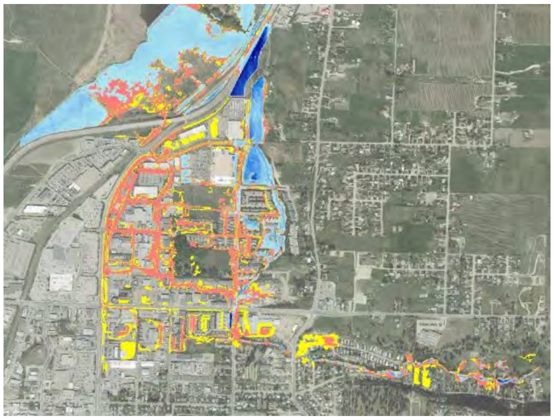
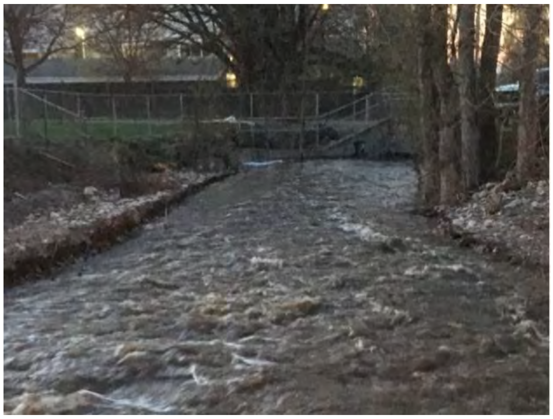
# CITY OF VERNON
# DETAILED FLOOD MAPPING, RISK ANALYSIS AND MITIGATION
# PART 1 – UPPER B.X. CREEK

## FINAL REPORT
***Revision No. 0***



Prepared for:

City of Vernon



25 August 2020

NHC Ref. No. 3005032

nhc
northwest hydraulic consultants
water resource specialists

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Prepared for:

**City of Vernon**
Vernon, BC

Prepared by:

**Northwest Hydraulic Consultants Ltd.**
Kamloops, BC

25 August 2020

NHC Ref No. 3005032

**Report Prepared by:**

Arian Cueto Bergner, Eng.
Hydraulic Modelling

Joel Trubilowicz, Ph.D., P.Eng.
Hydrologist

Julie Van de Valk, E.I.T.
Flood Risk Engineer

Rachel Managh, B.Sc.
GIS Analyst

**Report Reviewed by:**

Meg Broswick, P.Eng.
Project Manager, Associate

## DISCLAIMER

This report has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of **City of Vernon** for specific application to the **Upper B.X. Creek Detailed Flood Mapping, Risk Analysis and Mitigation** project. The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.** best professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation, and was prepared in accordance with generally accepted engineering practices.

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## CREDITS AND ACKNOWLEDGEMENTS

Northwest Hydraulic Consultants Ltd. (NHC) would like to thank the City of Vernon (CoV) for initiating this study, making available extensive background information and providing advice and support through-out the project. The key CoV representative is Mr. Trevor Scott, P. Eng., Infrastructure Engineer, with additional guidance provided by Margie Massier, GIS Asset Management Analyst; Geoff Mulligan, Infrastructure Management Technician; and, Sean Irwin, Operations Manager. Significant funding for this project has been provided by the Province of BC through the Community Emergency Preparedness Fund. The CoV would like to acknowledge Rebecca Bishop, Program Officer, at the Union of BC Municipalities for her support.

The following NHC personnel participated in the project:

- Surveys (Rachel Managh, Daniel Arnold, Pablo Rodriguez)
- Hydrologic Analysis (Joel Trubilowicz)
- Hydraulic Modelling (Arian Cueto Bergner, Chris Long)
- Mapping and GIS (Rachel Managh, Sarah North)
- Project Review (Dale Muir, Neil Peters)
- Project Lead and Management (Meg Broswick)

# EXECUTIVE SUMMARY

## Project Setting

The City of Vernon (CoV) experienced two large floods in 2017 and 2018, which resulted from a large snow pack, warmer than normal early season temperatures, and heavy precipitation. The entire Okanagan region experienced substantial flooding, which has renewed the focus on understanding flood risk in the region.

Upper B.X. Creek drains from Silver Star Mountain, which is located northeast of Vernon. The upper reaches of the watershed are generally forested with approximately 30 % of the upper watershed impacted by forest harvesting and a large portion also impacted by the mountain pine beetle. The lower reach of Upper B.X Creek is situated on an alluvial fan, which covers a large area that is now primarily occupied by Vernon's downtown.

The Upper B.X. Creek alluvial fan channel has a long history of flooding and sediment transport. Sediment removal has been documented since the 1980's and there are accounts of crossings becoming blocked and washed out during the 1996 flood of record. The recent freshet flood events mobilized substantial amounts of sediment to the fan, causing overbank flooding and infilling culverts. Given the estimated sediment budgets available for transport to the Upper B.X. Creek fan, sediment transport and aggradation within the fan channel are expected to continuously have an impact on the flood risk on Upper B.X. Creek.

## Part 1 Study Objectives

The purpose of this project is to prepare detailed floodplain and hazard maps for Upper B.X. Creek within the Vernon city boundary; assess the associated flood risk; evaluate mitigation options; and document and communicate the findings. The information developed is intended to be used for:

- Flood risk management (prevention and mitigation);
- Land use planning and land management;
- Emergency management; and
- Public awareness.

As the underlying goal is the assessment and mitigation of flood risk to the community, the mapping and associated hydrology, survey, modelling and analysis is aimed to be of the highest quality to avoid misrepresentation of the hazards. The flood maps and risk assessment provide the basis for the identification and implementation of mitigation measures to reduce flood risk.

## Hydrology of Upper B.X. Creek

Flows in Upper B.X. Creek have been estimated through a flood frequency analysis of Water Survey of Canada (WSC) data from gauge 08NM020 – B.X. Creek above Vernon Intake (WSC B.X.), which has been inactive since 1998. NHC has extended its record using data from an adjacent gauge, WSC 08NM142 – Coldstream Creek above Municipal Intake (WSC Coldstream).

Annual peak and maximum daily flows at both gauges occur almost exclusively in spring during freshet. The largest of these are usually enhanced by locally intense rainstorms that occur on top of an already melting snowpack. WSC B.X. experienced an event like this at the end of May 1996: 60 mm of rain fell within two days in Vernon (and presumably more at higher elevation), causing extreme flows that were more than double any other annual peak measured flow at the gauge.

A frequency analysis was performed by fitting the Generalized Extreme Value (GEV) distribution to the extended record. Results show that the 1996 event has a return period above 500 years; estimates of recent peak flows in Upper B.X. Creek using Coldstream Creek give return period flows of approximately 20 years for the 2017 flood and 40 years for the 2018 flood. Flow frequency results have been scaled to the upstream end of the study reach (71.5 $km^2$) using exponential, area-based scaling. Flows were scaled to the upstream end of the model as it is expected that the majority of streamflow during a flood event will be coming from runoff in the upper elevations of the watershed, where snowmelt and rain-on-snow are the primary flood generators.

### *Impacts of Climate Change*

Hydrological changes to the region are expected to include an earlier freshet onset due to warmer spring and winter temperatures. Additionally, a larger percentage of winter precipitation is expected to fall as rain, rather than snow. While temperature changes are generally well understood, the changes in total precipitation are less clear. As a whole there appears to be a trend towards more precipitation in the fall/winter/spring period, with either similar or less precipitation during the summer. The effect of the snowmelt freshet is expected to decrease due to decreasing winter snow accumulation, but the potential for heavy rain is expected to increase due to increasing total precipitation and a general trend of "more extreme extremes".

### *Design Flood Event*

The 1996 flood of record with an adjustment for climate change is selected as the design flood event, resulting in a flow of 19.5 $m^3/s$. The 500-year Swan Lake level has been used as the downstream boundary condition for this design event and is estimated as 390.1 m.

## Floodplain Map Development

The Hydrologic Engineering Center's River Analysis System (HEC-RAS), a hydraulic modelling software program developed by the US Army Corp of Engineers (USACE) (Version 5.0.7, 2019), has been utilized for the hydraulic analysis of Upper B.X. Creek. NHC selected a 1D/2D coupled model to simulate flood flows in the channel, using one-dimensional modelling based on cross sections of the channel; and the floodplain, using two-dimensional hydrodynamic flow routing through a mesh.

The hydraulic model covers a reach length of approximately 3.5 km, starting from approximately 1 km upstream of Pleasant Valley Road (600 m upstream of the Vernon city boundary) and ending at Swan Lake. The 1D model is based on digitization of the 2016 orthophoto, 57 cross sections derived from NHC in-channel surveys, overbank LiDAR data, five cross sections from the SEL survey, and a total of 22 crossings (13 bridges and 9 culverts) surveyed by NHC. Where culverts had variable levels of sediment infilling, full culvert dimensions were extracted from available record drawings and the 2015 Stantec inspection (Stantec, 2016). Moreover, two crossings with variable geometries along their length were modelled using the most restrictive cross section dimensions. Details on all crossings are presented in Appendix B.

### *Model Results*

For the design flood, Condition 1 flood extents reach 27th Street to the west and nearly 46th Avenue to the south. The flooding extent also covers the area east of the creek directly south (Vernon Works Yard) and north (industrial yard) of 48th Avenue. Finally, to the north, the flood extents cover about 300 m of both lanes of Highway 97. The Condition 1 scenario assumes no emergency diking or successful clearing of sediment infilling during the design flood event. The 20-year flood and 200-year flood with an adjustment for climate change were also modeled and flood extents provided to the CoV as GIS rasters.

## Floodplain and Hazard Maps

This entire document should be read before using any of the results from maps. A Qualified Professional or NHC should be retained to interpret results if not understood. Results may change as the channel, crossings and hydrology change with time.

### *Floodplain Map*

A floodplain map has been provided for the design flood event showing inundation limits and flood construction levels based on hydraulic model results for Condition 1 (Section 5.3).

Freeboard is added to the simulated water level to provide a minimum level for construction within the floodplain, referred to as the flood construction level (FCL). The freeboard accounts for local variations in water level (i.e. super elevation, turbulence, surging), as well as for the precision or confidence in the data and assessment. For Upper B.X. Creek, a 0.6 m freeboard has been applied to the design flood event , which is considered appropriate given that the flood mapping covers an active alluvial fan, and the flood inundation is very sensitive to culvert infilling/blockages.

### *Setbacks*

FLNRORD (2018) defined setbacks on small streams as 15 m from the natural boundary of the channel, given that the channel is not obstructed. As Upper B.X. Creek is located on an active alluvial fan and there is a history of flooding this setback should not be reduced (FLNRORD, 2018). Setbacks should be increased to 30 m in locations where structural mitigation is recommended. The increased setback is to provide space for the construction of structural mitigation such as dikes and the associated right of way

(ROW). This setback may need to be adjusted depending on the required height of the structural mitigation (MWLAP, 2003).

### *Hazard Map*

The flood hazard map depicts the design flood event under Condition 1. Simulated water depths are shown for each cell vertex in the 2D mesh and calculated velocities were filtered down to a 20 m grid to clearly represent overland flow velocities. Within the river channel, flood depths are based on 1D model results and velocities are based on 1D model velocities at cross section locations. 2D velocity arrows representing less than 0.05 m/s and 1D velocity arrows within the channel that overlap at a 1:4,000 scale were filtered from the hazard map. Freeboard was not included in mapped depths or extents on the hazard map

## Flood Risk Assessment

Flood risk is the process by which the consequences and likelihoods of flooding are assessed. Best practices for risk assessment include a spatial analysis using available flood hazard information and mapping of receptors (*people, economy, culture, and environment*). This project examined both the 20-year flood event, as well as the design flood event. For each of these events, modelled extent and depth results without freeboard were overlaid with spatial receptors using GIS analysis.

The risk assessment results presents a quantitative understanding of the impact of both the 20-year flood and the design flood event. Risk classification is based on ratings provided in the Risk Assessment Information Template (RAIT) and an example flood risk matrix provided by (EGBC, 2018a)). Risk classifications are not based on stakeholder consultation and as they are designed for a wider context, they may not reflect the impact to the local community.

The 20-year flood has a relatively high likelihood, with a 92 % chance of occurring over 50 years. A 1-in-20 year event is classified as 'likely' by the example EGBC flood risk matrix and given a relatively high likelihood of 4/5 in the RAIT. The design flood event has a return period between 50-500 years, classifying it as 'unlikely' by the example EGBC flood risk matrix and giving it a relatively low likelihood of 2/5 in the RAIT.

Either flood is relatively predictable and not expected to be a rapid onset event such as a debris flow or a dike breach, and therefore unlikely to cause death or serious injury. With effective evacuation, it is possible to remove all flooded residents, although there is potential for injury amongst those who remain in the area. In addition to those directly affected, it is likely that hundreds more will be affected through loss of business, damage to properties, and interruption to routine. Both the high and low likelihood floods are not likely to cause fatalities and injuries will likely be within local response capacity.

The 20-year flood is estimated to have a high economic consequence as per the example EGBC flood risk matrix including 'major asset loss; several weeks business interruption; and <$1 million dollars of damage'. The design flood event is estimated to have a severe economic consequence with 'severe asset loss; several months business interruption; and <$10 million dollars of damage'.

## Flood Risk Reduction Planning

Flood risk reduction planning is an ongoing, iterative process which requires careful consideration and community input. Flood risk reduction is based on information from both a flood hazard and flood risk assessment. Flood risk reduction planning builds on the available information about hazards and valued assets to develop a plan to minimize impact to valued community assets.

There is a variety of both structural and non-structural flood risk reduction options and options have been selected and discussed based on the results of the analysis in this area. This discussion is preliminary and does not constitute a comprehensive mitigation plan or recommended options.

### *Structural Mitigation*

Structural mitigation is considered as any specific engineering works that reduce flooding impacts. Site specific structural mitigation measures to reduce flood risk within the community have been developed for Upper B.X. Creek for use as a planning tool by the CoV. Further work will be required to prepare conceptual level plans and cost estimates for any suggested works.

Recommended structural mitigation includes:

- Sediment and debris management plan;
- Diking near Pleasant Valley Road;
- Crossing upgrades of the first 20th Street, 48th Avenue and second 20th Street crossings;
- Diking between 20th Street and Deleenheer Road; and
- Highway 97 crossing upgrade.

### *Non-Structural Mitigation*

Non-structural mitigation is considered flood protection that does not rely on the use of a dedicated flood protection structure (structural mitigation). The following are non-structural measures that can be considered by the CoV:

- Land use planning; including setbacks, limiting housing densities in flood prone areas, requiring site specific flood hazard assessments and requiring buildings to be built to the provided FCL;
- Development of emergency response plans;
- Flood risk education for the public; and
- Recovery pre-planning through the development of recovery plans and resources in advance of a flood or other hazard event.

# GLOSSARY OF TERMS

| | |
|---|---|
| *Aggradation:* | Long-term rise in streambed or floodplain elevation due to hydraulic deposition of sediment. |
| *Alluvium:* | Unconsolidated sediment (clay, silt, sand and/or gravel) deposited by moving water. |
| *Alluvial fan:* | A fan shaped mass of sediment (alluvium) that is deposited by streams; generally located where the land transitions from mountainous terrain to flatter plains. |
| *Crossing capacity:* | The maximum discharge that can be conveyed through a crossing (bridge or culvert). |
| *Debris:* | Loose material that has the potential to be transported and deposited by streamflow processes. Can include sediment as well as vegetation, including wood and logs, rubble, litter, etc. |
| *DEM:* | Abbreviation for "Digital Elevation Model": a 3-D representation of earth's terrain in the form of a raster (grid-type) dataset, where each raster cell corresponds to a horizontal geographic location on the surface of the earth, and the value assigned to the raster cell is the elevation at that location. |
| *Design flood:* | A flood of a given magnitude for which design parameters for stream-related infrastructure are determined. Generally includes an increase for the future impacts of climate change. |
| *Flood construction level:* | Refers to the elevation above which construction is permitted, incorporating freeboard over the design flood level. Purpose is to protect property that is susceptible to damage from floodwaters. |
| *Flood fringe:* | The flood affected area outside of the main flow area (floodway), where velocities and water depths are lower. |
| *Flood map:* | Shows the extent of inundation for a flood of a given magnitude, may or may not include freeboard. |
| *Floodplain:* | The entire area including and adjacent to a stream channel that encompasses the floodway and flood fringe. |
| *Flood risk:* | The product of the probability of a given flood occurring and the potential hazardous consequences of a flood of that magnitude. |

*Floodway:* Encompasses the main channel plus any active floodplain and flood channels where velocities are estimated to be greater than 1 m/s and/or depths greater than 1 m.

*Freeboard:* A vertical offset from the design flood surface level to account for uncertainties and unpredictability regarding hydraulic, hydrologic and geomorphologic properties.

*Hazard map:* Shows the extent of inundation for a flood of a given magnitude, including flow direction, velocity and depth details so the user may infer the level of hazard posed to at-risk elements.

*LiDAR:* Abbreviation for "Light Detection and Ranging": A remote sensing technology used to create DEMs that employs a laser to measure distances from known elevations to the surface of the earth.

*Non-structural mitigation:* Reduces flood risk without the act of physical construction. Examples include land-use planning, emergency response planning, and flood-risk education.

*QPD:* Abbreviation for "Peak Daily Flow": the maximum average daily streamflow that occurs in a given period of time (usually a year).

*QPI:* Abbreviation for "Peak Instantaneous Flow": the maximum instantaneous streamflow that occurs in a given period of time (usually a year).

*Riverside dike:* A dike situated directly adjacent to the main stream channel in which the water side of the dike is set directly above the streambanks, cutting off the channel from the floodplain.

*Sediment infilling:* The process through which sediment transported by a stream is deposited in such a way that reduces the cross sectional flow area of a channel or crossing, often resulting in reduced flow capacity.

*Setback:* Refers to the distance from a stream channel beyond which development is permitted. Purpose is to keep development safe from erosion risk and to minimize floodway obstructions that would restrict flow.

*Setback dike:* A dike that is situated beyond a given setback from the main stream channel. Setback dikes tend to be preferable to riverside dikes as they allow for flow onto the floodplain, and thus cause less restriction of channel flow capacity.

*Shear stress:* The component of stress that acts parallel to a material surface. In river hydraulics, shear stress refers to the coplanar stress imposed on the channel banks and bottom by flowing water and debris.

*Structural mitigation:* Reduces flood risk through the establishment of new or modification of existing physical features. Examples include dams, dikes, training berms, floodwalls, seawalls, bank protection works, flood retention basins, sediment basins, river diversions, floodways, channel modifications, sediment management, debris barriers, pump stations, and floodboxes.

*1D flow:* Flow that is modeled in one dimension, both in the stream channel and on the floodplain. Hydraulic computation is determined in one direction (along the channel centreline). For a given point along a stream, hydraulic properties (velocity, depth, etc.) from a 1D flow model will be the average across the channel cross section at that point, without the ability to capture lateral variation.

*2D flow:* Flow that is modeled in two dimensions, requiring a surface (such as a DEM). 2D flow modelling is able to capture lateral variation in hydraulic properties. 2D flow is often combined with 1D flow in hydraulic models, where 1D flow is used to model conditions within the channel and 2D flow is used to model conditions on the floodplain.

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# 1 INTRODUCTION

The City of Vernon (CoV) experienced two large floods in 2017 and 2018, which resulted from a large snow pack, warmer than normal early season temperatures, and heavy precipitation. The entire Okanagan region experienced substantial flooding, which has renewed the focus on understanding flood risk in the region. A large flood mapping project has been completed for the Okanagan mainstem system managed by the Okanagan Basin Water Board (OBWB) with technical work by Northwest Hydraulic Consultants Ltd. (NHC). The CoV Flood Mapping, Risk Analysis and Mitigation Project leverages recent improvements in regional understanding to increase understanding of flood risk in Vernon.

## 1.1 Project Objectives

The purpose of this project is to prepare detailed floodplain and hazard maps for B.X. Creek and Vernon Creek within the Vernon city boundary; assess the associated flood risk; evaluate mitigation options; and document and communicate the findings. The information developed is intended to be used for:

- Flood risk management (prevention and mitigation);
- Land use planning and land management;
- Emergency management; and
- Public awareness.

As the underlying goal is the assessment and mitigation of flood risk to the community, the mapping and associated hydrology, survey, modelling and analysis is aimed to be of the highest quality to avoid misrepresentation of the hazards. The flood maps and risk assessment provide the basis for the identification and implementation of mitigation measures to reduce flood risk.

## 1.2 Study Area

Vernon is located in the North Okanagan Regional District (RDNO), approximately 50 km north of Kelowna, BC. It is characterized by its mild climate and agricultural valleys set between the Shuswap Highlands and the Thompson Plateau. Vernon is located near the northern extent of the Okanagan basin, surrounded by numerous regulated lakes including Okanagan Lake, Kalamalka Lake and Swan Lake. In Vernon, B.X. Creek and Vernon Creek connect upland drainage areas to the surrounding lakes.

The CoV Flood Mapping, Risk Analysis and Mitigation Project was originally divided into two approximately equal parts that were outlined by the CoV. NHC suggested a change in the division of Part 1 and 2 which was accepted by the CoV. Specifically, Part 1 now includes modelling of Upper B.X. Creek to Swan Lake and Part 2 includes Lower B.X. Creek below Swan Lake and Vernon Creek from Kalamalka Lake to Okanagan Lake. By splitting the project at Swan Lake, Part 1 now encompasses the natural, uncontrolled portion of B.X. Creek, and Part 2 begins at the regulated reach of B.X. Creek (below Swan Lake). The proposed split of Part 1 and Part 2 was selected to better separate the natural and regulated portions of B.X. Creek, which is also a natural break for the separation of the two hydraulic models. Figure 1.1 presents the study area for both Parts 1 and 2, where Part 1 can be seen as Upper B.X. Creek.

For Part 1, the hydraulic model covers approximately 3.5 km of Upper B.X. Creek, extending approximately 600 m upstream of the Vernon city boundary near B.X. Road and approximately 450 m past the city boundary along Highway 97 to extend to Swan Lake. Modelling extends outside the Vernon city boundary to properly capture model boundary conditions; however, the mapping, risk and mitigation portion of the study is limited to the city boundary.

