along the west bank through Cutter Island Park (District-owned, low-vulnerability land use) to accommodate overflow water. It may have the benefit of alleviating overbank flooding on the east bank and reducing the water level at the bridge crossing. The channel could be integrated with features constructed as part of the Seymour River Estuary Restoration project that is underway at the mouth of the river. (The

---

[4] Detailed study is required to determine dike dimensions that meet Seismic Design Guidelines for Dikes (2014). A footprint larger than standard is expected in order to achieve seismic stability.

[5] The Sea Dike Guidelines (Ausenco-Sandwell, 2011) recommend that the required crest height in the year 2100 be based on wave run-up calculations with a slope gradient of 3:1 (H:V) and 2% wave overtopping.

length and width of the floodway would need to be maximized for the channel to have any noticeable benefit.)

***Sustainable Urban Drainage Systems (SUDS)***

- Incorporate rainwater management measures to encourage drainage. Swales, soak-aways, permeable paving, and constructed wetlands are some practical SUDS techniques. Maplewood Farm proposed a system of detention and infiltration mechanisms such as rain gardens and bio swales as demonstration sites to learn about stormwater (Maplewood Farm Review, 2012). These could also be implemented in the Maplewood Village landscape, in part by taking advantage of planned greenways and greenbelts.
- Build green roofs on medium-density apartment buildings planned for east of Riverside Drive. This would reduce stormwater flooding and support groundwater recharge.

These SUDS techniques are not effective at addressing extreme riverine and coastal flooding.

***Infrastructure improvements***

- When the Dollarton Highway Bridge and approach roads are slated for improvements, raise and increase the span of the bridge, which presently has an undersized opening. The Dollarton Bridge forms a constriction at high flows, and in the event of highway modifications, the bridge abutments should be set back from the channel. Preferably, the bridge should also be raised to ensure it has adequate freeboard (NHC, 2004).
- Upgrade the Maplewood Creek culvert crossing at Mt Seymour Parkway to convey the design flood. Until that time, monitor the existing culvert for blockages.

***Emergency planning and management***

- Monitor flood advisories and warnings issued by Provincial River Forecast Centre during times of expected extreme flows.
- Whereas sandbagging is not feasible along the river as the water levels rise too quickly, AquaDams may be a practical option for coastal flooding events.
- Use nearby recreation centres, such as the Ron Andrews Community Recreation Centre, and other high ground areas as safe gathering places during extreme floods. Designate safe access/egress routes to these locations.
- Generally avoid siting new essential facilities in flood hazard areas to maintain their functionality and community resilience. However, if a facility is proposed, ensure that it is constructed to a higher standard of protection (e.g. 0.2% chance flood event aka 500-year flood event used by FEMA) than other development, and that the level of protection exceeds the rising sea level hazard over time.
- Educate the public regarding flood preparedness. For instance, property owners may reduce vulnerability to flooding by refraining from storing valuables in basements of homes in the floodplain.

For all engineered strategies, qualified professionals should be consulted for site-feasibility and detailed design prior to implementation.

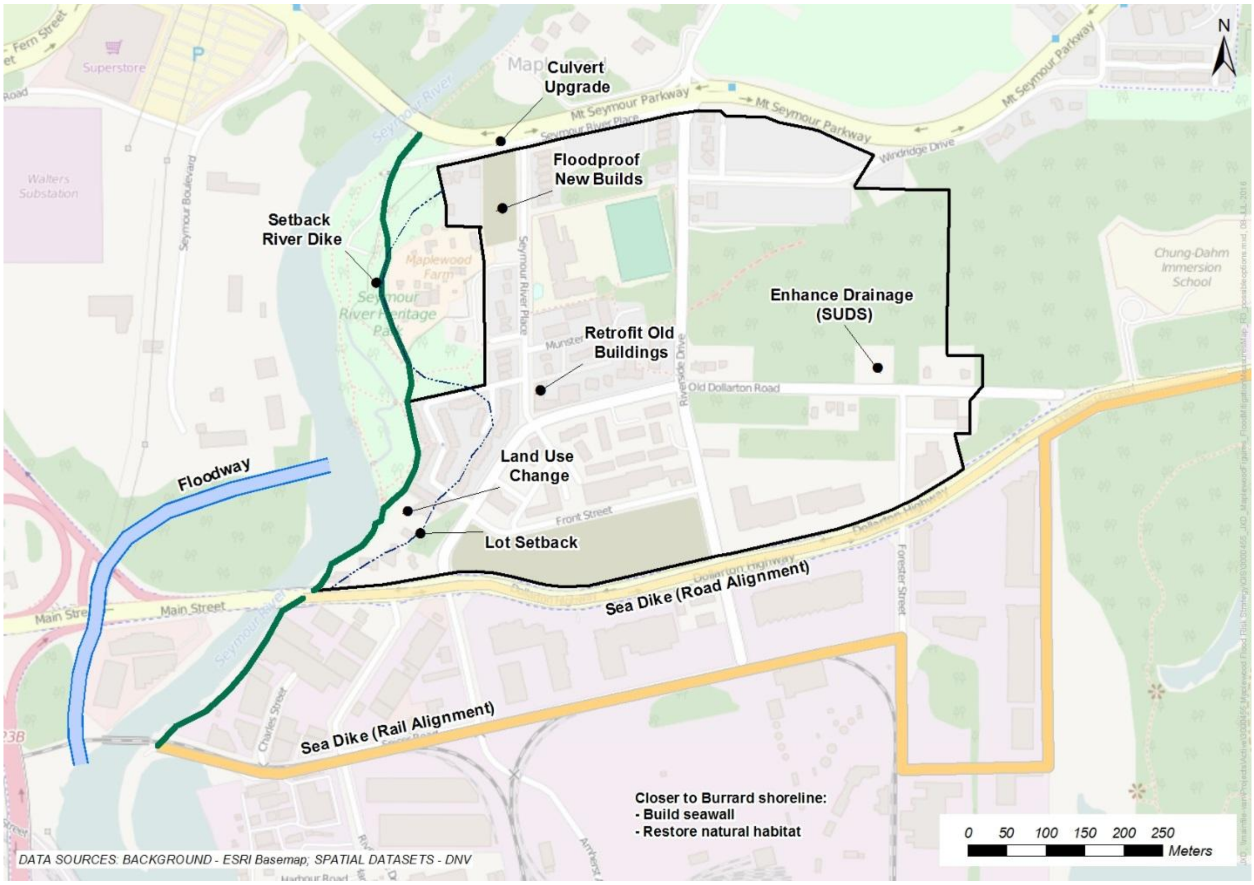



**Figure 11. Potential flood management measures in Maplewood Village. (Each measure shown assumes no other measures are implemented.)**

# 7 EVALUATION OF FLOOD RISK MITIGATION MEASURES

The village-scale risk assessment in Section 5 identified those development areas with the greatest flood risks that form high priorities for risk reduction efforts. An assessment of costs and benefits, constrained by other important environmental, social, and life-safety factors, provides a reasonable framework for evaluating the District's potential investments in flood risk reduction in this community.

## 7.1 General Considerations

Strategies that reduce flood consequences, such as hazard zoning, building elevation, land purchase, and setbacks, tend to have high documented benefit-cost ratios. Studies have reported benefit-cost ratios between 5:1 and 8:1 for non-structural strategies that reduce the consequences of flooding (NRC, 2014). There may be many other distributed benefits from flood risk reduction measures besides a reduction in damages. For example, a flood relief channel may be used for recreation and environmental management. It could also increase the value of nearby properties, by providing recreational space and to some extent improve the residents' enjoyment of the area.

Measures that will be cost-beneficial regardless of changes in future flood risk are often termed 'no regret' measures. These measures usually have some of the following features (Jha et al., 2012):

- Are low cost, and are therefore likely to have high benefit-cost ratios regardless of future conditions.
- Have benefits other than flood risk management.
- Are part of a wider program that contributes to development.
- Are not sensitive to changes in future flood risk.

Flexible solutions are those which can be adapted to changing future conditions. Although changes may be necessary in the future as risks change, flexible solutions allow for that change without major reinvestment or reversal of earlier actions. Many non-structural measures tend to be inherently flexible, for example, emergency plans. Structural measures are seen as less flexible, but some flexibility can sometimes be incorporated, for example with the installation of wider foundations for dikes so that they can be raised later without having to strengthen the base (Jha et al., 2012).

## 7.2 Methodology

In the absence of detailed costs and exact areas, an attempt was made to quantify the various interests at a high level so as to help evaluate the potential flood mitigation measures.

Multi-Criteria Analysis (MCA) is a complementary approach to incorporate less formal consideration of social and environmental issues into project evaluation. The approach is used to balance the needs of multiple stakeholders and to allow consideration of benefits and costs that do not ordinarily have an economic (market) value, such as biodiversity, well-being or community spirit. The process aims to establish the objectives of all of the stakeholders that may be affected by both the flood risk and the associated risk reduction measure. Consensual weighting is then determined for various criteria, through discussion with stakeholders (Jha et al., 2012).

A high-level version of Multi-Criteria Analysis (MCA) was used to assess the approximate costs and benefits of each of the identified options for Maplewood Village. The objectives were generated based on input received at the kick-off meeting with District staff. It was recognized that the primary focus of the flood risk mitigation strategy was to ensure 'safe development'. This encompasses both risk of injury to people and of damage to property, both business and residential. Damage to infrastructure (i.e. roads and other utilities) is another related consideration.

Concerns were expressed at the kick-off meeting about mitigation options affecting the landscape and ecosystem adversely, and these were included as evaluation criteria. Specifically, in terms of ecosystems, there was recognition that the Seymour River is a salmon-bearing watershed and that parks abound in this area. With regard to landscape, there were concerns about raised development fracturing the streetscape, as well as causing mobility and accessibility issues.

The ease of implementation and adaptability of options were not specifically mentioned by District staff but can influence decision-making significantly. Ease of implementation considers the planning and regulatory hurdles that would be required to implement the option. Adaptability, as discussed above, takes into account the option's flexibility, for instance, in being adapted for a different sea level or different use. These are two criteria that point to 'no regrets' solutions. Finally, as with any benefit-cost assessment, monetary costs are a factor in the evaluation.