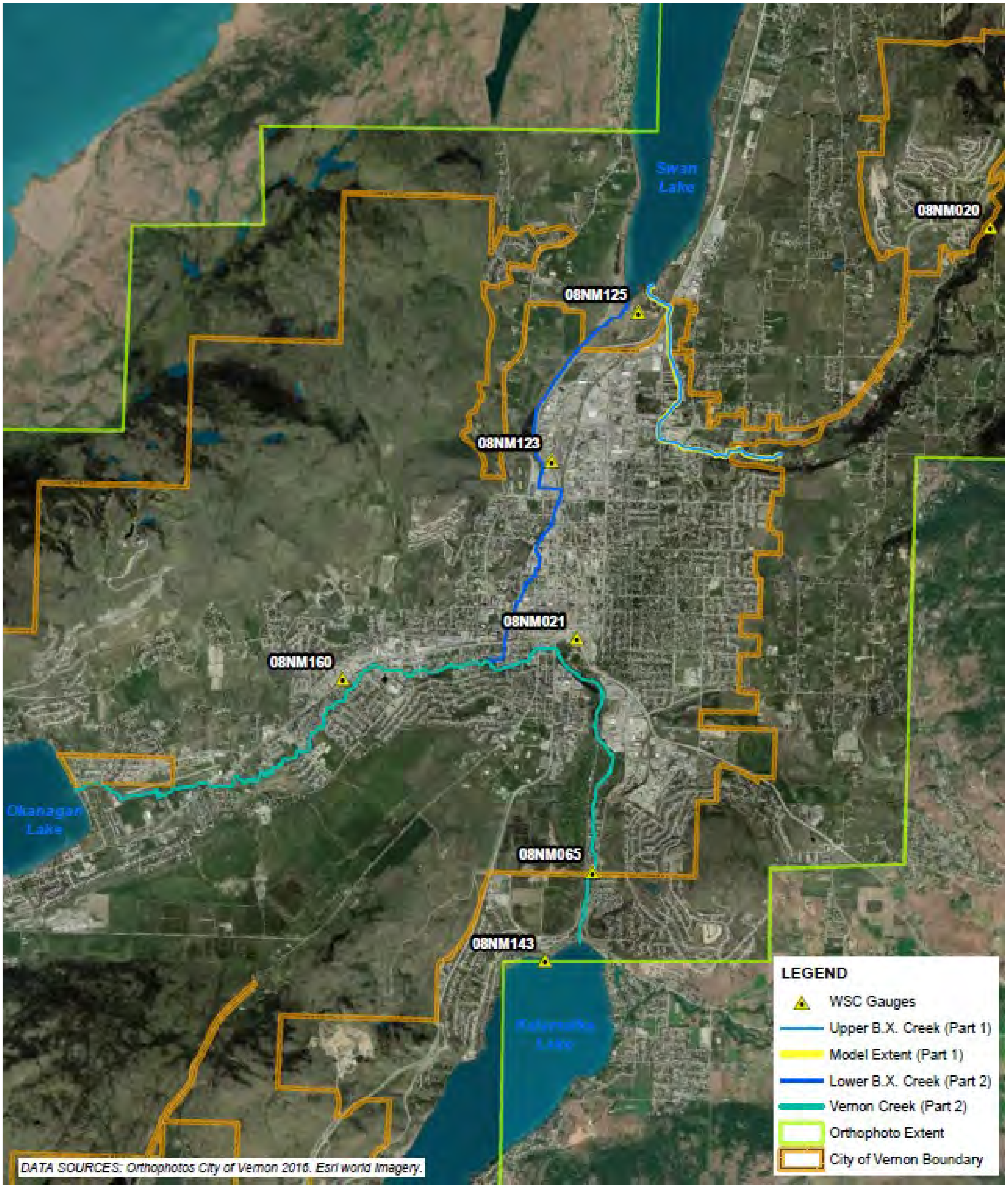



**Figure 1.1 Project location for Parts 1 and 2.**

## 1.3 Scope of Work

The current report presents the main tasks completed for the Detailed Flood Mapping, Risk Analysis and Mitigation Project for Part 1, Upper B.X. Creek. The project's scope of work addressed all items outlined in the CoV request for proposals and was segmented into discrete tasks for a systematic approach to completing the project. These tasks included the following:

- Data acquisition and background data review (Section 2)
- Site survey of creek cross sections and crossings (Section 3.2)
- Hydrologic analysis (Section 4)
- Hydraulic analysis through the application of a coupled 1D/2D model (Section 5)
- Flood mapping of inundation limits, flood construction levels and hazards (Section 6)
- Flood risk assessment (Section 7)
- Flood mitigation planning (Section 8)
- Stakeholder engagement and reporting

### 1.3.1 Flood Mapping, Risk Analysis and Mitigation

Flood risk reduction can be understood in three steps as depicted in Figure 1.2. While the steps are depicted in a linear fashion, they are a cycle which must be revisited and updated.

Flood risk reduction starts with understanding the hazard. This project has increased the understanding of the hazard through improved knowledge of the channel and floodplain topography, detailed hydrologic analysis, and hydraulic analysis. The results of the hydraulic analysis are presented in floodplain inundation and hazard maps, making the results of the analysis accessible to users including the public, engineering and design professionals, local government staff, and elected officials.

The next phase of flood risk reduction is a risk assessment to identify areas where valued community assets are exposed to the modelled flood hazard. The risk assessment for this project is based on available data and provides an understanding of exposed community assets.

With the understanding of the hazard and risk presented by this project, local community members and decision makers have the information to begin the final phase of flood risk reduction, taking action. Taking action for flood risk reduction can include structural and non-structural measures. Potential measures are identified in this project, however further analysis and community input is needed to develop a comprehensive flood risk reduction plan.


**Figure 1.2 Flood risk reduction process (NRCan).**

## 1.4 Applicable Guidelines and Regulations

The following guidelines and regulatory documents were adhered to for the flood and hazard mapping components of this project:

- Flood Mapping in BC, EGBC Professional Practice Guidelines, V1.0, 2017 (APEGBC, 2017)
- Flood Hazard Area Land Use Management Guidelines, Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD), Amended 2018 (FLNRORD, 2018)
- Federal Airborne LiDAR Data Acquisition Guideline, V2.0, 2018 (Natural Resources Canada and Public Safety Canada, 2018)
- Federal Geomatics Guidelines for Flood Mapping, V1.0, 2019 (Natural Resources Canada and Public Safety Canada, 2019)

Flood risk assessment is a non-standardized process in BC. Guidance for this project was attained from:

- Past flood risk assessments;
- Legislated Flood Assessments in a Changing Climate in BC Professional Practice Guidelines (EGBC, 2018b);
- Risk Assessment Information Template (RAIT) as part of the National Disaster Mitigation Program (NDMP) (Public Safety Canada, 2017); and
- In-progress Flood Risk Assessment Procedures developed by NHC for Natural Resources Canada (NRCan).

## 1.5 Limitations

Floodplain hazard mapping, assessment of flood risks, identification of mitigative options, and hydrologic and hydraulic modelling to support such work are core services for NHC. This study has been completed with ongoing review from the CoV and NHC's internal review team.

The study and its deliverables are subject to the general limitations outlined below. Further detail on the assumptions, uncertainties, and limitations of each component of the study are provided in each section, and notes provided on the floodplain mapping index sheet must be reviewed prior to use:

- Refer to the Disclaimer following the signature page.
- The models developed and used in this study are based on current land-use conditions and historic data, and changes to land-use or new information or data may require the model to be updated.
- There may be some errors in the data and software used in this study that have not been identified.
- Model simulations for historic, mid-century, and end-of-century conditions use synthetic climate that could have occurred historically and plausible climate that could occur in the future, given current projections on increases in greenhouse gas concentrations in our planet's atmosphere; what climatic conditions will exist in the future is not actually known.
- Average flood recurrence interval values estimated for design are based on extrapolation of frequency analyses and model simulations; therefore the resulting design values have an inherent uncertainty.
- The floodplain mapping is based on a bare-earth representation of topography with further generalizing assumptions made for some of the mapped areas. New development or re-development requires a site-specific flood hazard assessment.
- The occurrence of flood events larger than the flood-of-record for any areas included in the study will require a reassessment of the floodplain mapping.
- Residual risk, greater than that shown in this report, exists; that is, a more extreme event (larger average recurrence interval) or sequence of events could result in higher flood levels and greater flood inundation than that mapped.

This document should be read and understood in its entirety before applying the maps, models, or other findings or results from this study. The reader is advised to seek the advice of a Qualified Professional to understand the study, its results, and the implications of any assumptions, uncertainties, and limitations.

# 2 BACKGROUND

## 2.1 Upper B.X. Creek Watershed

Upper B.X. Creek drains from Silver Star Mountain, located northeast of Vernon. The watershed is situated at the southern extent of the Shuswap Highlands and is set within the larger Okanagan River watershed. The Upper B.X. Creek watershed drains southwest from a maximum elevation of approximately 1880 m to Swan Lake at approximately 390 m. The total watershed area[1] is measured as 76.4 $km^2$.

The upper reaches of the watershed are generally forested with approximately 30 % of the upper watershed impacted by forest harvesting and a large portion also impacted by the mountain pine beetle. It is anticipated that the majority of forest harvesting since 2003 has been focused on the removal of mountain pine beetle infested stands (Dobson, 2004). The Silver Star Mountain Resort is situated at the peak of the watershed, although covers only 1.5 $km^2$ of the total watershed area. The watershed transitions to a rural catchment near elevation 700 m, noted primarily as agriculture and rural neighbourhoods. Below elevation 500 m the watershed is largely urbanized and the contributing watershed is likely impacted by the CoV stormwater system.

The lower reach of Upper B.X Creek is situated on an alluvial fan, which begins near elevation 415 m, near the Pleasant Valley Road crossing. The alluvial fan covers a large area, which is now primarily occupied by Vernon's Harwood, East Hill, and North Vernon neighbourhoods. The current alignment of Upper B.X. Creek bends to the north directly downstream of the first 20th Street crossing to drain into Swan Lake. This is not likely a natural alignment as it closely follows the eastern edge of the alluvial fan. Rather the channel is expected to have been diverted at some point near the turn of the century. The CoV has a similar suspicion; however, no evidence was found to directly support this assumption. A review of the fan's topography shows that it slopes predominantly southeast towards Vernon Creek.

There is little storage observed within the watershed and channel gradients are noted by Golder, 2009a) as 10 % in the upper reaches (above El. 1000 m) to 5 % in the mid-reaches (El. 1000 to 500 m) and 2 % or less in the lower reach (below El. 500 m). This combination of limited storage and steep channel gradients allow for sediment transport from the upper and mid-reaches to the fan. Golder (2009a) estimated an annual sediment budget between 1,150 $m^3$/yr and 3,250 $m^3$/yr that would be available annually for transport to the fan. Furthermore, Golder (2009a) estimated the average annual sediment load delivered to the fan to range between 800 $m^3$/yr and 2,600 $m^3$/yr. Historically, this high annual sediment load during flood events has had the largest impact on channel and crossing capacity.

Aggradation is a natural process common on alluvial fans in which hydraulic deposition of sediment leads to a long-term rise in the elevation of the streambed or floodplain (Knighton, 1998). Given the

[1] This area covers the natural boundary of Upper B.X. Creek and does not include any changes in the lower reaches due to inputs from stormwater systems.

estimated sediment budgets available for transport to the fan, sediment transport and aggradation within the fan channel are expected to continue to increase the flood risk on Upper B.X. Creek.

## 2.2 Flood History of Upper B.X. Creek

The Upper B.X. Creek alluvial fan channel has a long history of flooding and sediment transport. The following describes the general history of flooding and sediment removal on Upper B.X. Creek within the Vernon city boundary[2]:

- Diversion of Upper B.X. Creek to Swan Lake (likely prior to incorporation in 1892).
- Sediment removal noted in the 1980s between railway (downstream of Highway 97) and Highway 97 and near Deleenheer Road (Golder, 2009a).
- May 31, 1996 flood recorded as the flood of record on the (now inactive) Water Survey of Canada gauge 08NM020 – B.X. Creek above Vernon. Flow overtopped the Pleasant Valley Road culvert[3], the 48th Avenue culvert and the second 20th Street culvert, which eventually resulted in a washout at the 20th Street culvert (Summit, 1996).
- Proposed channel improvements in 2003 including a crossing upgrade at Pleasant Valley Road and debris inceptor near the B.X. Ranch Park (KWL, 2003). The debris inceptor was constructed, but the date of construction is not known.
- 2008 freshet caused flooding and sediment accumulation in the fan channel (Golder, 2009b).
- Pleasant Valley Road culvert was upgraded in October 2008, which included a sediment trap downstream of crossing (KWL, 2008).
- Sediment traps recommended downstream of Pleasant Valley Road between 48th Avenue and 20th Street crossings, sediment removal recommended between 53rd Avenue and Deleenheer Road, sediment basin recommended in B.X. Ranch Park (outside of Vernon) (Golder, 2009a) (FOCUS, 2009).
- 2009 sediment removal from Pleasant Valley Road trap and 48th Avenue trap (Golder, 2018).
- 2013 sediment removal from Pleasant Valley Road trap and 48th Avenue trap (Golder, 2018).
- 2017 freshet caused flooding and sediment deposition in fan channel. Overbank flooding was observed downstream of 20th Street and upstream of 53rd Avenue (CoV communications and photos, 2019).

[2] Given the close proximity of Highway 97 and the importance of this crossing to the CoV and Upper B.X. Creek, it is included in this review.

[3] This crossing has since been upgraded to a larger culvert.

- 2018 sediment removal from Pleasant Valley Road trap and 48th Avenue trap in March, pre-freshet (Golder, 2018).
- 2018 freshet flood caused flooding and sediment deposition in fan channel. Flooding was comparable to the 2017 flood event and emergency dredging was carried out downstream of the 48th Avenue crossing (CoV communications and photos, 2019).

## 2.3 Available Data

The following reports were provided by the CoV and reviewed by NHC:

- Vernon Master Drainage Plan (Dayton Knight Consultant Engineers, 2001);
- B.X. Creek at Pleasant Valley Road, Hydraulic Assessment (KWL, 2003);
- Upper B.X. Creek Drainage Basin Study (MMM, 2008);
- B.X. Creek Sediment Removal Structure Design (Golder, 2009);
- Swan Lake Dam Engineering Assessment (Ecora, 2016);
- Swan Lake Dam Operations Plan (Ecora, 2019).

The CoV also provided the following data relevant to setting up the hydraulic model presented in Section 5:

- As-built drawings for creek crossings;
- Culvert and bridge inspection reports completed in 2015 by Stantec;
- Photographs of various 2017 and 2018 flooding locations;
- Survey of 10 cross sections completed in 2019 on Upper B.X. Creek.

Spatial data was collected from various federal (GeoGratis), provincial (GeoBC) and local (CoV Open Data) sources and includes the following key data:

- LiDAR data collected from April to October 2018 and in June 2019, provided by GeoBC on behalf of Emergency Management BC (EMBC);
- Building footprint layer;
- Location of stormwater culverts;
- 2016 orthophoto;
- Municipal boundary;
- Land use and land cover information based on CoV Official Community Plan and city zoning;
- Road centreline layer;
- Location of places of interest for flood mapping and risk assessment.

No historic flood mapping was found for the area of interest. Moreover, no historic flood spatial information such as digitized high water marks were available.

For more information on the background review and available data, refer to Appendix A for the NHC *Background Info and Survey Memo – Part 1 Upper B.X. Creek,* submitted to the CoV on September 17, 2019.

# 3 DATA ACQUISITION AND DEM DEVELOPMENT

## 3.1 Coordinate System and Datums

All elevation data and geographic information presented in this report use the following coordinate system and datums:

- Horizontal coordinate system: Universal Transverse Mercator (UTM) Zone 11. Coordinates are in metres.
- Horizontal datum: North American Datum of 1983 (NAD83) CSRS.
- Vertical datum: Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

The CGVD2013 vertical datum was used for modelling and mapping for this project as Canada has adopted CGVD2013 as the official datum, and the Province of BC is in the process of migrating to this new datum.

## 3.2 Survey

The quality of a floodplain map is directly related to the survey data used to develop the hydraulic model and maps. To maintain control of the quality of the data, NHC conducted the river survey and ground verification survey using NHC owned, maintained, and calibrated equipment. Overbank data points were collected where there was clear coverage and consistent elevation to provide checkpoints for ensuring consistency between the field survey and the LiDAR data collected by EMBC in 2018 and 2019. Survey cross section locations were identified prior to the survey to capture channel changes and accurately model bridge and culvert crossings. In total, 188 cross sections were surveyed with 57 along the 3.5 km reach of Upper B.X. Creek. Cross sections were collected primarily upstream and downstream of each crossing and at specific locations between crossings that were found pertinent to model development. Collected data includes bridge and culvert details for 110 structures within the project model extent, 24 of which are along Upper B.X. Creek. The extent of the survey is presented in Figure 3.1.

Over the span of 3.5 weeks (Sept 28$^{th}$ to October 25$^{th}$, 2019), survey data concentrating on channel bathymetry was collected for both Part 1: Upper B.X. Creek to Swan Lake and Part 2: Swan Lake along Lower B.X. Creek to the confluence of Vernon Creek, and Kalamalka Lake along Vernon Creek to the inlet of Okanagan Lake. The survey was performed using the following equipment:

- Trimble R10 GNSS RTK GPS rover receivers;
- Trimble R10 GNSS RTK GPS base receiver w/ Trimble TDL 450 35-watt radio;
- Nikon Nivo 5” total station;
- Trimble TSC3 and TSC2 controllers w/ Trimble Access field software; and
- Trimble Business Center desktop software.

SEL Survey collected bathymetric data obtained by the CoV in April 2019, as part of a creek monitoring plan on Upper B.X. Creek. A total of 5 cross sections along Upper B.X. Creek were combined with the NHC survey data. Data was collected in the CGVD28 vertical datum (Htv2.0) and was transformed with a vertical datum shift to CGVD2013 to match NHC collected survey data.

Figure 3.1 shows the surveyed cross sections and crossing locations. A crossing inventory outlining observed and surveyed crossing information can be found in Appendix B.

Detailed photographs of each crossing were taken during the survey and provided to the CoV with the collected survey data. Observations supported the definition of modelling parameters to represent the crossings, as well as the identification of culvert blockages and channel bed elevation changes.

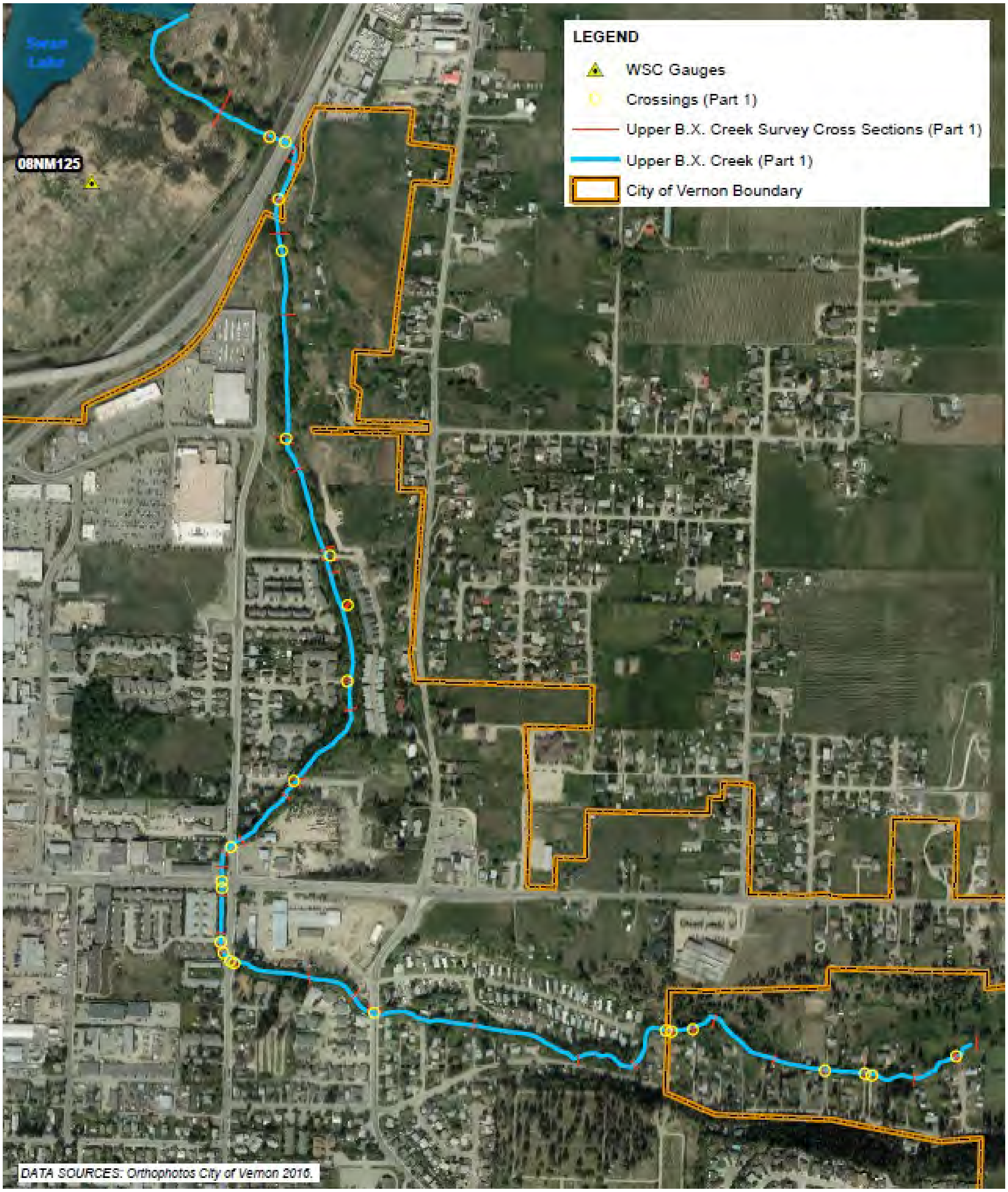



**Figure 3.1 Survey extent Upper B.X. Creek.**

## 3.3 Digital Elevation Model (DEM) Development

For modelling and mapping purposes, a digital elevation model (DEM) of the floodplain was derived from LiDAR DEM tiles obtained from GeoBC. LiDAR data was collected from April to October of 2018 by Eagle Mapping Services Ltd. LiDAR data was again collected from June 9-12, 2019 for areas that had insufficient coverage during the first acquisition period in 2018. The LiDAR data was processed to remove data points from 2018 where the bare earth had changed by the time of acquisition in 2019. Both LiDAR data sets use UTM Zone 11 NAD83 (CSRS) and CGVD2013. The DEM tile sets were mosaiced together to create one DEM covering both Part 1 and Part 2 study extents (775 $km^2$) for modelling and mapping purposes.

The LiDAR data has a reported density of 30 points per $m^2$ and a non-vegetated vertical accuracy root mean square error (95 % [1.96*RMSEz]) of 0.092 m. These are within NRCan's recommended LiDAR accuracy and density values for flood mapping (Natural Resources Canada and Public Safety Canada, 2018).

Bridges are typically removed from the LiDAR-derived bare earth DEM, so that the DEM approximately represents the channel under the bridge. Although this was the case with most of the LiDAR data supplied for Vernon, some smaller bridges were missed by the LiDAR provider. These areas have no significant impact on modelling, and mapped inundation extents have been adjusted to account for this.

Where cross sections were needed in the hydraulic model, the DEM data was combined with the bathymetric cross section survey data. Seven cross sections were also added after the survey was completed in order to represent unexpected features in the channel, such as a local bed elevation increase, channel widening or embankment elevation decrease. The bathymetry along these additional cross sections was estimated from available LiDAR data and interpolated from survey data. The DEM was used to represent the overbank areas in the hydraulic model. Quality control and accuracy checks were completed. The vertical Root Mean Square Error (RMSE) value was calculated as 0.038 m, well within the limits specified by the federal flood mapping guidelines (Natural Resources Canada and Public Safety Canada, 2018)

Colour orthophotos were collected by EMBC in 2018/2019 but had not been processed at the time of model completion for Part 1. 2016 orthophotos collected by CoV were used to interpret features on the floodplain, help assess channel and floodplain roughness, supplement field survey information, and provide context in the interpretation of the model results. They were also used to create the base image for floodplain mapping.