Criteria that indicate injury or damage to people, property and infrastructure were evaluated on a scale of 1 to 5 (with 0 for the Do Nothing option) as each of the proposed measures will provide some level of positive risk reduction. Capital costs and maintenance costs associated with each option are negative (0 to -5), while the reduction in emergency costs due to the option is positive (0 to 5). Landscape improvements and ecosystem benefits can be a positive or negative number (-5 to +5), depending on whether they enhance or detract those values. All criteria were given a weighting based on the importance of each to the District.

For each measure, scores were assigned against each criteria based on judgement, literature review, risk assessment spreadsheet results, and spatial layers from the District. Score brackets were developed based on the performance against the particular criteria: rows with many dark blue cells indicate significant positives from the option while more orange indicates significant negatives. Table 4 shows the outcome of the evaluation of options.

It should be noted that the flood mitigation options are currently evaluated as stand-alone options, however, a suite of options that work in tandem is more realistic. For instance, floodproofing new builds alone is not very effective for mitigating large-scale flooding, but its value improves when combined with a dike.

**Table 4. Evaluation matrix of flood mitigation measures based on social, economic and environmental criteria.**

Significant Positives
Positives
Neutral
Negatives
Significant Negatives

| Criteria | Residential property damage reduction | Business damage reduction | Infrastructure damage reduction | Landscape improvements | Ecosystem benefits | Ease of implementation | Adaptability | Capital and Maintenance Costs | Emergency costs' reduction |
|---|---|---|---|---|---|---|---|---|---|
| *Scale* | 0 to 5 | 0 to 5 | 0 to 5 | -5 to +5 | -5 to +5 | 0 to 5 | 1 to 5 | 0 to -5 | 0 to 5 |
| *Weighting* | 15% | 15% | 15% | 5% | 5% | 2.5% | 2.5% | 30% | 10% |
| **RIVER FLOODING MEASURES** | | | | | | | | | |
| **Land Use Planning** | | | | | | | | | |
| Lot Setbacks along Seymour R. | | | | | | | | | |
| Land Acquisition along Seymour R. | | | | | | | | | |
| **Building Design** | | | | | | | | | |
| Floodproof new builds | | | | | | | | | |
| Retrofit older builds | | | | | | | | | |
| **Flood Defenses** | | | | | | | | | |
| Build river dike | | | | | | | | | |
| **Floodwater storage & conveyance** | | | | | | | | | |
| Build floodway / diversion channel | | | | | | | | | |
| **Infrastructure Improvements** | | | | | | | | | |
| Upgrade Dollarton Hwy Bridge | | | | | | | | | |
| Upgrade Maplewood Creek culvert | | | | | | | | | |
| **Do Nothing** | | | | | | | | | |
| **COASTAL FLOODING MEASURES** | | | | | | | | | |
| **Land Use Planning** | | | | | | | | | |
| Establish Coastal Hazard DPA | | | | | | | | | |
| Minimize residential land uses | | | | | | | | | |
| **Building Design** | | | | | | | | | |
| Floodproof new builds | | | | | | | | | |
| Retrofit older builds | | | | | | | | | |
| **Flood Defenses** | | | | | | | | | |
| Build seawall | | | | | | | | | |
| Build sea dike | | | | | | | | | |
| Restore natural habitats | | | | | | | | | |
| **Do Nothing** | | | | | | | | | |

## 7.3 Trade-offs for Maplewood Village

Evaluating the performance of each option against the values-based criteria and comparing them against other options to understand how they perform relative to one another (Table 4) allows key trade-offs to be identified for decision-making. A discussion of the trade-offs associated with the flood management strategies outlined in Section 6.1 is provided below.

***Land use planning***

- Dense residential development along Seymour River Place on the floodplain adjacent to the river requires people and property to be protected from present and future flood hazards. These buildings could be elevated and retrofitted (as discussed above), but managed retreat is an alternative with potentially fewer residual risks. In this case, land-use measures would be used to relocate development entirely outside the flood boundary, either by acquiring properties or instituting lot setbacks.
- Lot setbacks would be significantly less expensive to the District than acquiring properties. Development restrictions (lot setbacks, density restrictions) would also be easier to implement than land acquisition. Lot setbacks, however, would only be effective when the parcels are re-developed.
- Both options offer potential for landscape improvements and ecosystem benefits by reclaiming the river floodplain and using it for low-vulnerability recreational uses.

***Building design***

- For new builds, the cost to elevate buildings is initially borne by developers (ultimately by occupants). In the case of older buildings, existing property owners would directly bear the cost of retro-fitting, unless financial incentives were provided.
- Implementing floodproofing for new development is relatively straightforward through existing bylaw/planning tools and offers a predictable change for developers. It is also adaptable as it is easily updated for a higher sea level over time.
- FCLs generally protect properties, but "islands" will be created unless the surrounding land is also elevated. In addition, District infrastructure (roads, utilities, etc.) need to be raised to meet building levels. Elevating emergency routes adjacent to Maplewood Village will need to be prioritized.
- Raising buildings to FCLs may detract from the streetscape if buildings on the street are constructed or upgraded at different times. However, the use of good urban design principles can minimize this concern. Undeveloped areas present an opportunity to create a more uniform, elevated streetscape.
- The decision to retrofit versus replace will be largely impacted by the age of the building. Light industrial and single-family dwellings in the floodplain are approximately 50-60 years old. One multi-family dwelling is approximately 40 years old.

***Flood defences***

- Dike and seawall options block floodwaters from reaching the community, and therefore protect the most area, including  people, property and infrastructure. However, the risks are high should these structures fail, unless secondary defences such as building FCLs are in place. Seawalls may also result in considerable spray.
- Dollarton Highway could be raised and engineered for coastal flood protection. However, the dual-use may pose technical challenges for design, construction and maintenance.
- The alternative of a raised seawall along the Burrard Inlet shoreline south of Maplewood Village protects both the residential-commercial lands of Maplewood Village as well as the industrial land base and critical transportation routes (e.g. rail, highway interchanges). However, the need to maintain ship and rail access to and from the industrial lands of lower Maplewood may limit the viability of this option.
- Dikes may detract from the landscape, although measures can be taken to improve aesthetics and make them more habitat-friendly. With a river setback dike, habitat restoration opportunities can be created and a floodable park established on the river-side. The dike can also be complemented by locating a trail and pedestrian greenway on top of it. The sea dike option is less amenable to improving the landscape and ecosystem as it lies inland in an industrial area and would either take advantage of a rail alignment or existing road. In contrast, the seawall at the Burrard Inlet shoreline presents an opportunity to restore the existing hard shoreline and improve aesthetics and habitat in the process. However, it would not be useable as a recreational amenity due to its setting in an industrial zone.
- The costs associated with constructing (and maintaining, to a lesser degree) the dike and seawall options are generally high. With the latest seismic guidelines issued by the Province (MFLNRO, 2014), it is estimated that the costs of constructing a dike that meets seismic standards have increased two- to three-fold. Dikes also require greater setbacks from the water’s edge to be seismically-safe, resulting in potentially higher costs associated with securing the right-of-way.
- Dikes are not easily adaptable structures, but some flexibility can be incorporated into their design. One of the requirements for raising dikes to protect against higher sea levels in the future is the availability of a large right-of-way (an 1.0 m increase in crest elevation, requires a 6.0 m increase in footprint based on 3:1 side slope), which is difficult to obtain in an urbanized environment. A seawall could be raised more easily over time, without requiring a larger footprint.
- Restoring natural habitats typically offers the most protection as a coastal flood defense measure when large geomorphic features such as barrier islands or wetlands are constructed or restored. In an urban environment like Maplewood with space constraints and where the coastal flood risk is not from a large, open body of water, these measures are less effective in protecting people, property and infrastructure. Still, this can be considered a no-regrets solution as the cost is relatively modest, and there are other benefits to its implementation.

***Floodwater storage, conveyance and energy dissipation***

- A flood diversion channel is proposed for the west bank through Cutter Island Park, which lies on District-owned park land. The channel could potentially offer ecosystem benefits and landscape improvements, while affording some degree of protection to people, property and infrastructure in Maplewood Village. Hydraulic benefits of various designs can be evaluated through numerical modelling (Section 7.4).

- As the channel would be located away from existing and future development at Maplewood Village, the risks of diverting water along this route are low. However, if the adjacent Squamish Nation lands are to be developed, the optimal location and effective capacity of the channel may be constrained.
- The diversion channel would need to cross under roads and the railway in order to drain into Burrard Inlet, involving costly construction and the cooperation of different jurisdictions such as CN Rail and Ministry of Transportation and Infrastructure.

***Infrastructure improvements***

- The under-sized Maplewood culvert contributes locally to the overall flood hazard and affects a few residential properties. However, the upgrade is relatively straightforward to implement, and conceptual designs have already been completed. The culvert upgrade could also potentially be integrated with other improvements in the area.
- The cost of upgrading the Dollarton Highway Bridge is significant. Since the bridge was upgraded as recently as 2005, bridge replacement is not expected in the near future. However, improvements to the design (i.e. raising and enlarging the span) could be implemented as part of future highway interchange reconfigurations. By setting back the east abutment, the dike can be aligned with a consistent setback, improving approach flow conditions at the bridge and eliminating upstream water level increases.

## 7.4 Adverse Impacts

A stated goal of the flood management strategy was to ensure no adverse impacts to adjacent areas from the shortlisted options for Maplewood Village. The main neighbouring jurisdiction that could be impacted is the Squamish Nation, located on the west bank of the Seymour River channel across from Maplewood Village. This section describes numerical modelling carried out and preliminary results from the flood profile simulations.

### 7.4.1 Modelling Methodology

NHC used an existing 2D numerical model of the lower Seymour River to provide a quantitative understanding of the potential impacts of two structural options to mitigate river flooding. The model had to be extended a short distance downstream with topographic data in the lower estuary and does not extend all the way upstream to Mt. Seymour Parkway Bridge.

The model was used to understand the impacts from the two options:

1. Floodway/flood diversion channel – specifically, the impact on water levels on the west bank floodplain of the lower Seymour River.
2. Setback dike – specifically, the impact on water levels in the same area from constructing a setback dike along the east bank floodplain (an alternative to the floodway option).