# 4 HYDROLOGIC ANALYSIS

This section outlines the methodology and justification for design flow estimates on Upper B.X. Creek and water elevations in Swan Lake used as boundary conditions in the hydraulic model. Sections 4.1 through 4.8 are excerpts from the NHC technical memo *City of Vernon: Detailed Flood Mapping, Risk Analysis and Mitigation Design Flow Estimation – Part 1 Upper B.X. Creek*, submitted to the CoV on January 14, 2020 (Appendix C).

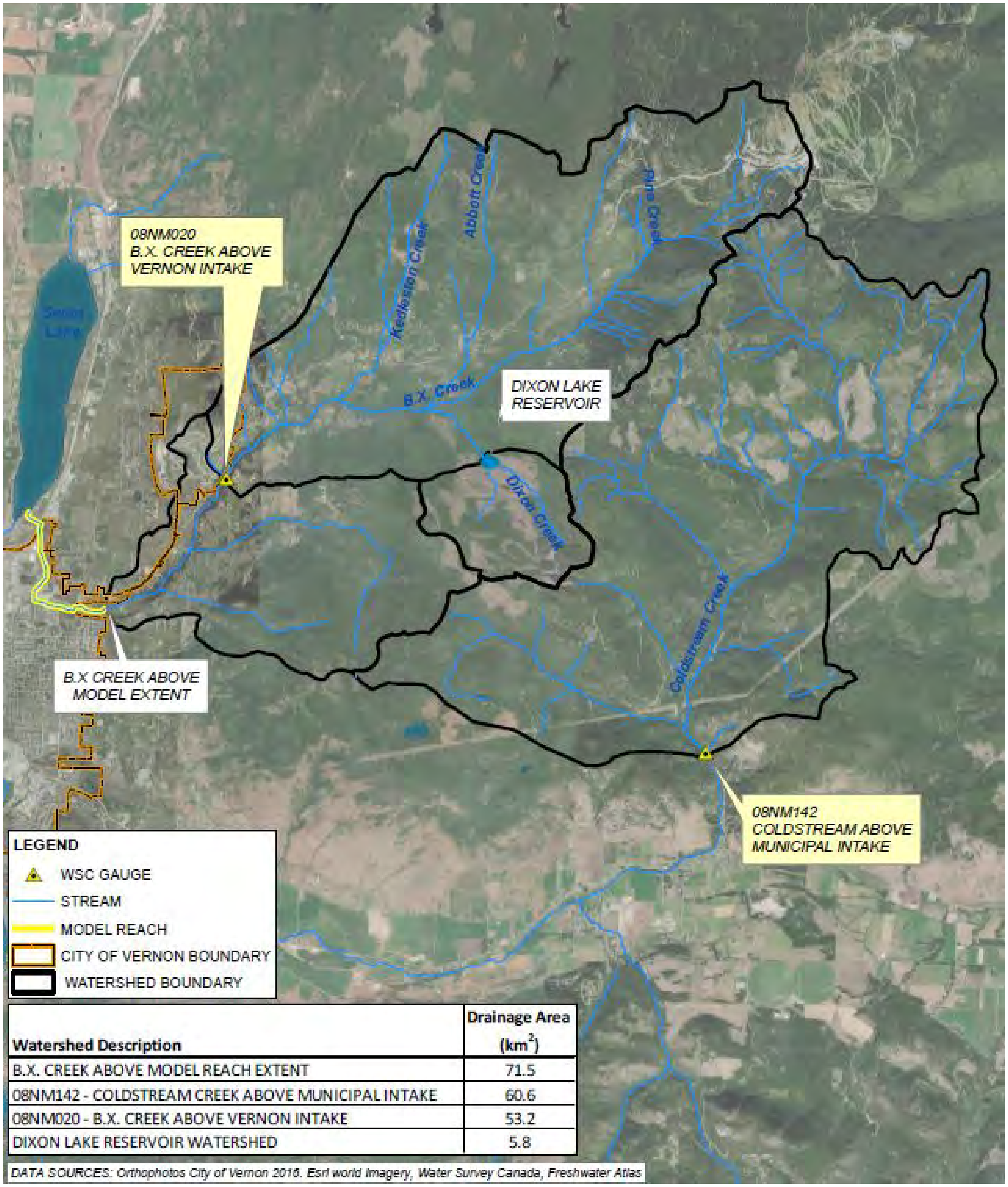
## 4.1 Design Flows at Upper B.X. Creek

Flows in Upper B.X. Creek have been estimated through a flood frequency analysis of Water Survey of Canada (WSC) data from gauge 08NM020 – B.X. Creek above Vernon Intake (WSC B.X.), located upstream of the model reach. Since WSC B.X. has been inactive since 1998, NHC has extended its record using data from an adjacent gauge, WSC 08NM142 – Coldstream Creek above Municipal Intake (WSC Coldstream). This adjacent gauge has a watershed of similar size and apparently similar vegetation and land use characteristics to those of the Upper B.X. Creek watershed (Figure 4.1). A gauge summary is shown in Table 4.1.

**Table 4.1 WSC gauges used in peak flow analysis.**

| ID | 08NM020 (WSC B.X.) | 08NM142 (WSC Coldstream) |
|---|---|---|
| Name | B.X. Creek above Vernon Intake | Coldstream Creek above Municipal Intake |
| Area ($km^2$) | 53.2 (NHC delineated) | 60.6 (WSC delineated) |
| Reg. Status | Regulated | Unregulated |
| Activation status | Deactivated | Active |
| Annual Peak Instantaneous Flow (QPI) Record | 1977-1998 | 2003-2011 |
| # years (QPI) | 21 | 9 |
| Annual Max Daily Flow (QPD) Record | 1921-1998 | 1968-2018 (2015 and later is preliminary) |
| # years (QPD) | 46 | 50 |

Annual peak and maximum daily flows at both gauges occur almost exclusively in spring during freshet. The largest of these are usually enhanced by locally intense rainstorms that occur on top of an already melting snowpack. WSC B.X. experienced an event like this at the end of May 1996: 60 mm of rain fell within two days in Vernon (and presumably more at higher elevation), causing extreme flows that were more than double any other annual peak measured flow at the gauge.




| Watershed Description | Drainage Area (km$^2$) |
|---|---|
| B.X. CREEK ABOVE MODEL REACH EXTENT | 71.5 |
| 08NM142 - COLDSTREAM CREEK ABOVE MUNICIPAL INTAKE | 60.6 |
| 08NM020 - B.X. CREEK ABOVE VERNON INTAKE | 53.2 |
| DIXON LAKE RESERVOIR WATERSHED | 5.8 |

**Figure 4.1 Watersheds and gauges used in design flow estimation.**

## 4.2 Flow Regulation Investigation

Flows at WSC B.X. are flagged as regulated by WSC. Research indicates this was likely due to the former Dixon Lake reservoir, which was deactivated in 2000 (Mike Noseworthy, Senior Dam Safety Engineer, BC FLNRORD, pers. comm., November 2019). We employed the methods of Moin and Shaw (1985) to assess whether the gauge data at WSC B.X. should be used for design flow estimation. Results showed that the watershed is well under the recommended threshold for peak flow regulation, and is suitable for treatment as an unregulated watershed. As a second check we calculated the unit mean annual flood ($m^3/s/km^2$) for both WSC B.X. and WSC Coldstream, and found that it was higher for WSC B.X., which supports the finding that regulation did not significantly impact flood flows on B.X. Creek.

## 4.3 Record Extension

To extend the annual peak instantaneous flow (QPI) record for WSC B.X. from WSC Coldstream, we used a two step process known as the Maintenance of Variance Extension type 1 (MOVE.1) record extension technique (Hirsch, 1982), available in the United States Geological Survey (USGS) 'smwrStats' package[4] for the statistical programming language 'R' (Hornik, 2016). MOVE.1 is a regression technique which maintains the variance of the initial series in the extended series. The resulting 65 year QPI record for WSC B.X. is shown in Figure 4.2.

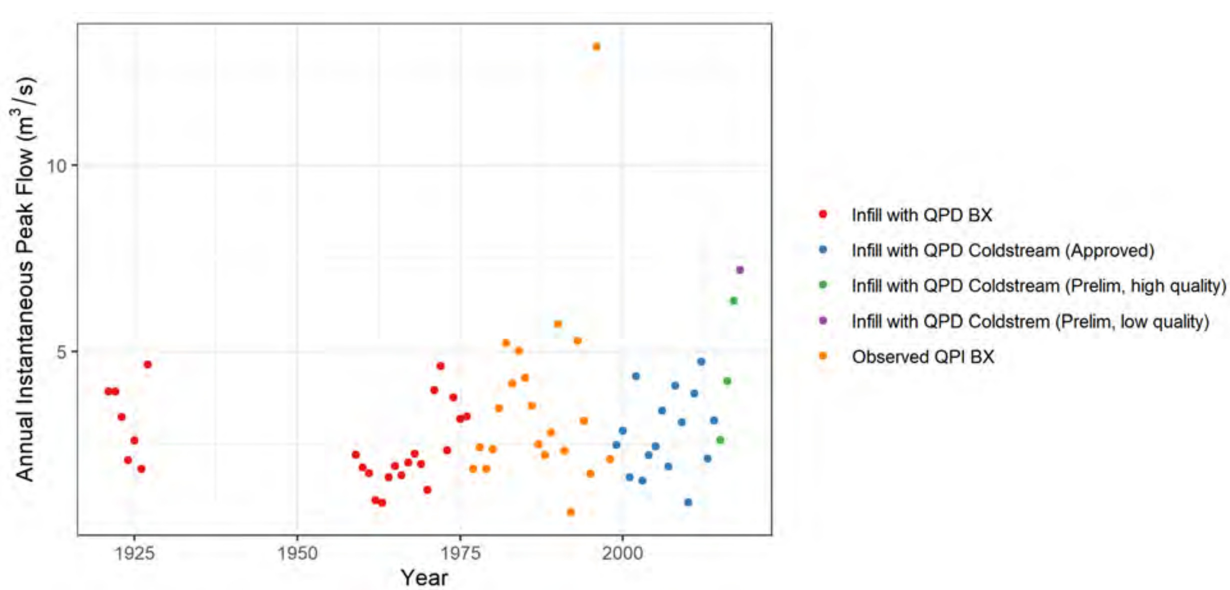



**Figure 4.2 Extended annual instantaneous peak flow (QPI) record for WSC B.X.**

[4] https://github.com/USGS-R/smwrStats

## 4.4 Frequency Analysis

After record extension, quality checks were performed on the series to determine its suitability for frequency analysis; the low quality 2018 peak flow estimate was excluded. The Upper B.X. Creek watershed has undergone extensive forest harvesting over the past decades in its upper elevations; forest harvesting can have an effect on peak flows and the annual water balance (Winkler et al., 2010). Though these effects can be difficult to isolate in a peak flow record, if they are found to impact the peak flow series, the record may require further adjustment prior to frequency analysis. The Mann-Kendall trend analysis and Grubbs-Beck test for low outliers both had negative results. The Grubbs test for high outliers indicated that the 1996 flood was a high outlier; as is typical, the high outlier was left in the record.

Frequency analysis was performed by fitting the Generalized Extreme Value (GEV) distribution via l-moments in the 'lmomco' package for R[5]. Frequency analysis results are shown in Figure 4.3. Results show that the 1996 event has a return period above 500 years; estimates of recent peak flows in B.X. Creek using Coldstream Creek give return period flows of approximately 20 years for the 2017 flood and 40 years for the 2018 flood. However, because they are transferred from another watershed, the estimates have a large amount of uncertainty.

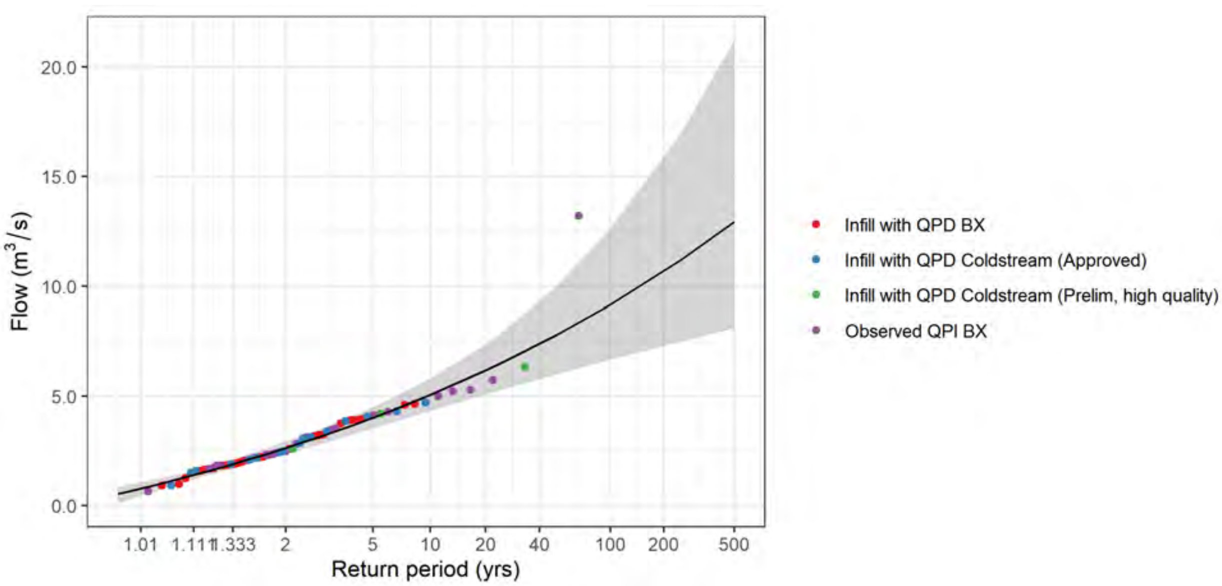



**Figure 4.3 Frequency analysis results for extended QPI record at WSC B.X., using the GEV distribution. Grey band indicates 90 % confidence intervals.**

[5] https://cran.r-project.org/web/packages/lmomco/index.html

## 4.5 Design Flows

Flow frequency results have been scaled to the upstream end of the study reach (71.5 km$^2$) using exponential, area-based scaling. Flows were scaled to the upstream end of the model reach (as opposed to the downstream end) because it is expected that the majority of streamflow during a flood event will be coming from runoff in the upper elevations of the watershed, where snowmelt and rain-on-snow are the primary flood generators rather than from precipitation within the city itself, where snow accumulation is far less and snowmelt would occur earlier in the spring. Additionally, there are no major runoff contributing sources (e.g. tributaries) along the model reach, and flow from storm sewers was not incorporated in this study, as it is not expected to have a large impact on the channel flows.

Eaton et al (2002) recommend a generalized scaling exponent of 0.75 for peak flows in most of BC, particularly in snow-dominant interior peak flow areas. Thus we expect that this exponent value is the most appropriate. The scaling equation is given as:

$$QPI_{Ungauged} = QPI_{Gauged}\left(\frac{A_{Ungauged}}{A_{Gauged}}\right)^{0.75}$$

Where $QPI_{ungauged}$ is the design flow (at any return period) needed for the point of interest, $QPI_{gauged}$ is the estimated design flow from the WSC gauge frequency analysis, $A_{ungauged}$ is the contributing watershed area at the point of interest, and $A_{gauged}$ is the watershed area at the gauge location. The scaled design flow results are shown in Table 4.2. As a conservative approach, we assumed that the Vernon intake, located between WSC B.X., and the upstream end of the model did not impact peak flows.

**Table 4.2 Frequency analysis results and design flow estimates for Upper B.X. Creek.**

| Return Period (years) | WSC B.X. QPI (m$^3$/s) | Scaled to top of model reach QPI (m$^3$/s) |
|---|---|---|
| 2 | 2.6 | 3.3 |
| 5 | 4.0 | 5.0 |
| 10 | 5.1 | 6.3 |
| 20 | 6.2 | 7.7 |
| 50 | 7.8 | 9.7 |
| 100 | 9.2 | 11.4 |
| 200 | 10.7 | 13.3 |
| 500 | 12.9 | 16.1 |
| 1996 Flood of Record | 13.2 | 17.7 |

A standard design event for flood mapping or infrastructure design is the 200-year instantaneous peak flow. However, in cases when an observed event has occurred that is larger than the 200-year event, this larger real event can be used as the design event; NHC has recommended this in a number of other studies prior (FLNRO and NHC, 2014; NHC, 2017, 2020a). This practice allows for more verification of floodplain accuracy, as there are likely some historical records of the true event, and there is likely to be a lower public confidence in a design event that is smaller than a flood that actually occurred. As shown in Table 4.2, the 1996 event exceeded both the 200 and 500-year return period estimates on B.X. Creek. The 1996 flood was a major rainstorm that occurred in May, during the height of the spring snowmelt freshet; the 1996 event with an adjustment for climate change (Section 4.7) has thus been is selected as the design flood event for Upper B.X. Creek.

## 4.6 Swan Lake Water Levels

Water levels for Swan Lake were estimated as a downstream boundary condition for the Part 1 hydraulic model. However, backwater effects below the Swan Lake dam have not yet been accounted for. These effects will be accounted for in the Part 2 study which will include hydraulic modelling downstream of the Swan Lake control dam.

A historical record of stage exists for Swan Lake (WSC gauge 08NM125 – B.X. Creek above Swan Lake Control Dam), from 1959-1979; however, changes in operations rules and the control structure itself (between 1979 and the present) meant that this gauge record was not suitable for computing design levels on Swan Lake. Thus, design levels for Swan Lake are based on outputs from NHC's Okanagan mainstem hydrologic and reservoir operations model (NHC, 2020a), developed using the Raven hydrological modelling platform (Craig and Raven Development Team, 2019). The hydrologic model was first calibrated to unregulated subbasins in the Okanagan River basin (ORB), with Okanagan Lake Regulation System (OLRS) operations and representations of the mainstem dams (including Swan Lake) added to the model to form an operations model. NHC addressed estimation of design lake level and river flow return periods for floodplain mapping through simulation of a climate ensemble. The hydrologic model was driven with the 50-member climate ensemble[6] representing plausible historical weather (starting in 1950) and how it may develop to the year 2100[7]. A full explanation of this hydrologic and operations model is available in the NHC Okanagan mainstem floodplain mapping report produced for OBWB (2020a).

Swan Lake is operated by wooden stoplogs at the Swan Lake control dam. Ecora (2019) provided discharge rating curves for 0, 1, 2, 3, and 5-stoplog scenarios and an annual schedule of targeted lake levels. The NHC ORB hydrologic model included a simplified version of this operations schedule to approximately replicate manual operation of the Swan Lake control dam, and a 1D storage area representing the stage and storage of Swan Lake. Outflow and sill level from the storage area varied

[6] Each ensemble member was randomly generated by Environment and Climate Change Canada, and then downscaled by NHC.

[7] How climate may develop is based on a projection of global warming (and resulting climate change) following Representative Concentration Pathway 8.5 (RCP8.5). This is a greenhouse gas concentration trajectory, with the '8.5' representing this RCP's net increase of 8.5 $W/m^2$ (watts per metre squared) in global average radiative forcings at the end of this century (2100).

based on the number of stoplogs in the model. Our simplified operations within the model were as follows:

- June through December: 5 logs
- January, February, May: 4 logs
- March, April: 3 logs

As the operations cycle recommended in the Ecora manual is new, direct calibration/testing compared to observed lake levels was not possible (i.e. all level records occur before the operation plan was put in place). However, the assumption was made that this operations plan would be followed from the present until further notice. After implementing the operations plan on the historical time period of the model (1945-2012), we operated the model using the 50 member 1950-2100 climate ensemble, generating 7,500 years of Swan Lake annual maximum levels.

### 4.6.1 Calculation of Design Levels

In a regulated system such as Swan Lake (and many other lakes in the region) most assumptions of standard flood frequency analysis, where an extreme value distribution is fitted to a relatively small sample of data, are violated; hence a standard frequency analysis method is inappropriate. The use of ensemble simulation, and the resulting 7,500 years of data output, has many advantages in this situation. Because of the large number of years simulated, a distribution fit is not required in order to extrapolate to low probability events that are necessary for determining design levels and flows.

Instead, a direct calculation of design levels and flows is possible using an empirical frequency analysis (sometimes referred to as a plotting position calculation). Empirical frequency is calculated, for each of i events in a record, as follows:

$$1 - AEP = \frac{i - a}{n + 1 - 2a}$$

where AEP is the annual exceedance probability, i is the rank (ascending) of a data observation, n is the total number of observations, and a is an adjustment factor. The AEP is converted to an return period (RP, years) as:

$$RP = \frac{1}{AEP}$$

A range of values for the adjustment factor (a) have been suggested in literature. In this analysis, a=0, used in what is known as the Weibull plotting position formula, was used. The Weibull formula provides unbiased exceedance probability for all distributions (Asquith, 2011). The Weibull formula produces the most conservative empirical results and hence was deemed most appropriate to use in this case.

Model results were used to empirically calculate the return periods for Swan Lake (and peak flows on Upper B.X. Creek). Since the 50 climate ensembles represent an equally likely potential climate, the combined 7,500-year snapshot of basin behaviour could be used to directly determine empirical probabilities. However, non-stationarity due to changing climate invalidates using the entire period from 1950 – 2100 to calculate return periods. Therefore, the future record was broken into shorter, 30-year periods (a commonly used length of time for representing climate normals) with results from all 50 ensembles lumped together as a single 1,500 year series; this is an approach for climate change analysis of extreme values accepted in scientific literature (Curry et al., 2019; Martel et al., 2020) and recommended by climatologists (Alex Cannon, ECCC, pers. communication 2018).

These separate climate periods are:

- Historical: 1950 – 2019
- Present: 2006 – 2035 (representing the present day +/- 15 years)
- Mid-Century: 2041 – 2070
- End-of-Century: 2071 - 2100

Empirical design levels for the present day for Swan Lake are shown in Figure 4.4 and Table 4.3.