For the floodway, an approximately 7 to 10 m wide channel on the western floodplain (Figure 12) was assumed, though more detailed design could determine the optimal channel dimensions for deriving maximum benefit. For the setback dike, a vertical wall along the alignment shown (Figure 12) was added in the model to block flow from moving eastward onto the floodplain. These mitigation options were evaluated under two time horizons: a 200-yr flood under current conditions and a similar flood with climate change incorporated (year 2100).

Although model results are approximate and unlikely to be accurate to the nearest centimetre, they allow for comparison of the options.

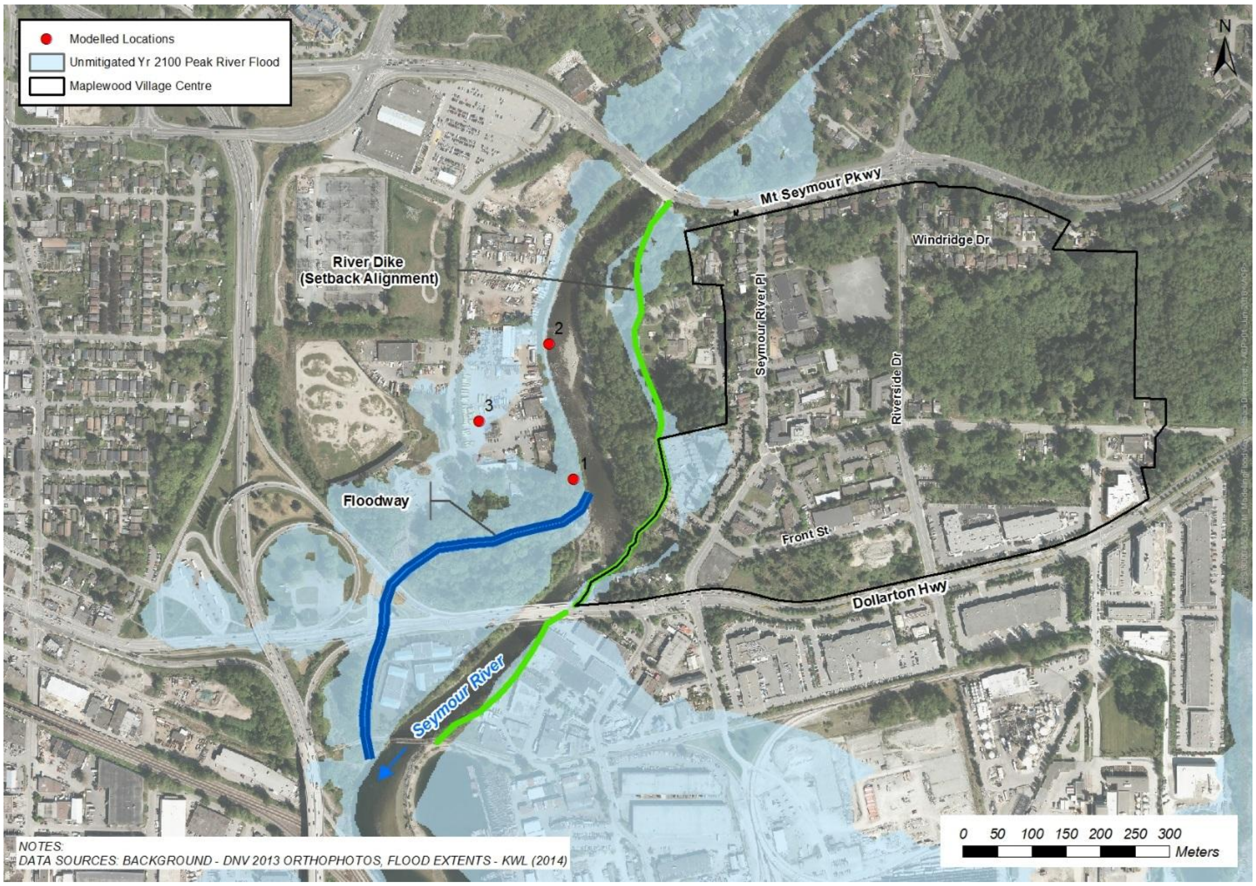



**Figure 12. Proposed floodway and setback dike configuration for modelling**

### 7.4.2 Model Results

The modelled water levels are tabulated in Table 5 and Table 6 for the floodway and setback dike options respectively. Referenced flood level locations are shown on Figure 12.

**Table 5. Summary of modelled water levels for Floodway option**

| Flood condition | Floodplain condition | Water Level (m GD) | | |
|---|---|---|---|---|
| | | Location 1 *(downstream)* | Location 2 *(upstream)* | Location 3 *(west)* |
| 200-year Flood | Existing | 5.75 | 6.46 | 5.83 |
| | w/ Floodway | 5.71 | 6.45 | 5.83 |
| | **Difference** | **-0.04** | **-0.01** | **0.00** |
| 200-year Flood with Climate Change | Existing | 6.07 | 6.58 | 5.86 |
| | w/ Floodway | 6.03 | 6.57 | 5.85 |
| | **Difference** | **-0.04** | **-0.01** | **-0.01** |