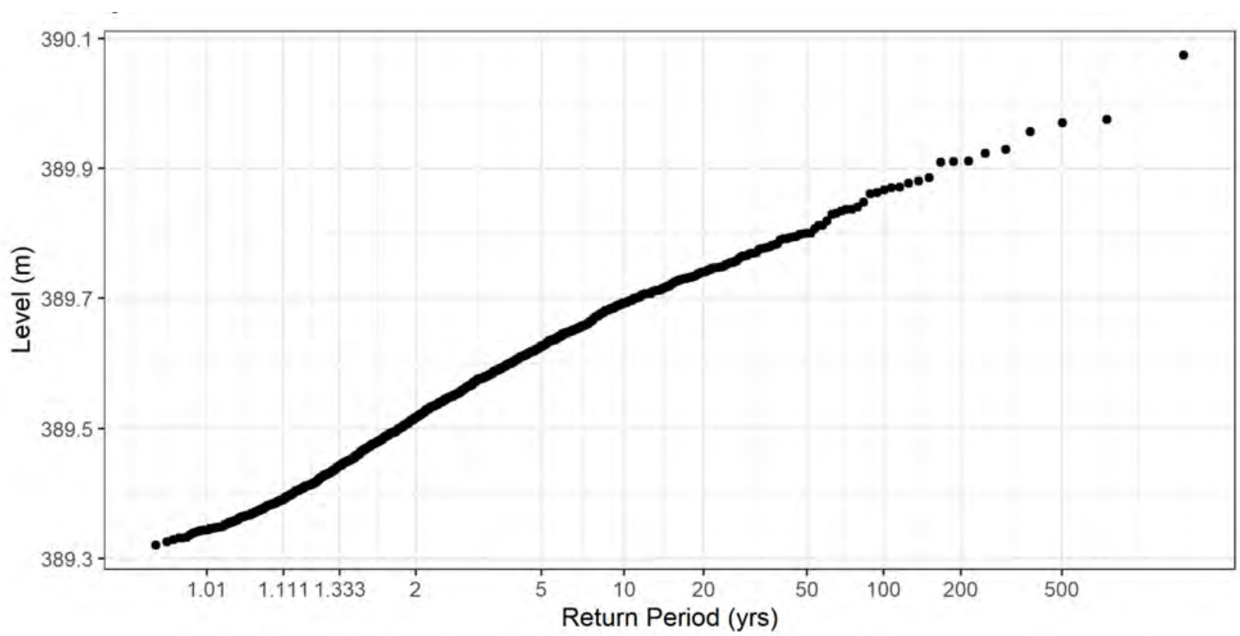



**Figure 4.4 Example empirical frequency analysis for Swan Lake 2006-2035 annual maximum levels from ensemble hydrologic modelling.**

**Table 4.3 Swan Lake design levels for the present day.**

| Return Period (years) | Level (m) |
|---|---|
| 2 | 389.5 |
| 5 | 389.6 |
| 10 | 389.7 |
| 20 | 389.7 |
| 50 | 389.8 |
| 100 | 389.9 |
| 200 | 389.9 |
| 500 | 390.0 |

## 4.7 Impacts of Climate Change

A full discussion of the potential impacts of climate change to the region is available in the NHC *Okanagan Mainstem Floodplain Mapping Project* report (2020a) and is briefly summarized here. Hydrological changes to the region are expected to include an earlier freshet onset due to warmer spring and winter temperatures. Additionally, a larger percentage of winter precipitation is expected to fall as rain, rather than snow. While temperature changes are generally well understood, the changes in total precipitation are less clear. As a whole there appears to be a trend towards more precipitation in the fall/winter/spring period, with either similar or less precipitation during the summer. Peak flows on Upper B.X. Creek and most moderate to larger streams and rivers in the region occur almost exclusively during the spring freshet, with the most extreme events (e.g. 1996 on Upper B.X. Creek) enhanced by heavy rainfall while snowmelt is occurring. These two factors are expected to be impacted differently as our climate changes. The effect of the snowmelt freshet is expected to decrease due to decreasing winter snow accumulation, but the potential for heavy rain is expected to increase due to increasing total precipitation and a general trend of "more extreme extremes". Thus, there may be a cancelling out effect of the two processes, but these interactions are best investigated through a hydrologic model. Ensemble simulation from NHC's Okanagan mainstem hydrology and reservoir operations model was also used to assess the potential impacts to the region from climate change.

The trend in annual maximum lake level for Swan Lake is shown in Figure 4.5 as a two-dimensional histogram (representing the full 7,500 years of simulation). Cells with the most common results are shown in yellow, and a trendline is shown in white. Results show only a slight tendency towards increasing levels, beginning in approximately 2050. As explained in Section 4.6.1, the model results for Swan Lake were split into 30 year periods for the actual empirical level estimation. These results are shown in Table 4.4, and were used directly in the hydraulic simulations.

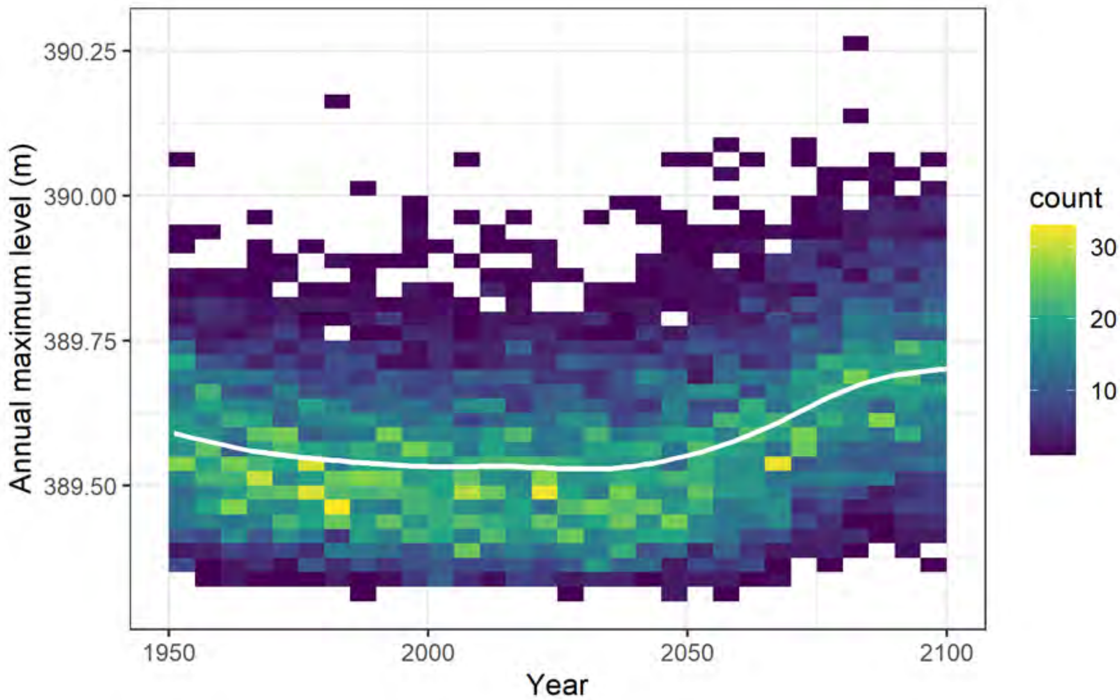



**Figure 4.5 Swan Lake ensemble simulation results, showing the maximum reservoir level reached per year as a 2D histogram. White line is a smoothed line showing the general trend over time.**

**Table 4.4 Swan Lake end-of-century (2100) design levels.**

| Return Period (years) | Level (m) |
|---|---|
| 2 | 389.67 |
| 5 | 389.79 |
| 10 | 389.86 |
| 20 | 389.92 |
| 50 | 389.97 |
| 100 | 390.00 |
| 200 | 390.04 |
| 500 | 390.08 |

As opposed to Swan Lake, model results from Upper B.X. Creek could not be used directly to estimate future peak flows. The hydrology model was not calibrated for Upper B.X. Creek and the daily timestep of the model, while appropriate for estimating lake elevations, is not appropriate for estimating peak flows on a watershed the size of Upper B.X. Creek. Thus, we used model output only for estimating the relative change in peak flows on this watershed.  This relative change was then applied to the design flows based off of the frequency analysis of B.X. Creek observations.  The relative change between empirically calculated present day (2006-2035) and future end-of-century (2070-2100) model output is shown in Table 4.5 (column 2).  All results showed changes less than a 10 % increase; however, EGBC (2018a) recommends a minimum climate change adjustment factor of 10 % for peak flow estimates. This 10 % increase acts as a factor of safety considering the large uncertainty in both present day and future peak flow estimates. Additionally, there are uncertainties due to potential land use changes within the watershed (e.g. forest fire, insect infestation, forest harvesting and urbanization) that are not captured within the hydrologic model and may impact future peak flows. Thus, we a applied a 10 % climate change factor to the Upper B.X. Creek frequency analysis and design flow estimates into the model reach.

**Table 4.5 B.X. Creek end-of-century (2100) design flows.**

| Return Period (years) | Modelled change (%) | Applied change (%) | Design flow at top of model reach ($m^3/s$) |
|---|---|---|---|
| 2 | 2.0 | 10 | 3.6 |
| 5 | 3.5 | 10 | 5.5 |
| 10 | 3.6 | 10 | 6.9 |
| 20 | 4.4 | 10 | 8.5 |
| 50 | 8.5 | 10 | 10.7 |
| 100 | 5.0 | 10 | 12.5 |
| 200 | 6.6 | 10 | 14.6 |
| 500 | 1.3 | 10 | 17.7 |
| 1996 Flood of Record | NA | 10 | 19.5 |

## 4.8 Design Event Summary

A summary of the design Swan Lake levels and B.X. Creek flows is shown in Table 4.6. The 1996 flood of record with an adjustment for climate change is selected as the design flood event, resulting in a design flow of 19.5 $m^3/s$. The 500-year Swan Lake level has been used as the downstream boundary condition for this design event and is estimated as 390.1 m.

**Table 4.6 B.X. Creek peak flow and Swan Lake level summary. Items with an asterisk were used in hydraulic modelling.**

| Return Period (years) | Model flow Upper B.X. Creek ($m^3/s$) | Swan Lake water level (m) | Design flow with increase for climate change ($m^3/s$) | Swan Lake water level with climate change (m) |
|---|---|---|---|---|
| 10 | 6.3 | 389.7 | 6.9 | 389.9 |
| 20 | 7.7* | 389.7* | 8.5 | 389.9 |
| 50 | 9.7 | 389.8 | 10.7 | 390.0 |
| 100 | 11.4 | 389.9 | 12.5 | 390.0 |
| 200 | 13.3 | 389.9 | 14.6* | 390.0* |
| 500 | 16.1 | 390.0 | 17.7 | 390.1* |
| 1996 Flood of Record[1] | 17.7 | NA | 19.5* | NA |

Notes:

1. 1996 flood of record with an increase for climate change is selected as the design flood event (19.5 $m^3/s$).

# 5 HYDRAULIC ANALYSIS

The hydraulic analysis of Part 1 is comprised of constructing and calibrating a numerical hydraulic model to define flood hazards on Upper B.X. Creek. This section discusses the model development and calibration results. Flood extents, depths and velocities are discussed in the Section 6.

## 5.1 Model Development

The Hydrologic Engineering Center's River Analysis System (HEC-RAS), a freely available hydraulic modelling software program developed by the US Army Corp of Engineers (USACE) (Version 5.0.7, 2019), has been utilized for the hydraulic analysis of Upper B.X. Creek. NHC selected a 1D/2D coupled model to simulate flood flows in the channel, using one-dimensional modelling based on cross sections of the channel; and the floodplain, using two-dimensional hydrodynamic flow routing through a mesh. This modelling approach combines the advantages of 1D and 2D modelling, such as the inclusion of crossings and debris scenario modelling represented in the 1D channel and the more detailed representation of the floodplain through a 2D mesh. This modelling method does present certain disadvantages, as a coupled 1D/2D model can often be more complex to develop and can exhibit stability problems at the 1D/2D interface.

The hydraulic model covers a reach length of approximately 3.5 km, starting from approximately 1 km upstream of Pleasant Valley Road (600 m upstream of the Vernon city boundary) and ending at Swan Lake. The 1D model is based on digitization of the 2016 orthophoto, 57 cross sections derived from NHC in-channel surveys, overbank LiDAR data, five cross sections from the SEL survey, and a total of 22 crossings (13 bridges and 9 culverts) surveyed by NHC. Where culverts had variable levels of sediment infilling, full culvert dimensions were extracted from available record drawings and the 2015 Stantec inspection (Stantec, 2016). Moreover, two crossings with variable geometries along their length were modelled using the most restrictive cross section dimensions (without taking into account the level of infilling noted during survey). Specifically, the first crossing at 20$^{th}$ Street, composed of an arch culvert followed by a box culvert, and the crossing at 48$^{th}$ Avenue, composed of a box culvert followed by an arch culvert recessed under the bridge, were both modelled to represent the arch culvert. Details on all crossings are presented in Appendix B.

The 2D floodplain model is composed of a 5 m by 5 m mesh with topography derived from the digital elevation model (DEM) described in Section 3. The applied DEM includes building footprints represented by a 10 m elevation increase with respect to bare earth LiDAR data. The 2D component does not include any municipal stormwater systems; therefore water can only flow along the terrain. This is based on the assumption that the design event would be a high intensity rain-on-snow event, and storm sewers would be flowing at capacity. The 2D mesh assumes there are no temporary berms, dikes, or sandbags along the creek banks.

The design flow events and corresponding Swan Lake water levels defined in Section 4 were applied as fixed upstream and downstream boundary conditions respectively. Evaluation of model parameters showed that the main channel roughness was one of the most significant factors controlling the simulated water surface elevation, with overbank roughness having very little effect. The applied channel roughness following calibration varied between 0.065 in the steeper portion of the reach upstream of the second 20th Street crossing[8] and 0.055 downstream of this intersection. The roughness coefficients in the floodplain were defined based on the land use type according to the National Land Cover Database naming convention developed in 2011 by the Multi-Resolution Land Characteristics Consortium presented in Table 5.1 (MRLC, 2011).

**Table 5.1 Roughness coefficient with respect to land use type.**

| Land use type | Manning's n |
|---|---|
| Barren land | 0.04 |
| Road | 0.013 |
| Cultivated crops | 0.06 |
| Developed high intensity | 0.15 |
| Developed low intensity | 0.08 |
| Developed medium intensity | 0.10 |
| Developed open space | 0.04 |
| Grassland / herbaceous | 0.045 |
| Mixed forest | 0.08 |
| Pasture / hay | 0.06 |

## 5.2 Model Calibration

Despite recent large floods, there is no survey record of flood levels or extents. The 1D model was calibrated using limited information consisting mainly of anecdotal accounts, news reports and photographic evidence of the 2017 and 2018 floods provided by the CoV. A sample of these photo records is illustrated in Figure 5.1. Water surface elevations were deduced from such information and compared to model results for calibration purposes. The main calibration parameters were channel roughness as described in Section 5.1 and culvert sediment infilling, which was recorded in the 2015 Stantec inspections (Stantec, 2016) and the October 2019 NHC survey.

[8] The first 20th Street crossing is located south of 48th Avenue. The second 20th Street crossing is located north of 48th Avenue near 4905 20th Street.

2017 – Park / Strata development upstream of 53rd Avenue

2018 – Inlet box culvert 48th Avenue crossing

2018 – Sand bag wall behind 4905 20th Street

2018 – Inlet box culvert second 20th Street crossing

**Figure 5.1 Photographic evidence of 2017 and 2018 floods used for calibration purposes.**

An accurate estimate of the 2017 and 2018 discharge was not available, as the WSC B.X. gauge is no longer active. Additionally, the modelled water elevations near crossings are highly sensitive to sediment infilling. Therefore, flows that were anticipated to be in the realm of the 2017 and 2018 flood events were tested on two separate model geometries that depicted different sediment infilling conditions at specific crossings. Observations from 2015 (Stantec, 2016) and 2019 were used to test these conditions (Table 5.2). A flow of 7.2 $m^3/s$ was selected as a suitable flow to reproduce the conditions observed in the Figure 5.1 photos.

**Table 5.2 2015 and 2019 observed culvert sediment infilling for calibration.**

| Crossing location | 2015 % infilling[1] | 2019 % infilling[1] |
|---|---|---|
| 48th Avenue | 51<br>(average of inlet and outlet infilling) | 39<br>(average of inlet and outlet infilling) |
| Second 20th Street | 46 | 19 |
| Deleenheer Road crossing | Not inspected (0) | 13 |
| Highway 97 | Not inspected (0) | 43 |

Notes:

1. In 2015, both the culvert at 48th Avenue and the second culvert at 20th Street presented higher infilling levels in comparison to 2019 values due to the substantial dredging efforts made in both March and May 2018.

Figure 5.2 shows the modeled profiles for the two observed channel geometries compared to observed water elevations. It can be noted that upstream of the 48th Avenue crossing, the modelled water surface elevation is substantially higher than observed. This discrepancy could be due to less infilling at the inlet of the culvert at the beginning of the flood event in comparison to what was measured during the 2015 inspection and 2019 survey.

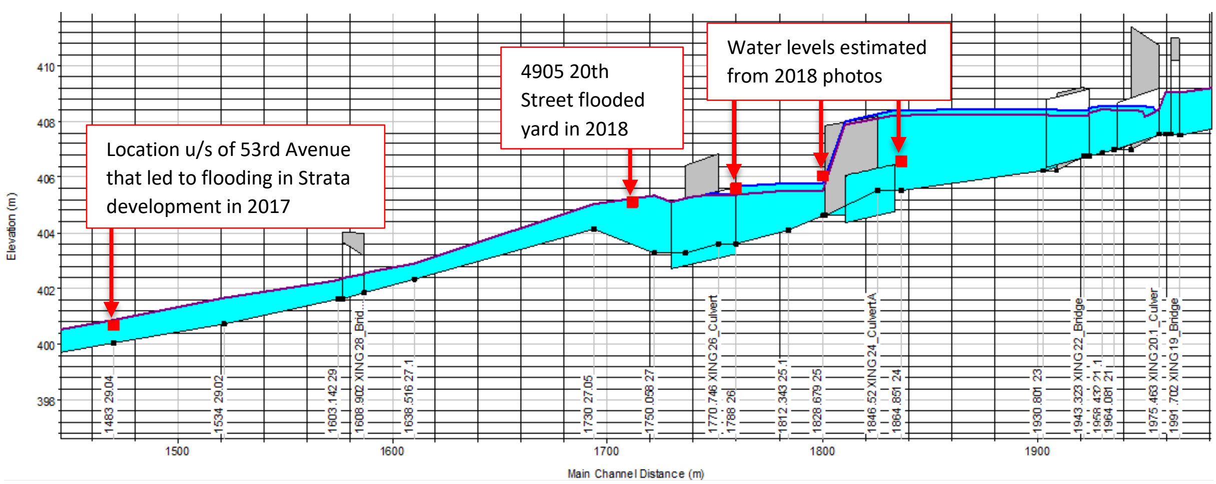



**Figure 5.2 Calibration results for the 2018 and 2017 spring flood with 2015 (light blue infill profile) and 2019 (purple profile) infilling levels.**

Given the sparsity of observed high water data and no available flow data for Upper B.X. Creek during the 2017 and 2018 flood events, no further calibration has been carried out. Further model calibration could be conducted if water level and flow data from high flow events is collected. It is also important to note that the model's ability to precisely represent the observed water surface is affected by assumption of a fixed bed based on a geometry that comes from time-specific bathymetric surveys and topographic data. However, it became evident through modelling the 2015 and 2019 culvert infilling conditions that sediment management is a key element affecting the hydraulic capacity of crossings on Upper B.X. Creek. The calibrated model was therefore used to assess the impact of various culvert infilling conditions on flood mapping results, as detailed in Section 5.3.

## 5.3 Modelling Approach

The calibrated 1D model defined the following main areas of overbank flooding:

- Overtopping of 20th Street / 48th Avenue  intersection;
- Overbank flow behind property on 4905 20th Street;
- Overbank flow upstream of 53rd Avenue onto community park and Strata development; and
- Overtopping of Highway 97.

As a coupled 1D/2D model, the overbank flow was then modelled through a 2D floodplain mesh representing the water flowing through town and around buildings. The 1D component of the model was linked to the 2D mesh through a series of lateral weirs representing the high terrain along the left and right banks which allowed water in and out of the channel. Flow overtopping at crossings (bridge decks) was assumed to stay within the 1D component of the model as the model formulation does not allow channel flow to be modified within the bridge/culvert calculations. Unless the road deck has a significant cross slope, this limitation is considered acceptable as overtopping flow would likely flow over the road and into the channel downstream of the crossing.

### 5.3.1 Culvert Sediment Infilling

The modelling results of the 2015 and 2019 culvert infilling helped identify culverts with limited capacity, resulting in overbank flooding. Noting the impact of their partial infilling, four culvert infilling conditions were selected for modelling purposes as presented in Table 5.3 and Figure 5.3.  The proposed percentage blocked from sediment infilling for each culvert is based on 2015 and 2019 observations and are expected to be reasonable since no specific dredging program has yet been established by the CoV. This approach presents a conservative methodology that takes into account future infilling issues and potential dredging activities on a culvert by culvert basis and can therefore define the impact of clearing each individual culvert to better focus sediment management efforts. The condition resulting in the largest flood extent was selected for floodplain mapping purposes, definition of FCLs, and hazard mapping (see Section 6).

### Table 5.3 Modeled culvert sediment infilling conditions.

| Crossing location[1] | Condition 1 | Condition 2 | Condition 3 | Condition 4 |
|---|---|---|---|---|
| 48th Avenue | 50 % blocked | 0 % blocked | 0 % blocked | 0 % blocked |
| Second 20th Street crossing | 50 % blocked | 50 % blocked | 0 % blocked | 0 % blocked |
| Highway 97 crossing | 50 % blocked | 50 % blocked | 50 % blocked | 0 % blocked |

Notes:

1. It was noted in 2019 that the infilling at the Deleenheer Road crossing did not impact upstream flooding and therefore wasn't varied. The culvert infilling at this crossing was defined as 25 % blocked in all four modelled conditions.


### Figure 5.3 Modeled culvert sediment infilling locations.

Design flows and water levels from Table 4.6 were applied as upstream and downstream boundary conditions respectively and inputted as a steady hydrograph. Simulations were run long enough to ensure stable water surface elevations across the flood extents, with simulation times ranging from 36 h to 48 h depending on the conditions being modelled. The following flood flows were selected for modelling and analysis:

- Flood of record (1996) with increase for climate change (19.5 $m^3/s$);
- 200-year flood with increase for climate change (14.6 $m^3/s$);
- 20-year flood (7.7 $m^3/s$).

Within BC, the 200-year flood plus an increase for climate change is the flood commonly used for floodplain maps, unless the flood of record with an increase for climate change is greater. As the 1996 flood is greater than the 200-year flood in this case, it was therefore retained as the flow condition for mapping purposes (design flood event). The 20-year flood without climate change was also selected for analysis as it is representative of a more common occurrence and is equivalent to the 2017 peak flow estimate.

## 5.4 Modelling Results

Using the design flood event, Condition 1 in Table 5.3 resulted, as expected, in the largest flood extent and therefore the worst case scenario considered for floodplain mapping purposes. Culvert sediment infilling for Conditions 2 through 4 were also modelled using the design flood in order to assess the impact of no sediment infilling on flood extents and crossing capacity. The lower recurrence floods (200-year flood plus climate change and 20-year flood) were modelled using Condition 1. Depth raster results are to be provided to the CoV for all aforementioned modelled conditions.

For the design flood, Condition 1 flood extents reach 27th Street to the west and nearly 46th Avenue to the south. The flooding extent also covers the area east of the creek directly south (Vernon Works Yard) and north (industrial yard) of 48th Avenue. Finally, to the north, the flood extents cover about 300 m of both lanes of Highway 97. The Condition 1 scenario assumes no emergency diking or successful clearing of sediment infilling during the design flood event.

### 5.4.1 Sensitivity Testing

#### 5.4.1.1 Sensitivity to Culvert Infilling

For the design flood, Condition 2, which unblocks the culvert located at the 20th Street and 48th Avenue intersection, results in similar flood extents as Condition 1. Condition 3, which considers clear culverts at both the 20th Street and 48th Avenue intersection and the second 20th Street culvert, results in a lesser flood extent as the upstream bank northwest of the 20th Street culvert does not overtop (along 24th Street and 53rd Avenue). The comparison of Conditions 2 and 3 is presented in Figure 5.4. Condition 4, which unblocks all culverts including the crossing at Highway 97, generates a flood extent similar to that observed for Condition 3 with less length and width of highway flooding (one lane along 250 m only).

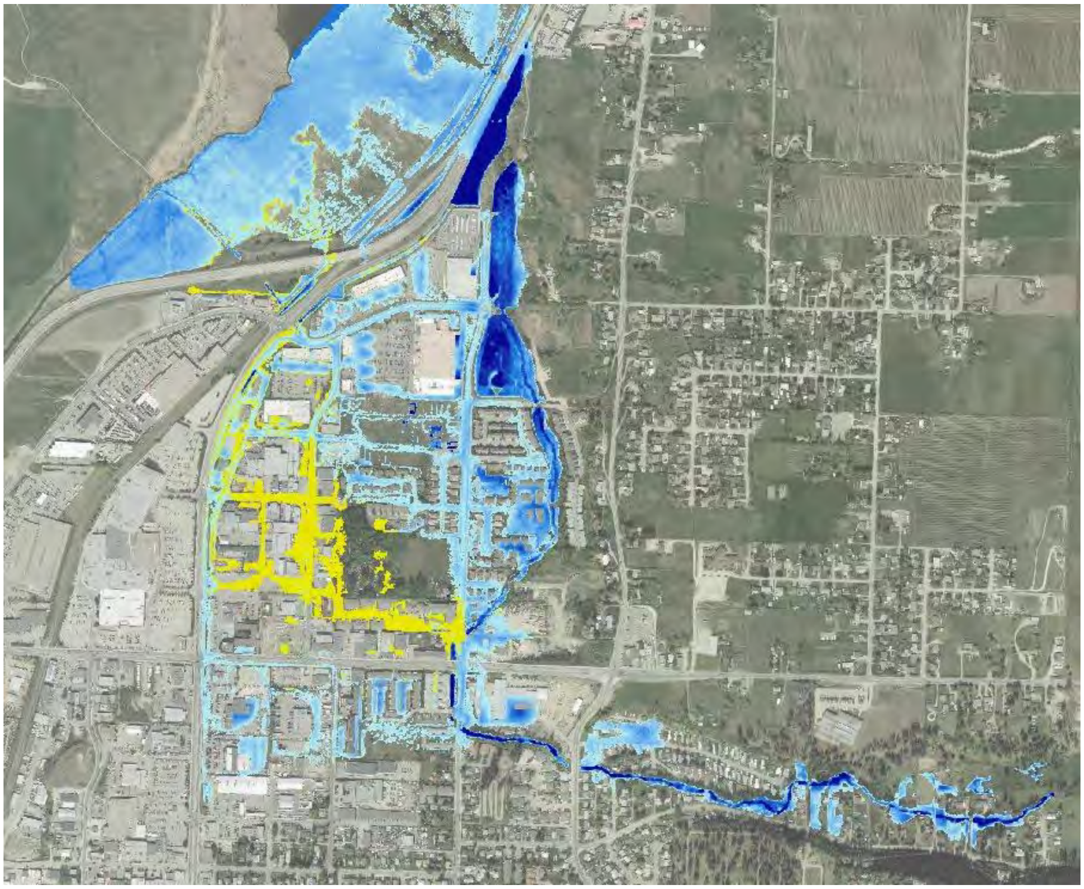


**Figure 5.4 Comparison of flood extents for culvert infilling Condition 2 (yellow + blue) and Condition 3 (blue) for the design flood.**

In terms of channel and overbank flow rates, Conditions 1 and 2 result in an in-channel flow of approximately 16 $m^3/s$ upstream of the highway crossing, indicating that 3.5 $m^3/s$ have ultimately entered the floodplain without flowing back into the channel. In the case of Conditions 3 and 4, the in-channel flow upstream of the highway is of 18 $m^3/s$, with therefore only 1.5 $m^3/s$ entering the floodplain and not returning to the channel.

Table 5.4 presents the sensitivity of the overbank flow rates at the main locations of outflow and inflow from/to the channel for each modelled condition. It is important to note that these observations are based only on the four modelled culvert sediment infilling conditions (unblocked or 50 % blocked) and that the amount and location of overbank flow during any particular event will be dependent on the extent that a crossing is blocked. Culvert infilling is expected to change over time and even during an event. Therefore, overbank flow could be greater or less than that modelled, especially if the culvert becomes partly blocked with debris. It should be noted that the modelled sediment infilling conditions does not include any blockage from debris (woody, urban garbage, etc.), which can further reduce the crossing capacity and increase flood inundation. Efforts to limit blockage, such as improving crossing capacity, removing upstream sediment and debris sources, and monitoring and maintaining crossings prior to and during high flow periods, will reduce the likelihood of overflow (see Section 8 for proposed mitigation measures). The hazard map presented in Section 6.2, which includes velocity vectors, illustrates the locations identified in Table 5.4 where flow leaves and enters into the channel.

**Table 5.4 Sensitivity of modelled overbank flow rates.**

| Segment Location | Overbank Flow | Comparison of Culvert Infilling Conditions |
|---|---|---|
| Pleasant Valley Road to 20th Street | Right bank | Similar flow leaves channel for each condition (approx. 5 $m^3/s$) directly upstream of pedestrian crossing at 20th Street only |
| 20th Street to 48th Avenue | Right bank | 7.5 times more flow enters the channel for Conditions 2, 3 and 4 (1.5 $m^3/s$) than Condition 1 (0.2 $m^3/s$) |
| 48th Avenue to 20th Street | Left bank | No flow leaves channel for Conditions 3 and 4, whereas approximately 3 $m^3/s$ leave channel for Conditions 1 and 2 |
| 20th Street to 50th Avenue | Right bank | Less flow enters back into channel for Conditions 2 (15 %), 3 (30 %) and 4 (30 %) in comparison to Condition 1 (5 $m^3/s$) |
| 20th Street to 50th Avenue | Left bank | 2.5 times more flow leaves the channel for Conditions 3 and 4 (1.9 $m^3/s$) than Conditions 1 and 2 (0.7 $m^3/s$) |
| 50th Avenue to 19th Street | Left bank | 12 % more flow leaves the channel for Conditions 3 and 4 (approx. 9.7 $m^3/s$) in comparison to Conditions 1 and 2 (approx. 8.3 $m^3/s$) |
| 19th Street to 53rd Avenue | Left bank | Similar flow enters channel for each condition (approx. 2.4 $m^3/s$) |
| 53rd Avenue to 55th Avenue | Left bank | Less flow enters back into channel for Conditions 3 (17 %) and 4 (12 %) in comparison to Conditions 1 and 2 (approx. 5.7 $m^3/s$) |
| Deleenheer Road to 58th Avenue | Left bank | Similar flow enters channel for each condition (approx. 1.8 $m^3/s$) |
| 20th Street extension to Highway 97 | Left bank | 90 % less flow leaves the channel for Condition 4 (approx. 0.7 $m^3/s$) in comparison to Condition 1 and 2 (7 $m^3/s$) and Condition 3 (8 $m^3/s$) |

#### 5.4.1.2 Sensitivity to Flow

In regards to the lower recurrence floods, results for Condition 1 show that the 200-year flood plus climate change covers a similar flood extent in comparison to the design flood event with the exception of lesser flooding south of 48th Avenue, east of the channel, and north of 58th Avenue. Flood extents for the 20-year flood are, as expected, significantly reduced with respect to the two greater modelled flows for Condition 1, as flooding is only observed east of the creek north of 48th Avenue, in the residential development around 53rd Avenue (Strata development), along 20th Street and in the parking lot south of 58th Avenue between 24th and 20th Streets. The comparison of the different flow scenarios under Condition 1 is illustrated in Figure 5.5 below. Channel flow upstream of the highway crossing and the resulting overall overbank flow rate are as follows for each modelled flow under Condition 1:

- Design flood event: 16 $m^3/s$ in-channel and 3.5 $m^3/s$ overall overbank flow;
- 200-year flood with climate change: 13.5 $m^3/s$ in-channel and 1.1 $m^3/s$ overall overbank flow;
- 20-year flood: 7.7 $m^3/s$ in-channel with all flow leaving the channel returning (except for ponded areas).

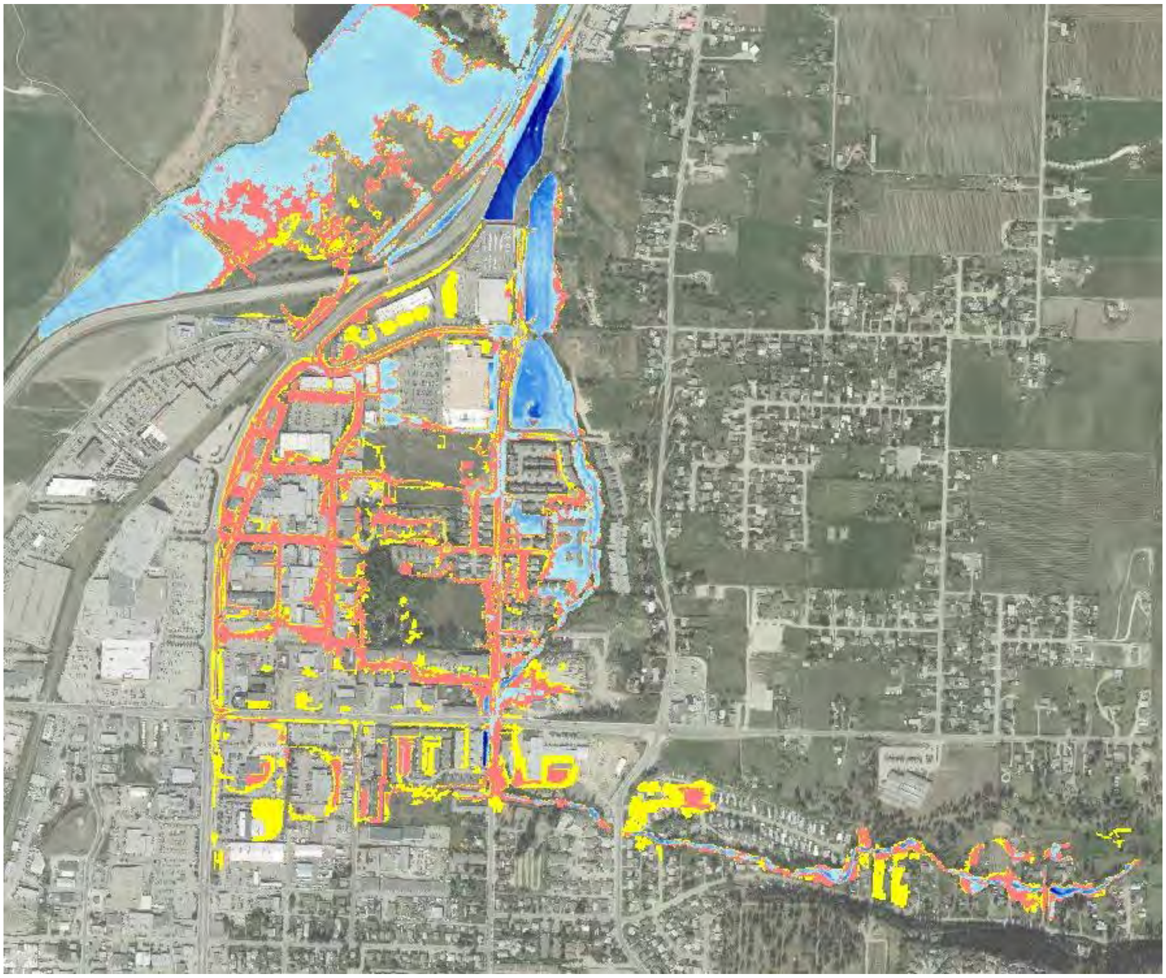


**Figure 5.5 Comparison of flood extents with Condition 1 for the design flood event (yellow + red + blue), the 200-year flow with climate change (red + blue) and the 20-year flood (blue).**

# 6 FLOOD AND HAZARD MAPPING

The hydraulic results for the design flood event were used for mapping. As mentioned previously, the culvert blockage condition resulting in the largest flood extent, Condition 1, was selected for floodplain mapping purposes, definition of FCLs and hazard mapping. Two types of maps were produced:

- Floodplain Map: Map of flood inundation limits and FCLs;
- Hazard Map: Map of flood hazards showing flood depths and velocities.

Each map is displayed on one 22" x 34" map sheet at a 1:4,000 scale. The coordinate system used is UTM Zone 11 metres NAD 83 (CSRS) and CGVD2013. The floodplain map is accompanied by a 1:25,000 scale index map which includes detailed map notes. The maps follow provincial floodplain mapping guidelines and standards (APEGBC, 2017). Two types of maps were produced:

- Map of flood inundation limits and FCLs;
- Map of flood hazards showing flood depths and velocities.

Provided index, floodplain, and hazard maps are included in Appendix D. Geographic information system (GIS) layers produced for flood mapping are summarized in Table 6.1.

**Table 6.1 Flood mapping GIS layers.**

| Description | Includes Climate Change | Includes Freeboard | Includes FCL | Extent Polygon | Depth Raster | Velocity Point |
|---|---|---|---|---|---|---|
| FLOODPLAIN INUNDATION AND HAZARD (1D & 2D MERGED MODEL RESULTS) | | | | | | |
| FCL isolines | Y | Y | Y-on map | N | N | N |
| CONDITION 1 – design flood event extent (with freeboard) | Y | Y | Y-on map | Y-on map | N | N |
| Mapping limit | n/a | n/a | n/a | Y | n/a | n/a |
| CONDITION 1 – design flood event extent (without freeboard) | Y | N | N | Y | Y | Y |
| CONDITION 2 – design flood event extent | Y | N | N | Y | Y | N |
| CONDITION 3 – design flood event extent | Y | N | N | Y | Y | N |
| CONDITION 4 – design flood event extent | Y | N | N | Y | Y | N |
| 20-year extent | Y | N | N | Y | Y | N |
| 200-year with increase for climate change extent | Y | N | N | Y | Y | N |
| MODEL REFERENCE LAYERS | | | | | | |
| River cross sections | Y | Y-depending on scenario | n/a | n/a | n/a | n/a |
| Model 1D/2D area boundaries | n/a | n/a | n/a | Y | n/a | n/a |

## 6.1 Flood Inundation Limits and Flood Construction Levels

A floodplain map has been provided for the design flood event showing inundation limits and FCLs based on hydraulic model results for Condition 1 (Section 5.3).

Freeboard is added to the simulated water level to provide a minimum level for construction within the floodplain, referred to as the FCL. The freeboard accounts for local variations in water level (i.e. super elevation, turbulence, surging), as well as for the precision or confidence in the data and assessment. APEGBC (2017) suggests that a minimum freeboard of 0.3 m should be applied to QPI flows and 0.6 m to QPD flows (Figure 6.1). For Upper B.X. Creek, a 0.6 m freeboard has been applied to the design flood event (QPI flow), which is considered appropriate given that the flood mapping covers an active alluvial fan, and the flood inundation is very sensitive to culvert infilling/blockages and the sparsity of calibration data in developing the hydraulic model.

The flood extents and FCLs were defined based on the water surface elevation calculated by the 2D component of the model with the addition of freeboard. Along the channel (1D model), water surface elevations plus freeboard along cross sections were used to create a two-dimensional surface. Water surface elevations plus freeboard from the 2D and 1D model results were intersected with the LiDAR DEM data, with the portion of the water surface above the DEM data defining the inundated area.

Within the channel, it was decided to map the water surface elevations from a 1D model only to represent a worst case scenario where water cannot leave the system onto the floodplain. The in-channel FCL is therefore based on 1D model results and assumes all flow is confined to the channel, representing temporary or permanent diking that would prevent flow beyond the channel extents.

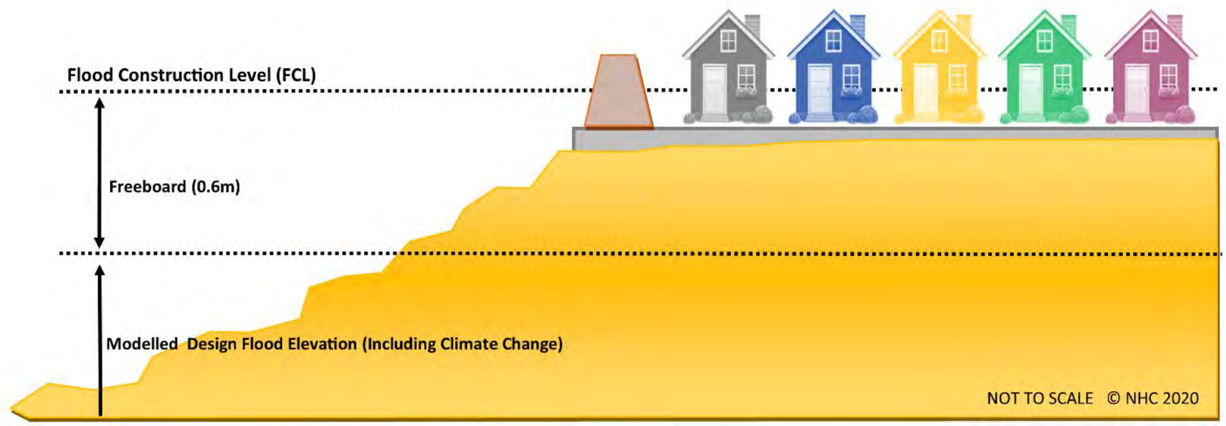



**Figure 6.1 FCL schematic for rivers.**

The flood inundation maps also defines the floodway and flood fringe. Floodway is considered the primary flow path during a flood event. Flood fringe is considered part of the floodplain where depth and velocity are generally low (< 1 m and < 1 m/s). For Upper B.X. Creek the floodway is generally limited to the existing channel, with the exception of a portion of 20th Street, where flow overtops the road at the first 20th Street crossing and re-enters the channel downstream of the second 20th Street crossing.

### 6.1.1 Use of FCLs

FCLs are documented on the floodplain maps with labelled Isolines. The FCL for a specific building or space is to be taken as the highest FCL applicable for that location, which is considered the upstream extent of the building or space. Where the building or space is located between isolines, two options exist for determining the applicable FCL:

- Approach 1: the FCL is taken as the value represented by the next upstream isoline, or
- Approach 2: the FCL is calculated through linear interpolation between the 2 isolines in which the upstream face of the building or space is located.

An example is presented below based on the building and mapped isolines shown in Figure 6.2:

- The highlighted FCL line has an elevation of 403 m, with the downstream FCL (shown as a black line) having an elevation of 402 m. The distance between these lines is 45 m, and the upstream side of the building is 16 m downstream from the 403 FCL isoline.
- The FCL for the labelled building using Approach 1 is 403.0 m and using Approach 2 it is 402.6 m (through interpolation of the FCL using a 1 m drop over 45 m).

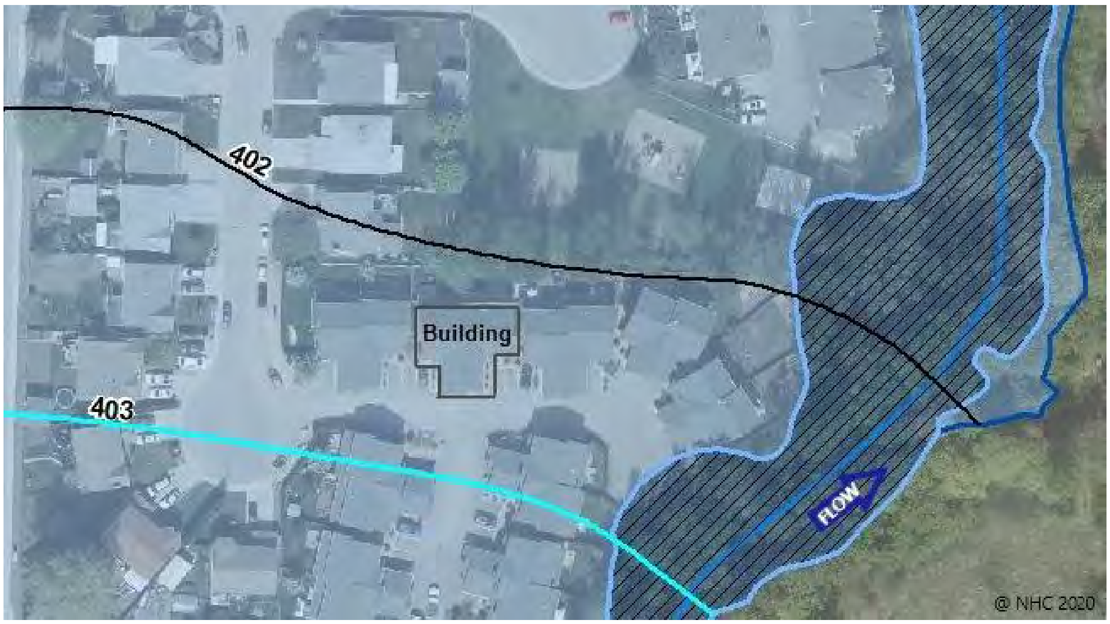



**Figure 6.2 Example of FCL line calculation.**

If Approach 2 is to be used, the user is recommended to extract distances from the CoV GIS mapping program to avoid scaling issues from floodplain maps.

### 6.1.2 Mapping Boundaries and Filtering

Modelled flood extents were bound by 27th Street to the west; however, the addition of freeboard raised the flood elevation on average 0.6 m above the road surface. To the west of 27th Street, the terrain slopes downward in the direction of Lower B.X. Creek. Therefore, applying the FCL elevation beyond 27th Street would not result in accurate FCL elevations west of 27th Street. As 27th Street is along the western edge of the modelled extent a reduction in freeboard was deemed acceptable and therefore FCL extents were clipped to the road centreline. A similar situation was encountered along Pleasant Valley Road, where the addition of freeboard exceeded the road centreline by an maximum of 0.4 m and due to the downward sloping terrain at this location, extending FCLs beyond the road results in unrealistically high FCL elevations beyond Pleasant Valley Road. The discussion of the flood hazard along Pleasant Valley Road is discussed further in Section 8. Otherwise, the map extents have been clipped to the Vernon city administrative boundary or following the natural topography along Upper B.X. Creek.

Filtering was used to remove isolated inundated areas and isolated elevated areas smaller than 100 $m^2$. This is typically done to improve the readability of the maps and to limit the reliance on slight variations in floodplain topography, which may change with time. An exception to this rule is isolated inundation areas within 40 m of direct inundation; these were mapped as inundated to account for culverts or seepage that may be connected to these isolated wet areas.

### 6.1.3 Setbacks

Setbacks from waterbodies are defined to maintain the floodway and allow for potential bank erosion. Additionally, setback may be increased in areas where structural mitigation is recommended. Setbacks have been defined on the floodplain maps.