**Table 6. Summary of modelled water levels for Setback Dike option**

| Flood condition | Floodplain condition | Water Level (m GD) | | |
|---|---|---|---|---|
| | | Location 1 *(downstream)* | Location 2 *(upstream)* | Location 3 *(west)* |
| 200-year Flood | Existing | 5.75 | 6.46 | 5.83 |
| | w/ Setback Dike | 5.84 | 6.47 | 5.83 |
| | **Difference** | **+0.09** | **+0.01** | **0.00** |
| 200-year Flood with Climate Change | Existing | 6.07 | 6.58 | 5.86 |
| | w/ Setback Dike | 6.19 | 6.61 | 5.86 |
| | **Difference** | **+0.12** | **+0.03** | **0.00** |

With the addition of the floodway, the results show essentially no change (i.e. within model error) at the upstream and west locations (Location 2 and 3) and a minimal reduction at the downstream location (Location 1) of 4 cm, suggesting that a significantly larger/longer channel would be required to have any measurable benefit.

Adding a setback dike on the east bank results in no or minimal increases in water levels in the upstream and west locations (Location 2 and 3). However, there could be an increase in the water level at Location 1 by 9 to 12 cm. This rise in water levels stems from the confinement of flow upstream of Dollarton Bridge, suggesting that bridge improvements should be made to increase conveyance.

These preliminary results indicate that a floodway could provide some marginal benefits to the Squamish Nation and that the dike could have some negative impact.

# 8 IMPLEMENTATION PLAN

Addressing flood risks requires an adaptive approach, particularly in dealing with climate change uncertainty. Projections of flow increases and sea level rise are approximate, both in terms of timing and magnitude, and actual future flood hazards may vary significantly.

Estimated economic building losses from flooding in Maplewood Village were shown to be significant under present conditions, suggesting that mitigation measures are already urgently required and their implementation should begin as soon as possible. Estimated losses for an end-of-century flood are nearly four times as high, as a result of increased flood hazards and additional land development. It is difficult to set particular trigger levels for implementing flood mitigation measures, considering the actual rate of sea level rise is projected to increase exponentially rather than linearly as generally shown on provincially-recommended graphs.

Key to successful flood management is proactively taking steps to mitigate flood damage and ensuing losses. Potential short-, medium-, and long-term actions the District may wish to consider are discussed below. It should be recognized that the present work provides a broad overview of options and more detailed assessments would be required before actual implementation.

## 8.1 Short-Term Actions

It is recommended that the District consider the following short-term actions by 2020:

*Explore Seymour River Setback Dike Option (East Bank from Mount Seymour Parkway to Dollarton Highway)*

- Consult with the Squamish Nation to learn about potential development/flood protection plans on the west bank. A river dike along the west bank could raise flood levels and should be discouraged − a setback dike or no diking being preferable.
- Consult with Ministry of Transportation and Infrastructure (MOTI) regarding future interchange improvements in the area that could provide an opportunity to increase conveyance at Dollarton Bridge.
- Develop and numerically model design concepts for the river setback dike and determine the required footprint. Seek input from local stakeholders.
- Secure dike rights-of-way through discussions with the District Parks Department.

*Explore the Seymour River Flood Diversion Channel Concept (West Bank)*

- Consult with Squamish Nation, MOTI and CN Rail. Determine land restrictions and construction limitations.
- Based on findings, calculate the maximum practical channel size and determine through modelling if the channel would be of benefit.

Increasing the Dollarton Bridge opening by setting back the bridge abutments, and constructing a setback dike on the east side of the river will likely provide the optimum flood protection. However, the impact of floods having larger return periods, incoming sediment load over time and potential future channel shifts and blockages should be considered before detailed design development.

*Additional Considerations:*

The following actions are also recommended, including several relating to land-use planning:

- Monitor the Maplewood Creek culvert for blockages on a semi-annual basis and following prolonged or intense rainfall events. Clear debris as needed.
- Undertake detailed design for upgrading Maplewood Creek culvert.
- Adopt year 2100 building FCLs for the area with the option for developers to lower building elevations through site-specific assessment by a Qualified Professional.
- Encourage or incentivize flood resilient design and construction.
- Restrict future development along Seymour River near Riverside Mews townhouses to the landside of the lot setback boundary (see Figure 11). This will reduce flood hazards if no dike is built, or allow for the MFLNRO-required buffer between the toe of dike and housing if the dike is built.
- Establish a Coastal Hazard Development Permit Area for the coastal floodplain. Provide an option to determine FCLs based on the joint probability of high tides, storm surge, wind set-up and wave run-up.
- Undertake a flood risk assessment and mitigation study for the proposed Maplewood Fire Facility in the coastal floodplain to ensure that the site is safe for the intended purpose and to provide input on a phased approach to coastal flood protection for the area.
- Align this flood management strategy with Fraser Basin Council's Lower Mainland Regional Flood Management Strategy, particularly as it relates to funding coastal flood mitigation measures[6].

## 8.2 Medium-Term Actions

The following actions are suggested for the five-year span from 2020 to 2025:

- Upgrade the Maplewood Creek culvert.
- Construct the optimized design of the Seymour River setback dike and/or floodway. Work with MOTI to consider enlarging the Dollarton Bridge opening.
- Undertake an engineering feasibility study to evaluate coastal flood protection options. Consult with CN Rail, Port Metro Vancouver, and other industrial stakeholders as appropriate. Secure rights-of-way for a coastal sea dike (along road or rail alignment) or seawall (along shoreline alignment).
- As practical, plan for raising infrastructure adjacent to buildings as they become slated for renewal/upgrade/improvement.