FLNRORD (2018) defined setbacks on small streams as 15 m from the natural boundary of the channel, given that the channel is not obstructed. As Upper B.X. Creek is located on an active alluvial fan and there is a history of flooding this setback should not be reduced (FLNRORD, 2018).

Setbacks should be increased to 30 m in locations where structural mitigation is recommended. The increased setback is to provide space for the construction of structural mitigation such as dikes and the associated right of way (ROW). This setback may need to be adjusted depending on the required height of the structural mitigation (MWLAP, 2003).

## 6.2 Flood Hazard

The flood hazard map depicts the design flood event under Condition 1. Simulated water depths are shown for each cell vertex in the 2D mesh and calculated velocities were filtered down to a 20 m grid to clearly represent overland flow velocities. Within the river channel, flood depths are based on 1D model results and velocities are based on 1D model velocities at cross section locations. 2D velocity arrows representing less than 0.05 m/s and 1D velocity arrows within the channel that overlap at a 1:4,000 scale were filtered from the hazard map. Freeboard was not included in mapped depths or extents on the hazard map.

The colour shading used to represent depth listed in Table 6.2 references the Okanagan Flood Mapping Standards (NHC, 2020b), which were adapted from the European Exchange Circle on Flood Mapping (EXCIMAP, 2007) and the national standard in Japan (Flood Control Division, River Bureau, Ministry of Land, Infrastructure and Transport (MLIT), 2005). The description of potential consequence for each depth level has not been altered to represent the exposure within the study area, and therefore may not directly be applicable.

**Table 6.2 Flood depth description.**

| Depth (m) | Description of potential consequence | Colour (RGB) | Example |
|---|---|---|---|
| < 0.1 | Most buildings expected to be dry; underground infrastructure and basements may be flooded. | Yellow (255/255/0) | |
| 0.1 – 0.3 | Water may enter buildings at grade, but most expected to be dry; walking in moving water or driving is potentially dangerous; underground infrastructure and basements may be flooded. | Green (8/255/0) | |
| 0.3 – 0.5 | Water may enter ground floor of buildings; walking in moving or still water or driving is dangerous; underground infrastructure and basements may be flooded. | Light Blue (115/178/255) | |
| 0.5 – 1.0 | Water on ground floor; underground infrastructure and basements flooded; electricity failed; vehicles are commonly carried off roadways. | Medium Blue (0/112/255) | |
| 1.0 – 2.0 | Ground floor flooded; residents and workers evacuate. | Dark Blue (0/38/115) | |
| > 2.0 | First floor and often higher levels covered by water; residents and workers evacuate. | Purple (76/0/115) | |

# 7 FLOOD RISK ASSESSMENT

A flood risk assessment was completed for the study area , evaluating the impacts of the different flood hazard scenarios simulated. This report section discusses the risk assessment approach, data sources, findings, conclusions, and limitations.

## 7.1 Approach

Flood risk assessment is the process by which the consequences and likelihoods of flooding are assessed. Best practices for risk assessment include a spatial analysis using the best available flood hazard information and mapping of receptors (*people, economy, culture, and environment*) that are affected by flooding. An outline of the components of risk assessment is provided in Figure 7.1 and detailed definitions of these terms follow.

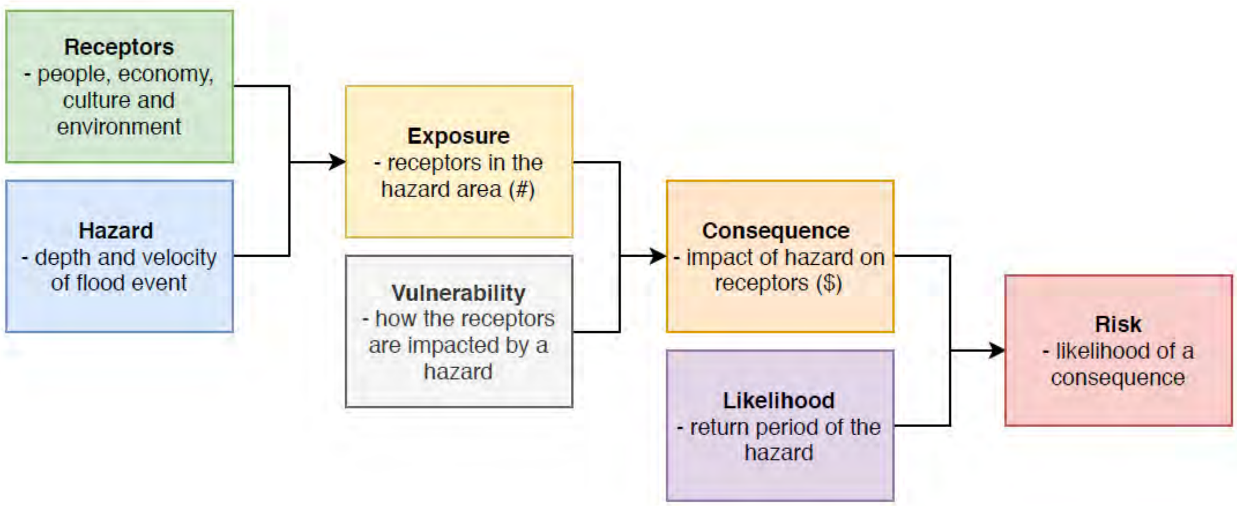



**Figure 7.1 Terminology and Concept Diagram.**

## 7.2 Terminology Definitions

### 7.2.1 Receptors

Within flood risk assessments, “receptors” is a term commonly used for the entities that may be harmed (a person, property, habitat, etc.) by a flood hazard (FLOODsite, 2005).

In this project, receptors are categorized as *people, economy, environment*, and *culture* as shown below in Figure 7.2. This figure includes the associated icons from the United Nations Office for the Coordination of Humanitarian affairs (OCHA) for each category.


**Figure 7.2 Receptor categories including icons (UN OCHA, 2018).**

For this project, both locally available and provincially available datasets were used, however no community input was collected and no ground-truthing was completed at the time of writing this report. Public engagement and community input was planned for a later time.

### 7.2.2 Hazard

A hazard is "a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation" as defined by the UN report on terminology relating to disaster risk reduction (United Nations, 2016). A flood hazard is the characteristics of flood waters including depth, velocity, debris, duration and speed of the onset of the event. For this study, both flood depth and velocity were modelled, however, flood depth forms the basis for much of the risk assessment.

### 7.2.3 Exposure

Exposure is "the [location] of people, infrastructure, housing, production capacities and other tangible human assets in hazard-prone areas" (United Nations, 2016). Exposure is assessed by identifying the receptors located within the delineated hazard areas; that is, within the inundation extents. For example, buildings which are in the flood hazard area are identified and considered in the calculation of exposure.

### 7.2.4 Vulnerability

Vulnerability is the measure of how susceptible a receptor is to a specific hazard. To illustrate the concept of flood vulnerability, a house constructed to an elevation lower than the local FCL would have a higher vulnerability compared to house built to an elevation higher than its respective FCL, even if both houses are on the floodplain. Vulnerability is determined by "physical, social, economic and environmental factors or processes which increase the susceptibility of a receptor to the [consequence] of hazard" (United Nations, 2016). Vulnerability of buildings can be analyzed through depth-damage curves which identify the percentage damage for each depth of flood inundation based on building type and elevation.

Vulnerability for other receptors are generally more challenging to quantify, and due to the level of detail of this assessment, have not been considered. Vulnerability could be added at a later phase for other receptors, such as social vulnerability (for people), environmental vulnerability (for habitat), flood resistance of particular crops (for agricultural lands); through local assessment of receptors; and through engagement with local stakeholders.

### 7.2.5 Consequence

When considering risk analysis, the concept of consequence is understood in the same way as impact. The UN defines disaster impact as "the total effect, including negative effects (e.g., economic losses) and positive effects (e.g., economic gains), of a hazardous event or a disaster. The term includes economic, human and environmental impacts, and may include death, injuries, disease and other negative effects on human physical, mental and social well-being" (United Nations, 2016).

To determine the consequence of a flood event, exposure to a hazard and vulnerability are combined. For example, a depth-damage curve for a structure with a given construction type (vulnerability) is applied to the value of a building with that construction type that is flooded to a depth of two metres (exposure). This combination of exposure and vulnerability gives the consequence of the flood event. This is used to calculate risk in combination with likelihood. The consequences of floods are often framed as net negative, however some benefits can also be realized; such as redevelopment or soil nutrient replenishment.

### 7.2.6 Likelihood

Likelihood is the probability of an event occurring. The probability is often presented with respect to the design life or as an annual probability, stated as the annual exceedance probability (AEP). The AEP is also expressed as its inverse, that is the average return period for an event; e.g. a 1 in 100 year flood has a return period of 100-years and 1 % AEP, and a 1 in 200 year flood has a return period of 200-years and 0.5 % AEP.

### 7.2.7 Risk

In engineering, risk is typically analyzed as "the combination of the likelihood of an event and its consequence" (California Natural Resources Agency, 2018). Put mathematically:

$$Risk = Consequence \times Likelihood$$

## 7.3 Methods and Results

This project examined both the 20-year flood event, as well as the design flood event (as discussed in Section 4.8). For each of these events, modelled extent and depth results without freeboard were overlaid with spatial receptors using GIS analysis as described below for each receptor.

### 7.3.1 People

To determine flood impact to people, population data was sourced from Canadian census data or based on individual buildings and an assumed or counted population per building. As census data are reported by aggregated areas (the smallest of which is a census block), there is substantial error associated with using these results to study populations of small areas.

A building-based analysis of population was used for this project. The official community plan (OCP) designations and aerial imagery were used to develop a building count. The census data (2016) was still used, but only to calculate average population per Vernon dwelling, which is 2.2 people per private household. This was used to determine the exposed population by a count of residential dwellings. Adjustments were made for multi-unit dwellings based on zoning. This approach provides a representation of residential population, but does not necessarily reflect the number of people who work, visit, or do business in the exposed area. The estimated number of dwellings (residential units in residential buildings) and people exposed is shown in Table 7.1.

**Table 7.1 Count of effected people based on number of effected dwellings.**

| Factor | 20-year Flood Event | Design Flood Event |
|---|---|---|
| Dwellings | 43 | 115 |
| Population | 95 | 232 |

### 7.3.2 Economy

Key economic receptors include buildings, infrastructure, and agricultural land. There is no agricultural land within the study area. Buildings and infrastructure which are exposed to flooding were identified within the following datasets:

- Stormwater mains;
- BC hydro infrastructure including: underground hydro distribution (secondary lines), underground hydro distribution (primary lines), overhead hydro distribution (secondary lines), overhead hydro distribution (primary lines), hydro poles, hydro junction boxes, and underground transformers;
- Fortis BC gas infrastructure including: distribution valves and distribution pipes;

- Shaw and Telus telecom infrastructure including: telecom facilities, telecom poles, underground lines, cable wires, and other structures;
- Roads;
- Buildings; and
- OCP zoning designations.

#### 7.3.2.1 Utility Infrastructure

Utility infrastructure that was found within the extents of the given flood event is summarized in Table 7.2. More detailed notes on which infrastructure components were flooded can be found in Appendix E. As infrastructure ranges from below grade to well above grade, the relationship between flood depth and consequence is not consistent. Therefore, flood depth was not considered for this assessment of consequence. The results shown should be used to understand disruption to utility infrastructure rather than damage. To determine potential damage to infrastructure, utility companies should be involved in identifying anticipated impact of inundation. Impacts can include water damage and short-circuiting, undermining poles and structure foundations, flooding underground hydro or transmission infrastructure, storm sewer backups, and increased uplift forces for inundated buoyant infrastructure (i.e. pipelines and closed chambers).

**Table 7.2 Impacted utility infrastructure.**

| Infrastructure Category | Infrastructure Type | Quantity | 20-year Flood Event | Design Flood Event |
|---|---|---|---|---|
| Stormwater | Pipes | Count | 16 | 100 |
| Stormwater | Pipes | Length (m) | 776 | 5422 |
| BC Hydro | Underground hydro distribution (secondary lines) | Count | 32 | 207 |
| BC Hydro | Underground hydro distribution (secondary lines) | Length (m) | 650 | 4,734 |
| BC Hydro | Underground hydro distribution (primary lines) | Count | 0 | 91 |
| BC Hydro | Underground hydro distribution (primary lines) | Length (m) | 0 | 5,797 |
| BC Hydro | Overhead hydro distribution (secondary lines) | Count | 12 | 71 |
| BC Hydro | Overhead hydro distribution (secondary lines) | Length (m) | 351 | 1,998 |
| BC Hydro | Overhead hydro distribution (primary lines) | Count | 8 | 61 |
| BC Hydro | Overhead hydro distribution (primary lines) | Length (m) | 295 | 2,583 |
| BC Hydro | Hydro poles | Count | 2 | 45 |
| BC Hydro | Hydro junction boxes | Count | 3 | 15 |
| BC Hydro | Hydro underground transformer | Count | 1 | 1 |
| FortisBC Gas | Distribution valves | Count | 0 | 1 |
| FortisBC Gas | Distribution pipes | Count | 59 | 187 |
| FortisBC Gas | Distribution pipes | Length (m) | 2,739 | 8,646 |
| Shaw Telecom Infrastructure | Facility | Count | 10 | 10 |
| Shaw Telecom Infrastructure | Pole | Count | 4 | 70 |
| Shaw Telecom Infrastructure | Underground line | Count | 52 | 246 |
| Shaw Telecom Infrastructure | Underground line | Length (m) | 3,312 | 12,141 |
| Telus Telecom Infrastructure | Facility | Count | 0 | 2 |
| Telus Telecom Infrastructure | Poles and manholes | Count | 1 | 73 |
| Telus Telecom Infrastructure | Cable wire | Count | 76 | 356 |
| Telus Telecom Infrastructure | Cable wire | Length (m) | 5,362 | 19,412 |

#### 7.3.2.2 Transportation Infrastructure

Transportation infrastructure also overlaps with the modelled flood extents. Some railway near the edge of the Vernon city boundary north of Anderson Way and 27$^{th}$ Street is exposed to the design flood. The railway does not appear to be exposed to the 20-year flood. The roadways were assessed based on their stated width or an assumed width of 5 m if no width data was available. Table 7.3 shows the overtopped infrastructure listed by road-type. Appendix E identifies individual road segments exposed as well as average and maximum flood depths for these segments.

**Table 7.3 Overtopped road infrastructure.**

| Road Type | Quantity | 20-year Flood Event | Design Flood Event |
|---|---|---|---|
| Arterial | Count | 2 | 10 |
| | Length (m) | 1,462 | 6,095 |
| Collector | Count | 15 | 17 |
| | Length (m) | 5,296 | 7,072 |
| Local | Count | 12 | |
| | Length (m) | 3,751 | 9,180 |
| Lane | Count | 2 | 330 |
| | Length (m) | 623 | 866 |
| Frontage | Count | 0 | 1 |
| | Length (m) | 0 | 462 |
| SROW (street right of way) | Count | 4 | 8 |
| | Length (m) | 901 | 4,417 |

#### 7.3.2.3 Building Infrastructure

To evaluate the impact to buildings from the flood hazard, the building footprints were overlaid with the flood results. To account for the DEM which included raised building footprints, the building footprints were buffered by 2 m to overlap them with surrounding floodwaters. The maximum flood depth, without freeboard, for each building within this buffer was identified. The ER2 Rapid Risk Evaluation Tool (revision 2.05, August 2016) developed by the University of New Brunswick was used to estimate flood damage to structures and contents. The depth-damage curves built into the ER2 Rapid Risk Evaluation tool were used to estimate the consequence of the flood depth. Without a comprehensive building database, several assumptions were made about all structures including that they are of average quality and built in 1995. These values were selected to provide a representative value which could be used for all structures. As the elevations used to calculate the flood depths are for the first floor elevation, foundation type was set to '0'. Parameters in the tool not relevant to percent damage calculations such as presence or absence of a garage were not used. The assumptions, which varied by occupancy type, are identified in Table 7.4.

**Table 7.4 Building type assumptions for ER2 Rapid Risk Evaluation Tool.**

| Occupancy Type | Parameter | Value Assumed | Reasoning |
|---|---|---|---|
| Nursing Home | Stories | 2 stories | Multi-story based on air photos; flooding does not exceed first floor depth so exact number of stories does not affect calculation. |
| | Basement | No | Assumed value based on likely configuration. |
| Retail Trade | Stories | 1 story | 1 story assumed based on typical configuration observed from air photos. |
| | Basement | No | Assumed value based on likely configuration. |
| Single Family Dwelling | Stories | 2 stories | 2 stories assumed based on typical configuration observed from air photos. |
| | Basement | Yes | Majority of homes assumed to have basements. |
| Light Industry | Stories | 1 story | 1 story assumed based on typical configuration observed from air photos. |
| | Basement | No | Assumed value based on likely configuration. |

There were numerous sheds also identified in the building footprints. Damage to sheds and parking structures was not estimated. There were 13 sheds and parking structures impacted in the 20-year flood and 83 sheds and parking structures impacted in the design flood.

The results of the flood damage assessment are summarized in Table 7.5. Full damage results are provided in Appendix E.

**Table 7.5 Building damage summary.**

| Occupancy Type | Quantity | 20-year Flood Event | Design Flood Event |
|---|---|---|---|
| Nursing Home | Count | 0 | 2 |
| | Average Structure Damage | 0 % | 10 % |
| | Average Content Damage | 0 % | 63 % |
| Retail Trade | Count | 2 | 42 |
| | Average Structure Damage | 18 % | 10 % |
| | Average Content Damage | 77 % | 37 % |
| Single Family Dwelling | Count | 27 | 113 |
| | Average Structure Damage | 25 % | 24 % |
| | Average Content Damage | 24 % | 23 % |
| Light Industry | Count | 2 | 11 |
| | Average Structure Damage | 6 % | 14 % |
| | Average Content Damage | 5 % | 29 % |

Datasets of key community facilities were examined for overlap with flooded areas, including datasets showing emergency services, health care facilities, schools, day cares, community centres, and more. These datasets were confirmed through a desktop study with Google Maps, however the datasets were not augmented or confirmed through community input or ground-truthing. Key facilities identified through this, and the reason for their potential sensitivity to flooding, are identified in Table 7.6.

**Table 7.6 Key community facilities.**

| Community Facility Name | Flood Event | Reason for Sensitivity |
|---|---|---|
| CoV Works Yard | Design Flood Event | May be a key response facility for the CoV where equipment for culvert clearing or sandbagging is based. |
| Good Samaritan Heritage Grove Retirement Centre | Design Flood Event | Residents may have limited mobility and face difficulties in a potential evacuation, requiring extra time and assistance. |
| Chartwell Carrington Place Retirement Residence | Design Flood Event | |
| Pharmacy in Walmart | 20-year and Design Flood Events | As a component of the healthcare resources in the area, flooding eliminating access to or function of the pharmacy may disrupt people's access to medications. |
| House of Dwarfs Daycare | Design Flood Event | Children would require extra assistance and notice to evacuate with their guardians. Impact to available childcare in the region may impact availability of response personnel. |

### 7.3.3 Environment

Potential environmental impacts can be characterized by contamination sources, areas sensitive to contaminants, and habitat impacts.

Contamination sources can include household or industrial chemicals, sewage, and agricultural chemicals or wastes. Some local governments maintain a record of potential contamination sources based on land use or an on-the-ground survey. No household or industrial contamination source datasets were available for this project, so these sources were not characterized. No waste water treatment plants, agricultural lands or large potential sources of sewage were identified within the study area.

Environmental impact can also be characterized by identifying areas most sensitive to contaminants including wells, water intakes, and sensitive ecosystems. Drinking water in Vernon is provided by the Mission Hill Water Treatment Plant which draws water primarily from Kalamalka Lake. As such, it is assumed that there are no water intakes in the study area. Wells were not considered as a sensitive impact; while there may be some wells within the study area, they are not likely used for drinking water as there is municipally supplied water.

As there is sanitary sewer collection in Vernon and no available information on any potential septic fields, the risk of contamination from septic fields is not considered. However, flooding can cause sewage backups at individual residences or through breakage of a municipal sewer pipe. This can cause contamination of the floodwaters by sewage, leading to difficult cleanups as well as human and environmental health impacts.

GeoBC Data Catalogue was reviewed to identify local sensitive ecosystems, critical habitat, and species at risk. This data was compared with inundation extents to determine potential exposure. Critical habitat and species at risk found within the floodplain include Western Rattlesnake, Desert Nightsnake, Great Basin Gophersnake, American Badger, Black Cottonwood, and Common Snowberry-Roses.

### 7.3.4 Cultural

Potential cultural impacts were identified through looking at First Nations reserves or known heritage sites in the area as well as recreational, spiritual, and community areas. Potential cultural receptors include trails, recreation facilities, community halls, and places of worship. Data examined for this project includes Google Maps and the GeoBC Data Catalogue. Community engagement could be used to further expand or refine the identified receptors.

The main cultural impact in this area is to the B.X. Creek Trail. As the B.X. Creek Trail is located adjacent to the creek, it is expected be flooded along much of its length with depths reaching over 1 m in some locations during the design flood. This trail will be exposed to depth, velocity and erosion hazards and should be closed during any anticipated flood events. Damage to the trail can be anticipated in any flood event which exceeds the bank full stage.

The Heron Glen Tot Lot is also flooded during both the 20-year and design flood events. No other cultural receptors were found through a desktop analysis, however, receptors may exist which could be identified by community members through consultation.

## 7.4 Classification and Findings

The risk assessment results presented above provide a quantitative understanding of the impact of both the 20-year and design flood events. This section discusses the results and provides a risk classification for each category. The classification is based on ratings provided in the RAIT and an example flood risk matrix provided by (EGBC, 2018a). The risk matrix developed as a synthesis of these two resources is presented in Table 7.7, and classifications are discussed in the following text. These classifications are not based on stakeholder consultation and as they are designed for a wider context, they may not reflect the impact to the local community.

**Table 7.7 Suggested project risk matrix.**

| Likelihood | Return Period (years) | Risk Level | | | | |
|---|---|---|---|---|---|---|
| **Likely** | <30 | M | H | H | VH | VH |
| **Moderate** | 30-50 | L | M | H | H | VH |
| **Unlikely** | 50-500 | VL | L | M | H | VH |
| **Very Unlikely** | 500-5000 | VL | L | L | M | H |
| **Extremely Unlikely** | >5000 | VL | VL | L | L | M |
| | **Consequence:** | **Negligible** | **Minor** | **Moderate** | **High** | **Severe** |

Notes:

The Risk Level letters represent the following characterization of risk as defined by the example EGBC flood risk matrix. These descriptions are provided as an example only; risk tolerability should be established based on community input.

- **VH, very high risk** is unacceptable; short term (before next flood season) risk reduction is required.
- **H, high risk** is unacceptable; medium-term risk reduction plan must be developed and implemented in a reasonable time frame (within 2 to 5 years); planning should begin as soon as possible.
- **M, moderate risk** may be tolerable or mitigated with short to long term planning.
- **L, low risk** is tolerable; continue to monitor if resources allow.
- **VL, very low risk** is broadly acceptable; no further review or risk reduction required.