[6] Note that the Lower Mainland Flood Vulnerability Assessment did not consider river flooding from rivers other than the Fraser River. In addition, development in the Seymour River floodplain is a concern in the short-term whereas a longer-term approach is more feasible for coastal mitigation.

- Monitor climate change predictions, including sea level rise projections, and evaluate local impacts.

## 8.3 Long-Term Actions

In the long term, from year 2025 onwards, the following actions will likely become necessary:

- Continue to monitor climate change and sea level rise predictions to inform design of structural measures and planning measures.
- Construct the preferred coastal flood protection option, keeping in mind latest climate change projections.
- Plan to raise and enlarge span of Dollarton Highway bridge as part of future bridge renewal, if it is not completed sooner. Realign downstream end of setback dike.

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# Appendix A: Flood Management in Other Jurisdictions

# 1 INTRODUCTION

Emerging best practices locally and from elsewhere in the world were reviewed to help inform what innovative flood mitigation measures could be applied in the District. Nations that are leading the charge on this subject include the Netherlands, the United Kingdom, and the US (specifically, New York, New Jersey, and New Orleans). Some evolving theories on the approaches to flood management and the effectiveness of strategies to mitigate flood impacts are discussed below.

## 1.1 High-level Adaptation Strategies

Recent lines of thinking on response strategies for dealing with accelerated sea level rise center around the following actions: Accommodation, Retreat, and Protection. Avoidance is another one that should be added when considering new development or redevelopment. The avoidance strategy involves directing new development away from vulnerable areas through voluntary measures and improved regulation, and equally, retaining existing less-vulnerable land uses.

Accommodation

Accommodation implies that people continue to use the land at risk but do not attempt to prevent the land from being flooded (IPCC, 1990). Accommodation strategies tend to "harness traditional zoning, building code, and flood prevention code tools to increase developments resilience to sea level rise" (Herzog and Hetch, 2013). One of the most common ways of accommodating floodwaters is through elevated and floating buildings, applicable in both a river and coastal setting. By elevating on piles, floodplain area is retained and floodwaters are allowed to spread out. In an urban setting, key design principles can be incorporated such that use, access, parking and streetscape and visual connectivity are maintained (NYC Department of City Planning, 2014). Two examples are shown in Figure 13.

**Figure 13. House in coastal Mississippi with elevated construction, structural materials doubling as finished and green roof, which survived Hurricane Katrina (left). City of North Vancouver library courtyard with grade transition addressed through landscape design (right).**

Soft structural measures built into the landscape are also becoming more common. Floodable parks are those that invite floodwaters into areas that are water-compatible while keeping them out of populated neighbourhoods. Recently completed was Corktown Common, an urban park in Toronto that doubles as a protective barrier against flood waters of the Don River. Tokyo has made use of small, limited spaces, such as tennis courts, for runoff storage.

In a riverine context, floodways can also accommodate floodwaters. They typically divert excess flow of water at a point upstream, around vulnerable assets in the floodplain, and discharge it back into the main channel downstream. Whereas many cities in the US are transforming their underutilized floodways into active recreational amenities, they can also be constructed from the start to be congruent with park uses and landscaped as wetlands.

### Retreat

Retreat can refer to an unplanned response in the aftermath of severe storms or a planned response to avoid the costs of other adverse effects of shore protection (Titus, 2009). A managed retreat strategy is often contemplated in the context of sea level rise planning, which proposes the relocation of homes and infrastructure inland to less vulnerable areas. This was one of the options studied for Corporation of Delta and its trade-offs assessed as a means of adapting to sea level rise (Flanders, 2011). In practice, this can be accomplished through conservation easements[7] or rolling easements[8].

Acquisition programs are another measure to achieve retreat. The buy-out of existing homes in a floodplain was proposed by the Alberta government following major riverine flooding in various communities in Southern Alberta in 2013. Homeowners in the floodway[9] were offered payment to move off this flood hazard zone, with the government also banning all future building there.

Limitations and restrictions on development can be useful on a smaller scale. Where high density re-development is being considered for a lot on the floodplain, retreat can be accomplished through building setbacks. Setting limitations on the density or size of new buildings on a lot are other measures that have been employed.

### Protection

Protection involves the use of hard structural options or soft solutions to protect the land from floodwaters so that existing land uses can continue. Examples of hard options include coastal armouring, seawalls and dikes whereas soft structural solutions may consist of barrier islands, dunes and wetlands. The drawbacks of hard structures are that they are recognized to disrupt natural habitats. Soft structures are not usually feasible in urban coastal settings where space is at a premium.

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[7] A restriction placed on a piece of property to protect the shore from development.

[8] Institutional arrangement that prevents landowner from protecting the shore, ensuring that the shore can migrate inland instead of being squeezed between an advancing sea and a fixed property line. Roads, infrastructure, and parks can also be relocated inland if necessary.

[9] Where flood waters are deep and/or flowing quickly.