Both a relatively high likelihood event and a relatively low likelihood event were analyzed. The 20-year flood has a relatively high likelihood, with a 92 % chance of a 1-in-20 year event occurring over 50 years. A 20-year event is classified as “likely” by the example EGBC flood risk matrix and given a relatively high likelihood of 4/5 in the RAIT. Based on these two ratings, the 20-year flood is classified as a 4/5 or “likely” for this project. The design flood event has a return period between 50-500 years, classifying it as “unlikely” by the example EGBC flood risk matrix and giving it a relatively low likelihood of 2/5 in the RAIT.

The impact to people of these flood events is primarily displacement, damage experienced, and disruption of daily activities, such as transportation and commercial activities. Approximately 94 and 232 people are displaced from their homes due to the 20-year flood and the design flood, respectively. As flooding on Upper B.X. Creek is relatively predictable and not expected to be a rapid onset event such as a debris flow or a dike breach, it is unlikely to cause death or serious injury. With effective evacuation, it is possible to remove all residents from the path of the floodwater. There is potential for injury amongst responders and locals who remain in the area. In addition to those directly affected, it is likely that hundreds more people will be affected through loss of business, damage to properties, and interruption to routine. As both the high and low likelihood floods are not likely to cause fatalities and any injuries will likely be within local response capacity, both floods are ranked as 1/5 by the RAIT. As characterized by the example EGBC flood risk matrix, minor injuries of few individuals is classified as negligible. The RAIT also classifies displacement based on a percentage of the total population and the duration of displacement. The total population of the Vernon is 48,073 as per the 2016 census. While this assessment is of only the impact related to Upper B.X. Creek, this should be considered together with flooding in related systems. In 20-year flood, 0.2 % of the population is displaced, and in the design flood, 0.5 % of the population is displaced. As per the RAIT, this is classified as a 1/5. The displacement is likely to be one week, which is classified as a 2/5 on the RAIT. Overall, based on these ratings, both the 20-year flood and design flood events are classified as a 1/5 or "low" risk.

The economic impact has been examined through affected utility and transportation infrastructure, buildings, and community facilities. Overlaying utility infrastructure with the flood events shows the design flood typically has a four-fold or greater impact than 20-year flood. The stormwater system is likely sensitive to flooding as there is potential for sewer backups with homes, depending on connection type and backflow valve installation. This can result in costly repairs and risks to human health. The other underground utilities may also be at risk from floodwater, especially the underground hydro transformer and other junction or distribution facilities which are below the waterline. Enhancing infrastructure resiliency helps reduce flood risk, especially by reducing recovery times. The RAIT characterizes impact to utilities in terms of impacts to a percentage of the area's population. As this study only examines a portion of the flood event which will likely affect other areas downstream, it is not a representative portion.

The impact on transportation is likely to be one of the most significant risks associated with these potential floods. Transport throughout this portion of the Vernon will be difficult during a flood as much of the floodwater flows along the roads. This hampers emergency response, property protection, and evacuation. Loss of access while road repairs are made could increase the duration of disruption. The disruption to arterial roads as well as the railway in design flood event would be significant disruptions to access in the area and the wider community.

The 20-year flood is expected to damage 31 buildings, compared to the 168 buildings anticipated to be flooded in the design event. The flood depths and damages are relatively low in both events, especially for buildings farther from the creek. As the flood depths are low and much of the flow happens along roads, it is possible that sandbagging and other temporary flood defense mechanisms may reduce potential damage. There are many buildings which, while they may not experience damage, will be inaccessible. Of particular note are the community facilities identified in Table 7.6. The CoV Works Yard is likely a key facility in flood mitigation efforts and steps to ensure it can function as such during a flood event would help reduce flood risk. Also, the two retirement homes and the daycare which are exposed to flooding in the design event have increased flood risk as evacuation from these facilities will require extra time and resources. While there are other pharmacies in the area, specific plans should be developed to ensure a flood-resilient medication supply chain is accessible, especially to those who may have lower mobility.

Based on the discussed economic impacts, the 20-year flood is estimated to have a high economic consequence as per the example EGBC flood risk matrix including "major asset loss; several weeks business interruption; and <$1 million dollars of damage." The design flood is estimated to have a severe economic consequence with "severe asset loss; several months business interruption; and $1-$10 million dollars of damage."

The environmental impact of the flooding is based on limited information as identified above, including consideration of potential contamination sources and receptors, and habitat. As characterized by the example EGBC matrix, the environmental impact is most likely recoverable within months for both the 20-year and design flood events, corresponding with a "moderate" risk rating.

The cultural impact of the flooding is also based on limited information and no community input. Based on the descriptions provided in the example EGBC flood risk matrix and the documented impact of the flood, the social and cultural impact is likely best characterized as moderate ("recoverable within weeks") for a 20-year event and as high ("recoverable within months") for the design flood event. Community input is needed to refine rating for use in decision-making.

The ratings discussed above are shown for each event on the flood risk matrices in Table 7.8 and Table 7.9.

**Table 7.8 Risk matrix for 20-year flood event.**

| **Likely 20-year flood event** | M | H | H | VH | VH |
|---|---|---|---|---|---|
| **Consequence Categories** | **Negligible** | **Minor** | **Moderate** | **High** | **Severe** |
| People | X | | | | |
| Economy | | | | X | |
| Environment | | | X | | |
| Cultural | | | X | | |

**Table 7.9 Risk matrix for design flood event.**

| **Unlikely design flood event** | VL | L | L | M | H |
|---|---|---|---|---|---|
| **Consequence Categories** | **Negligible** | **Minor** | **Moderate** | **High** | **Severe** |
| People | X | | | | |
| Economy | | | | | X |
| Environment | | | X | | |
| Cultural | | | | X | |

An overall rating combining different consequence categories was not developed as community input on consequence classifications, relative importance, or risk tolerance was not included in this project.

## 7.5 Limitations

Limitations of the flood risk assessment include the following:

- The community was not engaged in the process at the time of writing this report to provide input on receptors or risk rating;
- The receptors were based on a desktop study of data and were not ground-truthed;
- The population is based on 2016 values (the latest Canadian census information available) but changes may have happened in the past 4 years;
- The impact to people is calculated based on dwelling location to reflect potential evacuation needs. In reality, more people use this area and would be impacted by the flood through aspects such as transportation or business disruption;
- Only direct impacts are estimated – impacts due to disruption of business through a flood event and rebuilding process are not estimated;
- Damage estimates are based on damage curves developed for the United States as comparable Canadian curves are not yet available. Construction standards differ in Canada so these damage estimates may not be representative; and
- Building characteristics were assumed for a selection of damage curves, including presence of a basement for all structures. An accurate building inventory could improve damage estimation for buildings.

# 8 FLOOD RISK REDUCTION PLANNING

Flood risk reduction planning is an ongoing, iterative process which requires careful consideration and community input. As presented in Figure 1.2, flood risk reduction is based on information from both a flood hazard and flood risk assessment. Flood risk reduction planning builds on the available information about hazards and valued assets to develop a plan to minimize impact to valued community assets. Table 8.1 outlines examples of structural and non-structural mitigation options that are commonly used in British Columbia.

**Table 8.1 Example of mitigation measures.**

| **Non-Structural**<br>***Reducing Exposure & Vulnerability*** | **Structural**<br>***Reducing Flood Hazard*** |
|---|---|
| • Hazard and risk assessment<br>• Land use planning<br>  o Zoning<br>  o Bylaws<br>  o Relocation or retreat<br>• Public awareness and education<br>• Emergency routing and safe zone delineation<br>• Emergency preparation and planning<br>  o Community flood response plan<br>  o Community preparedness<br>  o Home and business response plan<br>  o Individual preparedness<br>• Monitoring and warning systems<br>• Maintenance | • Barrier to the hazard<br>  o Dikes (new or improved)<br>  o Flood gates<br>• Armouring against hazard<br>  o Riprap banks/dikes<br>  o Spurs and groynes<br>• Conveyance improvements<br>  o Dredging<br>  o Dike set back<br>  o Removing constrictions (culverts, bridges)<br>  o Reducing channel roughness<br>  o Pumps<br>• Flood flow<br>  o Diversion of flow<br>  o Upstream storage<br>  o Infiltration |

There is a variety of both structural and non-structural flood risk reduction options presented in the following section. The risk reduction options presented have been selected and discussed based on the results of the analysis in this area. This discussion is preliminary and does not constitute a comprehensive mitigation plan or recommended options. To plan for and implement the options presented, consideration should be given to the following:

- Community preferences, values, and equity;
- Risk-based prioritization;
- Lifecycle costs of both building and maintaining any measures;
- Return on investment;
- Annualized protection provided, including potential benefits to mitigating high frequency, low magnitude events;

- Potential ecosystem enhancement or negative impacts;
- Other potential co-benefits such as recreation, stormwater attenuation;
- Local groundwater impacts (not examined through this project);
- Climate change and anticipated future land use conditions; and
- Design life of infrastructure to be protected (see Table 8.2 for encounter probabilities based on a range of return periods and design lives).

**Table 8.2 Encounter probabilities for a range of return periods and design life durations.**

| Return periods (years) | Design Life | | | |
|---|---|---|---|---|
| | 25 years | 50 years | 75 years | 100 years |
| **1-in-10** | 93 % | 99 % | 100 % | 100 % |
| **1-in-33** | 53 % | 78 % | 90 % | 95 % |
| **1-in-50** | 40 % | 64 % | 78 % | 87 % |
| **1-in-100** | 22 % | 39 % | 53 % | 63 % |
| **1-in-200** | 12 % | 22 % | 31 % | 39 % |
| **1-in-500** | 5 % | 10 % | 14 % | 18 % |
| **1-in-1000** | 2 % | 5 % | 7 % | 10 % |

## 8.1 Structural Mitigation

Structural mitigation is considered as any specific engineering works that reduce flooding impacts, including dams, dikes, training berms, floodwalls, seawalls, bank protection works, flood retention basins, sediment basins, river diversions, floodways, channel modifications, sediment management, debris barriers, pump stations, and floodboxes (EGBC, 2018a). Site specific structural mitigation measures to reduce flood risk within the community have been developed for Upper B.X. Creek for use as a planning tool by the CoV. Figure 8.1 shows the locations discussed in this section. Further work will be required to prepare conceptual level plans and cost estimates for any suggested works.

The design of structural mitigation needs to include additional modeling that will investigate how mitigation structures will transfer risk and investigate countermeasures for mitigation of the potential transfer. Structural mitigation shall be designed to the applicable local standards and provincial guidelines, and include consideration for operation and maintenance, as they will become the responsibility of the CoV once constructed. For any considered option, land tenure or acquisition should be considered, as there is currently limited space along Upper B.X. Creek.


**Figure 8.1 Suggested structural mitigation options for Upper B.X. Creek.**

### 8.1.1 Sediment and Debris Management Plan

There is a well documented history of sediment transport and the associated flood risk on Upper B.X. Creek; however, there does not appear to be a detailed sediment and debris management plan developed for the CoV. Sediment traps have been installed downstream of Pleasant Valley Road (Photo 8.1) and between the 48th Avenue and 20th Street crossings, and sediment removal was noted at these sites in 2009, 2013 and 2018 (Photo 8.2) (Golder, 2018). Additional undocumented removal efforts may have been carried out by the CoV. Conversations with the CoV has confirmed that there is no formal sediment management plan, and removal efforts are done on an as-needed basis.

**Photo 8.1 Sediment trap downstream of Pleasant Valley Road crossing (NHC, 2019).**

A sediment basin has been recommended in the B.X. Creek Ranch Park since 2009 (FOCUS, 2009; Golder, 2009a), but it was not approved by the RDNO. It is NHC's understanding that the CoV is currently pursuing the design and construction of a basin somewhere along Upper B.X. Creek.

**Photo 8.2 Sediment removal between 48th Avenue and 20th Street crossings (CoV, 2018).**

The 2009 *Upper B.X. Creek Sediment Yield Study* (Golder, 2009a) identified sediment sources and estimated the annual sediment yield for Upper B.X. Creek. However, the scope of the current study did not include detailed reviews of previous studies to determine the suitability for the preparation of sediment and debris management plans. Therefore a detailed geomorphic assessment may need to be carried out to characterize sediment sources and provide potential strategies for mitigation, including but not limited to:

- Stabilizing sediment source(s) in the upper to mid-watershed;
- Sediment traps/basins, including consideration of size and locations; and
- Trash racks and sediment traps/basins at culvert entrances, where possible.

As documented by Golder (2009a), both basins and traps require regular maintenance in order to be effective, and a lack of maintenance can have a large impact on downstream infrastructure. Therefore, a sediment and debris management plan is needed to ensure these structures are maintained and operated as intended. A sediment management plan should include the following:

- The location of all existing and proposed sediment basins and traps;
- Annual maintenance requirements and maintenance triggered by flood events on existing and proposed sediment basins/traps and problematic crossings (Section 8.1.3);

- Inspections on the condition of sediment basins/traps and problematic crossings (Section 8.1.3). Should include the timing of inspections (annual and post-flood events) and a check sheet on what to inspect to ensure reasonable quality control;
- Need for additional sediment basins; and
- Reporting requirements to better document sediment removal efforts to better quantify sediment volumes and removal costs.

As this mitigation approach would cover a greater area of Upper B.X. Creek and requires detailed investigations to suggest locations, it is not included in Figure 8.1.

### 8.1.2 Diking near Pleasant Valley Road

The left bank of Pleasant Valley Road was identified as a potential flood hazard location during modeling and mapping. Although model extents did not result in flow overtopping Pleasant Valley Road during the design flood event, the addition of freeboard in this area did present a potential hazard. As discussed in Section 6.1.2, the addition of freeboard produced depths that were a maximum of 0.4 m above Pleasant Valley Road. The topography to the west of Pleasant Valley Road slopes downward in a southwesterly direction, and therefore the flood extents were trimmed at the road centreline to avoid overly conservative FCLs west of Pleasant Valley Road.

Due to the sediment and debris concerns in Upper B.X. Creek, this reduction in freeboard indicates a potential transfer of flood risk west of Pleasant Valley Road. The crossing at Pleasant Valley Road was not modeled with any blockage and the model estimates that water elevations during the design flood event are within 0.4 m of the top of the culvert. This indicates that a small blockage at this crossing could backwater the upstream channel and increase the flood risk upstream of Pleasant Valley Road.

Structural mitigation in this area would reduce the potential flood risk west of Pleasant Valley Road, but would need to consider the impacts of the existing properties along Upper B.X. Creek. Mitigation options could include raising Pleasant Valley Road to act as a dike, or constructing a permanent dike near the left bank of Upper B.X. Creek. Setback dikes are preferable over riverside dikes; however both could be investigated due to the existing space constraints.

The recommended setback for the left bank through this area is 30 m, as seen in Figure 8.1.

### 8.1.3 Crossing Upgrades

Modeling and mapping show that the two 20$^{th}$ Street crossings and the 48$^{th}$ Avenue crossing are unable to pass either the 200-year flow or the design flood event (refer to Figure 8.1 for crossing locations). The capacity of these crossings are closely related to the amount of sediment infilling present prior to the flood event. This reach of Upper B.X. Creek is heavily influenced by these crossings, as all three crossings are within 220 m of each other and each constricts the natural cross sectional area of the channel. Overbank flooding occurs upstream of each of these crossings, including the private drive crossing between the first 20th Street crossing and the 48th Avenue crossing. This indicates a lack of crossing capacity to maintain flow in the channel.

The hazard map shows the changes in velocities through this reach. A reduction in velocity is seen upstream of the first 20th Street crossing and upstream of the 48th Avenue crossing. This reduction in velocity reduces the shear stress of the channel, which results in sediment deposition at the crossing inlets, further reducing the crossing capacity (Photo 8.3).

**Photo 8.3 Sediment deposited at outlet of 48th Avenue crossing (NHC, 2019).**

NHC did investigate the change in flood extents when these three crossings were completely free of sediment; however, given the amount of sediment transport to the fan, this is considered an unlikely situation.

The current arrangement of this reach is prone to aggradation. Additional work is required to identify possible solutions to increase the channel and crossing capacity, while maintaining sediment transport through this reach. As space is a large constraint in this reach, a possible solution will likely involve clear span bridges (for all crossings including the private drive crossing) and raising roads to increase the channel and crossing capacity. Ultimately, this assessment should accompany the mitigation discussed in Section 8.1.4, as they are closely related.

### 8.1.4 Diking between 20th Street and Deleenheer Road

The left bank of Upper B.X. Creek has been identified as a concern during the 20-year, 200-year and the design flood event. This bank is low in some areas and during the higher flow events, flow is observed leaving and re-entering the channel along this reach. The left bank directly downstream of the second 20th Street crossing (Photo 8.4) and the park upstream of 53rd Avenue have been identified as locations where flow will leave the channel, and during high flow events, it will re-enter the channel from the floodplain between 53rd Avenue and Deleenheer Road. This can be seen from the velocity arrows on the provided hazard map. This reach is defined in Figure 8.1.

**Photo 8.4 Low left bank downstream of second 20th Street crossing (NHC, 2019).**

Given that flow was observed leaving and re-entering the channel through this reach, more detailed modeling of raising the left bank for structural mitigation will need to be investigated to avoid transferring the flood risk further downstream. This assessment may result in small segments of this reach requiring mitigation structures, or alternatively it is possible that the entire reach may require some form of protection. Additionally, the modeling and assessment of the upstream crossings should be investigated along with this reach to ensure that impacts of the upstream improvements will not have a negative impact on this reach.

A 30 m setback is recommended through this reach to provide space for potential diking.

### 8.1.5 Highway 97 Crossing Upgrade

The Highway 97 crossing was identified as being undersized. This crossing is not owned by the CoV, but it has been flagged as an important structure as it provides critical passage into and out of Vernon, and a loss of this access could have a big impact on the CoV's emergency response. The Ministry of Transportation and Infrastructure (BC MoTI) standard for highway crossings is to design to a clear water 200-year flood with a adjustment for climate change and suitable clearance (BC MoTI, 2019). The current modelling indicates that this crossing does not have the capacity to pass this flow. The CoV may want to start conversations with BC MoTI and provide them with information regarding this crossing.

## 8.2 Non-Structural Mitigation

Non-structural mitigation is considered flood protection that does not rely on the use of a dedicated flood protection structure (structural mitigation). The following are non-structural measures that can be considered by the CoV.

### 8.2.1 Land Use Planning

Land use planning can be used to reduce flood risk. A variety of land use planning tools are authorized for flood risk reduction by provincial acts and can be used, including zoning, development permit areas, and bylaws indicating setbacks. Some policies which these measures can be used to implement include:

- Where dikes may be considered in the future, maintaining setbacks of at least 30 m for future dike alignment to preserve right-of-way;
- Limiting density increases through rezoning or developing no-build zones in the highest hazard areas;
- Requiring site-specific flood hazard assessments in the floodplain or identified high hazard areas; and
- Requiring building to the FCL elevation for all developments which require a building permit (e.g. new construction or major renovations) within the floodplain or a designated area. The CoV should consider reviewing existing by-laws to include the FCL requirements for suitable developments.

### 8.2.2 Emergency Response Planning

Pre-planning a response to potential flooding can help ensure an efficient, safe, and effective response. The following are suggestions for the CoV for further emergency response planning.

- Identify key locations to monitor flows to trigger emergency plan actions;
- Pre-plan locations for temporary community flood barriers and culvert blockage clearing during high-water events; and
- Refine evacuation routes and an evacuation plan based on updated flood hazard mapping.

Figure 8.2 is an example of monitoring locations, temporary flood barriers and emergency dredging sites. The CoV should create a formal plan and accompanying map that describes what actions should be carried out at what stage of flooding, along with defined evacuation routes based on the hazard map results. Locations of temporary barriers should be selected by the CoV to best protect their assets; the provided example locations are based on modeling and mapping results and do not consider the protection of specific infrastructure, but rather where flow is observed leaving the channel.


**Figure 8.2 Suggested emergency response planning measures for Upper B.X. Creek.**

### 8.2.3 Flood Risk Education

Ensuring that the local community, including individuals and businesses, are aware of the flood risk helps to empower local community members to undertake flood risk reduction projects. The development of a flood story map to digitally share the flood hazard information with the Vernon community is recommended. This is a helpful medium to share information, and should be used alongside other outreach methods including highlights in community media (social and traditional), public meetings (included as a later phase of this project), and seasonal reminders. As these flood hazard maps are shared, key aspects to share with the community include:

- What areas are exposed to flood risk, including the potential for flooding;
- The likelihood of various floods in easy to understand language (i.e. what is the chance of a 1-in-20 year flood happening in the next five years);
- What aspects of flood risk reduction are an individual's responsibility and/or governmental responsibility;
- Publicly accessible flood forecasting information sources for the CoV;
- What individuals can do to reduce flood risk, such as flood proofing or raising homes, and installing sewer backflow valves;
- What individuals can do to prepare for imminent floods, including sand bagging and preparing for potential evacuation; and
- What the CoV is doing to reduce community flood risk, including next steps for flood mitigation consultation.

### 8.2.4 Recovery Pre-Planning

BC is modernizing their emergency management legislation and practices to include a focus on recovery as a key pillar for emergency management alongside mitigation, preparedness, and response. Consideration of recovery plans and resources in advance of a flood or other hazard event is recommended. Recovery plans can include the identification of:

- Pre-determined roles for city personnel and community volunteers;
- Plans to access designated financial resources;
- Assistance agreements with neighbouring communities;
- Pre-prepared designs of structural mitigation to apply for funding, when available;
- Disposal plans for debris; and
- Identification of contractors to support engineering and construction needs.

The CoV may want to consider pre-planning for recovery from floods and possibly other potential hazards such as wildfires.

## 8.3 Prioritization of Mitigation

The prioritization of flood mitigation within a community should be developed based on the flood hazard, understanding of flood risk, community priorities, and implementation constraints. An understanding of flood hazard as developed in this project is key to planning mitigations effectively through identifying impactful mitigations and evaluating potential effects on flood depths or erosion upstream or downstream from the mitigation. Risk assessments help prioritization as communities may chose to prioritize high risk areas to minimize the impact to vulnerable buildings or populations. Mitigation measures should be selected to align with community priorities, which can include protection of cultural sites and community landmarks, or selecting mitigation designs which complement recreation or habitat uses in an area. Implementation constraints can include lifecycle project costs, co-benefits, potential negative impacts, available land, permitting requirements, and available funding.

Of the above identified structural and non-structural mitigation options, the four that are anticipated to have the largest benefit to the community are identified below. Further investigation into the cost and prioritization of these options will be completed to support the CoV in securing funding and planning mitigation projects.

1. Emergency Flood Response Plan

The recommended highest priority is the development of a Emergency Flood Response Plan that will guide the CoV through the response stage to a potential future flood event. This is a low cost mitigation measure that can be prepared quickly and would provide large benefits to the community. An effective Emergency Flood Response Plan ensures efficient use of resources to minimize flooding.

2. Sediment and Debris Management Plan

The development of a sediment and debris management plan is recommended prior to the design and construction of other structural mitigation options, as it can be used as a tool in the design of other mitigation options. Sediment transport to the fan is identified as a flood hazard for Upper B.X. Creek and the design of structural mitigation should include a detailed understanding of how existing infrastructure (sediment traps/basins) along with their maintenance and operation will impact proposed structural mitigation.