Elevated development on fill is a small-scale measure that offers flood protection. Road raising is another small-scale measure. It is a minor example of a broader move to address safety while at the same time using space in a multi-functional way.

In the designing of infrastructure, recent thinking has also emphasized building adaptability into infrastructure. For example, if a seawall being considered for flood protection, it can be designed such that it can be gradually raised as sea levels rise.

Overall, there has been a general move away from exclusively hard strategies and towards integrating more soft approaches. The US Army Corps of Engineers (USACE) is now compelled to study the feasibility of implementing a non-structural approach to flood mitigation before they can consider a structural one. This is related to a shift away from managing the hazard and instead managing the risk, by reducing the exposure and/or vulnerability.

In most of these strategies, but especially the protection strategies, there has been a move towards integrating structural flood mitigation to be more congruent with landscape design. By building with nature, hard structures can be softened, and in the process, enhance the landscape, recreational and ecological values. One example is the piloting of 'green' dikes in the Netherlands, where water retaining substrate structures have been installed along the toe of the Western Scheldt dike. Stormwater management strategies, which mainly function to delay and store water, have already moved in this direction.

## 1.2 Restoring Ecosystem Functions

Many parts of the world are realizing that the traditional system of flood prevention based on dikes is ineffective and are reconsidering them as a strategy. They are recognized to cut rivers off from their floodplains, destroying lands that provide natural protection from flood. They have also given people a false sense of security, allowing them to settle and develop right next to rivers on lands that were once floodplains. The Netherlands, with its history of flooding, low-lying land mass and the expectation of sea level rise, has been advancing strategies on how to address higher water levels. It has recently embarked on a scheme called de-poldering, which involves the removal of dikes.

A related and even broader plan called Room for the River was approved in 2007 by the Dutch government. A variety of techniques are taken as part of this philosophy, including setting back dikes, creating detention reservoirs, and lowering the channel and floodplains to give additional space for rivers in several locations. Besides alleviating the flood level, it is envisioned that this will create room for living, recreational activities, culture, water and nature.[10] The corollary concept of 'Retain, Store, Drain' complements Room for the River[11]. It considers the river system as a whole and seeks to enhance retention of waters on the upper watershed, then the storage of waters in reservoirs (wetlands) and, in the lower river, the draining of excess water.

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[10] http://www.ruimtevoorderivier.nl/english/eu-funded-projects/room-for-the-river-waal/

[11] Blogs.ei.columbia.edu

Similar to the Room for the River plan, and closer to home, The Nature Conservancy established the Floodplains by Design program. It has carried out integrated projects that improve flood protection for towns and farms, while restoring salmon habitats, improving water quality, and enhancing outdoor recreation[12]. An example is the Calistoga Reach project that was undertaken after the 2006 and 2009 floods in Orting, WA. New man-made channels were created when the old levees were torn out and replaced with new earthen berms set farther back. In the November 2014 high flows, the river had room to spread out, slow down, and it stayed within the levees. Salmon also are taking advantage of the new habitat.

In coastal landscapes, there has been increasing awareness that natural landforms and habitats provide a first line of defense in reducing the risk of wave damage, overwash and flooding in the coastal zone (National Research Council, 2014). Flood damage in southern Louisiana from hurricanes like Katrina has been exacerbated by the loss of miles of protective wetlands and barrier islands along its coast (Dean, 2006). The City of Richmond has studied the possibility of constructing barrier islands that would create habitat and provide wave dissipation offshore from the dike. Dune systems have also been installed on shorelines in the Netherlands and New Jersey. Many large coastal cities lack the space necessary to take advantage of nature-based risk reduction approaches alone and will instead need additional hard structures to substantially reduce coastal hazards (National Research Council, 2014). Unlike river dikes, coastal armouring, with the exception of jetties or groynes, does not transfer the problem elsewhere in the system.

## 1.3 Holistic Approach

Over the past century, most coastal risk management programs have emphasized coastal armouring, while doing little to decrease development in harm's way (National Research Council, 2014). There is an argument for employing multipart strategies: the 'multiple lines of defense' concept endorses using a combination of nature-based approaches and hard structures to maximize storm surge risk reduction (Louisiana CPRA, 2012). Coupling nature-based approaches with hard structures to buffer infrastructure against the flood hazard provides an effective coastal risk reduction strategy if space allows (National Research Council, 2014).

Flood protection through building measures alone may not be effective, particularly where flood elevations are substantially above grade. In such cases, interventions at a larger scale, such as seawalls, levees, or surge barriers may offer less disruptive and more economical means of reducing flood risk. Case studies on the effectiveness of stormwater management have some applicable outcomes for riverine and coastal flood management. They indicate that on-site controls are effective in managing water associated with small-medium storms but not for extreme events. Through local monitoring, the City of Surrey recognized the value of implementing measures such as detention ponds to handle the large events, in conjunction with on-site controls.

[12] http://www.floodplainsbydesign.org/

An example of a comprehensive flood management strategy has been developed for New Jersey in the post-Sandy period. Referred to as the ‘Resist, Store, Delay, Discharge’ strategy, it deploys both hard infrastructure and soft landscape for coastal defense (resist); recommends policies to enable the urban fabric to slow down water (delay); a green circuit to trap water (store) and water pumps to support drainage (discharge).