3. Diking between 20th Street and Deleenheer Road

Two structural mitigation options discussed in Section 8.1 are anticipated to reduce the majority of flood risk from Upper B.X. Creek - crossing upgrades and diking between 20th Street and Deleenheer Road (Sections 8.1.3 and 8.1.4). Both options are large capital projects that will include property acquisition and construction of sizable infrastructure; however, the diking along the downstream channel is anticipated to have a lower capital cost. As both options have similar reduction in flood risk, the diking option may be more feasible for the CoV. The design of this mitigation option should assume that the upstream crossing upgrade will be completed in the future, increasing flow and sediment transport to the downstream channel.

4. Crossing Upgrades

The crossing upgrades at the first 20$^{th}$ Street crossing, first 48$^{th}$ Avenue crossing and second 20$^{th}$ Street crossing are considered large capital projects that will likely require raising roads (and associated utilities), construction of large clear span structures that do not constrict the waterway, and possibly property acquisition. The cost of this mitigation option is anticipated to be greater than the downstream diking and have a similar reduction in flood risk. Design of this option should consider sediment transport, suitable clearance at crossings, existing channel constrictions, and channel improvements between crossings.

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# APPENDIX A Background Info and Survey Technical Memo

400-235 1st Ave | Kamloops, BC V2C 3J4 | 250.851.9262 | www.nhcweb.com

nhc
northwest hydraulic consultants

NHC Ref. No. 3005032

17 September 2019

**City of Vernon**
Community Services Building
3001-32 Avenue
Vernon, BC
V1T 2L8

**Attention:** **Trevor Scott, P.Eng.**
Infrastructure Engineer

**Via email:** tscott@vernon.ca

**Re:** **Background Info and Survey Memo – Part 1 Upper B.X. Creek**

Dear Mr. Scott:

The following memo summarises our findings on the background information review and preparation for the channel survey. This memo covers Part 1 of the project which includes upper B.X. Creek and Swan Lake.

# 1 INTRODUCTION

NHC is conducting a study to develop floodplain mapping for the City of Vernon (CoV). The project will develop two hydraulic models, firstly of Upper B.X. Creek and secondly of Lower B.X. Creek and Vernon Creek. The resulting floodplain maps will be used in the future by organizations and other users to support long-term planning activities and flood mitigation programs.

The first task to be completed in this study is the collection, consolidation and review of relevant existing information included in past reports and various spatial data sources. NHC has extensive experience handling very large data sets and well established data management methods. The key data for this study includes:

- Channel bathymetry
- Geometry of bridge openings and culverts
- Floodplain topography
- Hydrometric data.

This memo outlines the data collected and consolidated, as well as the management approach. Any identified data gaps will also be noted.

In addition to data review, this memo also presents survey planning for Part 1 of the project.

# 2 DATA MANAGEMENT APPROACH

## 2.1 Quality Control

NHC is OQM certified under EGBC's Organizational Quality Management (OQM) program and has established a system of quality control procedures that are initiated at the beginning of a project and are utilized throughout the development of the project. The aim of NHC's QC approach is to identify problems early on in order to identify practical and economical solutions and correct defects in finished products.

## 2.2 Data Management

All data will be stored on NHC's server in the North Vancouver office and will be backed up daily. Occasionally, data will be moved to individual workstations as required. Under these circumstances, data will be regularly transferred back to the server environment at the end of each day.

### 2.2.1 Geographic Information Systems

Geographic Information Systems (GIS) provides an ideal means for managing and analyzing spatially referenced project data using the most current and complete datasets. GIS is being used to:

- Compile all the topographic and bathymetric data;
- Develop a Digital Elevation Model (DEM);
- Plan upcoming field surveys;
- Review the spatial distribution of hydrometric data for hydraulic model calibration and validation;
- Assist in hydraulic model development; and
- Generate floodplain map layouts.

All spatial data will be produced using Esri software. All vector data will be provided in zipped shapefiles, and all raster data will be provided in GeoTIFF format, unless otherwise requested. Data will be zipped and provided either as an email attachment or via OwnCloud share site.

### 2.2.2 Datum

CGVD2013 is a new vertical datum for Canada, designed for modern positional instrumentation such as GPS, and is the datum that is gradually being adopted across the country. The vertical datum for all data used for this project will be CGVD2013. As needed conversion of information associated with older datums will be necessary. This conversion will be conducted by using a conversion grid created by NHC by using NRCan's GPS.H tool. The elevations of all converted data will be checked for consistency by checking individual sample points in the online version of the GPS.H tool.

While compiling the various datasets, NHC has noted the datum so that the required datum conversions can be applied.

# 3 DATA COLLECTION

## 3.1 Past Consultant Reports

### 3.1.1 Vernon Master Drainage Plan (Dayton Knight Consultant Engineers, 2001)

The Master Drainage Plan (MDP) presents stormwater management strategies and conceptual plans for the six basins of the CoV. The MDP along with the CoV Stormwater management Policy and Design Manual include design criteria and procedures to be respected by potential developers. The MDP presents an analysis of drainage basin characteristics, climatic patterns, stream flow, land use, water quality, fisheries, water use, snow pack, and known drainage issues. A computer model (Chapter 4) was developed to simulate runoff in response to storm events with 1:5, 1:10, 1:25, 1:100 and 1:200 return periods. A HEC-RAS model was used to calculate water surface profiles in Vernon Creek (results shown in Appendix 11). According to the MDP model, the flow capacity of Vernon Creek and B.X. Creek is insufficient to carry runoff during large storm events. The MDP proposes to use Kalamalka and Swan Lakes as detention basins, as well as two constructed basins. Flows would also be diverted to Okanagan Lake.

The MDP presents characteristics of both B.X. and Vernon Creeks including profiles, crossing locations, geometric characteristics, and bed and bank material (Chapter 3 and Appendix 8). It is mentioned that flooding of B.X. Creek has occurred east of Kin Park and at 25th Avenue.

The flow records stations used in this report are the following:

- 08NM021 Vernon Creek at Vernon 1921-1960
- 08NM160 Vernon Creek near the mouth 1969-1981
- 08NM065 Vernon Creek at outlet of Kalamalka Lake 1927-1990
- 08NM020 B.X. Creek above Vernon Intake 1921-1990
- 08NM123 B.X. Creek below Swan Lake control dam 1959-1978

The following appendices present pertinent information for the current project:

- Appendix 6: Kalamalka Lake monthly Operating plan and outlet structure curves;
- Appendix 7: Known drainage problem locations as provided by the CoV;
- Appendix 8: Detailed inventory of stream crossings;
- Appendix 9: Photographic record and field notes or crossings inventory including dimensions.

The CoV has provided all supporting information related to the Master Drainage Plan including HEC-RAS model files that will be reviewed in detail during hydraulic modelling.

### 3.1.2 BX Creek at Pleasant Valley Road, Hydraulic Assessment (KWL, 2003)

This report looks at proposed works for a culvert crossing at B.X. Creek with Pleasant Valley Road. The culvert consists of an 1800 mm pipe that does not have the necessary capacity to convey the 10-year return flood. Long term it is recommended that the crossing be replaced with a permanent structure that would be able to pass the 200-year return flood. In the meantime, a short term solution is recommended.

This report includes a hydrological analysis of B.X. Creek. Peak flows are estimated using discharge data from WSC gauge 08NM020 (1921-1927 and 1959-1998).

### 3.1.3 Upper BX Creek Drainage Basin Study (MMM, 2008)

This report aims at reviewing and establishing stormwater management improvements for Upper B.X. Creek basin and recommends nine different projects to achieve this goal. This study includes a hydrologic and hydraulic analysis. The hydrology assessment is based on KWL's 2003 study which used Water Survey of Canada (WSC) Gauge No. 08NM020 – B.X. Creek above Vernon Creek. The hydraulic analysis is based on the development of a HEC-RAS model of Upper B.X. Creek between Swan Lake and just upstream of Pleasant Valley Road. The model consists of 40 cross sections and was run for the 50-year, 100-year and 200-year flood events. Appendix 1 of the report presents cross section information such as roughness values and results, as well as information on the Swan Lake control structure. Appendix 8 includes a series of maps where cross section locations are identified.

The HEC-RAS model from this study hasn't been provided at this time.

### 3.1.4 BX Creek Sediment Removal Structure Design (Golder, 2009)

Following the Upper B.X. Creek Drainage Basin study, the CoV undertook certain channel improvements in B.X. Creek in order to manage sediment transport in the creek thus increasing flood conveyance. The work included sediment removal between Deleenheer Road and Highway 97. Discharge estimates for B.X. Creek at Pleasant Valley Road are presented, as well as proposed channel dimensions and characteristics following sediment removal.

### 3.1.5 Swan Lake Dam Engineering Assessment (Ecora, 2016)

This report presents a dam safety engineering assessment of Swan Lake dam that includes a topographical survey of the dam and a simplified dam break analysis as well as flood inundation mapping (see figure 5a to 5f in report). Figure 3.2a presents critical elevations surrounding Swan Lake dam of culverts located on both Upper and Lower B.X. Creek. Figure 3.2b shows a plan view of Swan Lake dam located on Lower B.X. Creek.

### 3.1.6 Swan Lake Dam Operations Plan (Ecora, 2019)

An operation plan for Swan Lake Dam was developed in order to protect recreational fisheries and ensure flood mitigation and domestic and irrigation water needs are filled. This report includes a hydrological analysis based on hydrometric stations 08NM020 (discharge at B.X. Creek above Vernon intake), 08NM125 (level at B.X. Creek above Swan Lake control dam) and 08NM123 (discharge at B.X.

Creek above Swan Lake control dam). Flood frequency analyses were complete for 10 and 100-year return periods. A rule curve for storage and release from the dam was determined. This report presents a series of photographs of culverts on B.X. Creek. Moreover, Appendix A contains survey data of certain culverts on B. X Creek and of Swan Lake dam.

## 3.2 Client information

A series of additional background information was sent by the CoV on September 6th 2019. This information included the following relevant data:

- As-built drawings of stormwater sewers and creek crossings for Lower and Upper B.X. Creeks and Vernon Creek.
- Design reports and drawings of Upper B.X. Creek watershed improvement projects (10 sites) as defined in the drainage basin study conducted by MMM (2008).
- Culvert and bridge inspections
  - 2013 : photographs of various crossings (crossings are identified by addresses or street intersections);
  - 2015: inspection and condition assessment completed by Stantec that includes coordinates, dimensions and ratings of each crossing as well as a photo log;
  - 2017 : list of inspected crossings with comments (crossings are identified by addresses or street intersections and no dimensions are included in inspection reports).
- Supporting files related to the 2001 Master Drainage Plan (AutoCAD, HEC-RAS, etc).
- Photographs of various 2017 and 2018 flooding locations as well as flood damage assessments and some historical media coverage of flooding in the area.
- Survey of 10 cross sections completed in 2019 on Upper B.X. Creek from 58th Avenue near Swan Lake to Star Road dam (pdf file only, vertical datum to be confirmed).
- Stormwater management policies and design manual for the CoV (1999).
- Estimates of sediment volume transported down B.X. Creek after the 2017 and 2018 freshets.

## 3.3 Spatial Data Available

Spatial data has been collected from various federal (GeoGratis), provincial (GeoBC) and local (CoV Open Data) sources. Table 3-1 presents an inventory of all readily available data.

Other data of interest that has not yet been made available consists of the following:

- 2019 LiDAR data – The CoV is in contact with the Okanagan Basin Water Board (OBWB) and expects the updated 2019 LiDAR soon. The LiDAR has been flown and the data is being processed. The CoV and NHC have set up a data sharing agreement to use the OBWB LiDAR for this project.

- 2019 orthophoto data – No information on the status of this data has been communicated to NHC by the CoV. However, NHC expects that the 2019 orthophoto data will be sent following the submission of the 2019 LiDAR data.

- 2016 DEM data from CoV Open Data site – Vertical datum must be confirmed for this data.

- Survey of 10 cross sections on Upper B.X. Creek – Vertical datum must be confirmed for this data.

- Location of key places of interest to be shown and labelled on flood mapping and critical assets for risk assessment.

- Location of water and wastewater treatment facilities.

Finally, after review of publicly accessible data (GeoBC's historic flood mapping layer) and discussion with the CoV no historic flood mapping seems to exist for the area of interest. Moreover, there is no historic flood spatial information such as digitized high water marks.

## Table 3-1: Inventory of readily available spatial data

| Category | Data Type | Location | Date | Description | File Type | Source | Status and Notes | Use Restrictions | Projection, Horizontal Datum, Vertical Datum |
|---|---|---|---|---|---|---|---|---|---|
| Topography | CoV Contours 2016 | City of Vernon (CoV) | Apr-16 | Contour lines and spot heights, data captured Apr-2016 | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N, vertical datum unknown |
| | CoV DEM 2016 | City of Vernon | Apr-16 | DEM breaklines and spot heights, data captured Apr-2016 | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N, vertical datum unknown |
| | 2019 Lidar | Okanagan Basin Water Board | To be confirmed | Data currently being processed. Will be made available by CoV. | To be confirmed | Okanagan Basin Water Board | Not yet available | To be confirmed | To be confirmed |
| Imagery | City of Vernon Ortho 2016 | City of Vernon | | 2016 orthophoto, 10cm resolution | ECW | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon Ortho 2013 | City of Vernon | | 2013 orthophoto, 10cm resolution | ECW | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| Administrative | Municipal Boundary | City of Vernon | 2019 | City of Vernon municipal boundary | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | Municipal Boundaries | Area of interest (AOI) | 2017 | Legally defined municipal boundaries | SHP | GeoBC | Downloaded 2018 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| | Regional Districts | AOI | 2019 | Regional district boundries | SHP | GeoBC | Downloaded 2019 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| | Indian Reserve Boundaries | AOI | 2018 | Indian reserve boundaries | SHP | GeoBC | Downloaded 2018 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| Cartographic/Reference | BCGS 1:5000 Scale Map Grid | AOI | 2019 | BCGS 1:5000 scale map grid | SHP | GeoBC | Updated 2019 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| Cadastral | City of Vernon Parcel Polygons | City of Vernon | 2019 | Parcel polygons | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon Address Points | City of Vernon | 2019 | Address points | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon Water Lines | City of Vernon | 2019 | Water lines | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| Land Use / Land Cover | City of Vernon OCP Landuse | City of Vernon | 2019 | Official Community Plan landuse | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon OCP Development Districts | City of Vernon | 2019 | Official Community Plan development districts | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon Zoning | City of Vernon | 2019 | Zoning | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| Transportation | National Railway Network Railway Lines | AOI | 2013 | National Railway Network railway lines | SHP | GeoGratis - National Railway Network | Downloaded 2014 | Publicly available from GeoGratis | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| | National Railway Network Railway Crossing Points | AOI | 2013 | National Railway Network railway crossing points | SHP | GeoGratis - National Railway Network | Downloaded 2014 | Publicly available from GeoGratis | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| | Digital Road Atlas network | AOI | 2018 | BC Digital Road Atlas network | FGDB | GeoBC | Downloaded 2018 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| | City of Vernon Roads | City of Vernon | 2019 | City of Vernon road centrelines | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| Utilities | City of Vernon culverts | City of Vernon | 2019 | City of Vernon stormwater culverts | SHP | City of Vernon Open Data | Downloaded Sept-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon mains | City of Vernon | 2019 | City of Vernon stormwater mains | SHP | City of Vernon Open Data | Downloaded Sept-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon nodes | City of Vernon | 2019 | City of Vernon stormwater manholes and outfalls | SHP | City of Vernon Open Data | Downloaded Sept-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon treatment structures | City of Vernon | 2019 | City of Vernon stormwater treatment structures | SHP | City of Vernon Open Data | Downloaded Sept-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| Hydrography | City of Vernon Creeks | City of Vernon | 2019 | City of Vernon creek lines | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | City of Vernon Waterbodies | City of Vernon | 2019 | City of Vernon waterbody polygons | SHP | City of Vernon Open Data | Downloaded Aug-2019 | Publicly available from City of Vernon Open Data | NAD_1983_UTM_Zone_11N |
| | Freshwater Atlas Lakes | AOI | Unknown | BC 1:20K Freshwater Atlas Lakes | SHP | GeoBC | Downloaded 2018 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| | Freshwater Atlas Named Streams | AOI | Unknown | BC 1:20K Freshwater Atlas Named Streams | SHP | GeoBC | Downloaded 2018 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| | Freshwater Atlas Streams | AOI | Unknown | BC 1:20K Freshwater Atlas Streams | SHP | GeoBC | Downloaded 2018 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| | Freshwater Atlas Watersheds | AOI | Unknown | BC 1:20K Freshwater Atlas Watersheds | SHP | GeoBC | Downloaded 2018 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| Hydrometric Stations | Water Survey of Canada Hydrometric Stations | AOI | 2017 | Point locations of WSC hydrometric stations, both active and discontinued | SHP | GeoBC | Downloaded 2017 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |
| Places | Placenames | AOI | 2012 | Placename points from BC Gazeteer | SHP | GeoBC | Downloaded 2012 | Publicly available from GeoBC | Reprojected to NAD_1983_CSRS_UTM_Zone_11N |

## 3.4 Previous NHC Reports

NHC is developing flood inundation mapping and flood construction levels for the 7 mainstem lakes on the Okanagan River including Kalamalka and Okanagan Lakes which are of particular interest for the current project (boundary conditions of part 2 hydraulic model). NHC has developed a process-based hydrologic and reservoir operations model using the Raven platform to simulate the natural and regulated portions of the system in order to estimate flows and water levels.

In addition, NHC completed bridge scour evaluations of structures in the Okanagan-Shuswap area in early 2017 which include the following structures located in the current area of interest:

- Structure 07746 Tillicum culvert located on Tillicum Road near intersection with Silver Star Road.
- Structure 09051 East Vernon culvert located on East Vernon Road near intersection with Silver Star Road.
- Structure 06892 Swan Lake culvert located on Highway 97 north of intersection with 27th Street.
- Structure 02396 Vernon Creek culvert number 3 located on Highway 97 south of intersection with 25th Avenue.

# 4 DATA APPLICATION

Following the data collection, the following presents an overview of how collected data will be applied for the project.

## 4.1 Proposed Model Extents

The proposed model extents were defined by the CoV in the project RFP. For Part 1 the model was suggested to extend from Camp Tillicum, on Dixon Dam Road, to Swan Lake, which includes approximately 9.3 km of B.X. Creek. The floodplain maps are to be clipped at the CoV city boundary, however the model was proposed to extend approximately 5.7 km past the boundary. NHC is suggesting that the model extent be reduced to 1 km past the city boundary, which would extend from the city boundary to the weir located near BX Ranch park. The resulting length of B.X. Creek included in the model would 4.0 km. Figure 1 shows the proposed model extents for Parts 1, including the proposed 4.0 km and the original extended length of 9.3 km. Figure 1 also includes the proposed model extents for Part 2 and the CoV boundary.

## 4.2 Channel bathymetry

Other than the survey information sent by the CoV (10 cross sections on Upper B.X. Creek from 58th Avenue to Star Road dam), no channel bathymetry is available for the creeks being modelled. A survey of creek cross sections will be completed in October 2019. Cross section locations have been selected to capture channel changes and hydraulic structures. A total of 70 cross sections have been selected at appropriate locations along the proposed 4.0 km of B.X. Creek.

Figure 2 presents the location of cross sections for the Part 1 survey along Upper B.X. Creek.

This survey will be integrated with 2019 LiDAR data representing floodplain elevations. Overbank data points will be collected in areas where there is clear coverage and consistent elevation to provide checkpoints between field survey and LiDAR data. During survey, identifiable high water marks will be recorded to assist in model calibration and validation.

## 4.3 Floodplain topography

The floodplain topography will be established based on the 2019 LiDAR. It is assumed that this data uses the 2013 Canadian Geodetic Vertical Datum (CGVD 2013), NAD83 (CSRS) UTM Zone 11 North coordinate system and has a horizontal resolution of 1 metre. These assumptions will be confirmed upon receipt of the data. The LiDAR tiles will be converted to GeoTIFF format and assembled as a mosaic dataset to be clipped to the study area.

As mentioned previously, the 2019 LiDAR data is currently being processed by the Okanagan Basin Water Board and will be made available to NHC by the CoV.

## 4.4 Geometry of creek crossings

Creek crossing locations have been identified through a visual review of CoV's 2016 orthoimagery (see Figure 2). Initial assessment totals 16 crossings for Part 1 (Upper B.X. Creek). This number will be revised during survey if needed. As-built drawings and information (dimensions, materials, condition) from inspection reports (see section 3.2) will be imported into a shapefile and made available to surveyors to be verified in the field. Any crossings that lack existing data will be surveyed in the field.

## 4.5 Roughness values

### 4.5.1 Channel roughness

Initial estimates of channel roughness will be made using standard hydraulic engineering formulae for hydraulically rough turbulent flow that relate roughness to the water depth and size of sediment in the channel. During survey, channel texture and substrate size observations will be recorded and used as initial estimates for hydraulic modelling. These initial values will be modified later during the model development and calibration phases.

### 4.5.2 Floodplain roughness

Values of floodplain roughness depend largely on the type and density of vegetation that is present. Land use mapping found in the Open Data Catalogue from the CoV will be used as a starting point to define land cover and floodplain roughness. Initial floodplain roughness will be reviewed and updated to reflect current conditions where changes are known to have occurred as a result of bank erosion or urban development on the floodplain.

## 4.6 Hydraulic model calibration

### 4.6.1 Hydrometric data

Model calibration and verification will require water level measurements at recording gauging sites or water surface profiles surveyed during specific flood events. To date, no water level surveys have been performed during flood events in the area of interest. Most Water Survey of Canada (WSC) hydrometric stations in the area of interest have been discontinued. Historical data exists for the following hydrometric stations:

- 08NM160 Vernon Creek near the mouth – discharge data available from 1969 to 1999
- 08NM021 Vernon Creek at Vernon – discharge data available from 1921 to 1960
- 08NM123 Lower B.X. Creek below Swan Lake control dam – discharge data available from 1959 to 1978
- 08NM125 Lower B.X. Creek above Swan Lake control dam – water level data available from 1959 to 1979
- 08NM020 Upper B.X. Creek above Vernon Intake – discharge data available from 1921 to 1999

The following two hydrometric stations currently provide real time data in the area of interest:

- 08NM143 Kalamalka Lake at Vernon Pumphouse – water level data
- 08NM065 Vernon Creek at outlet of Kalamalka Lake – water level and discharge data

Figure 1 presents the location of listed hydrometric stations.

In addition to hydrometric gauging stations, reservoir operations will be used to create boundary conditions for the hydraulic model. As mentioned previously, NHC has developed a process-based hydrologic and reservoir operations model for Okanagan, Kalamalka and Swan Lakes that will be used for the current project.

### 4.6.2 Past Flood Events

Water levels recorded during flood events could serve to calibrate the hydraulic model. As mentioned previously however, no high water marks exist for the area of interest. The CoV has provided photographs of flooding for various locations and spatial information will be inferred from this photographic evidence.

It is important to note that during the spring 2017 floods, a LiDAR was flown and orthophotos were produced during the peak of the flood event in the Okanagan Basin. High water marks (HWM) could be then extracted based on the water surface elevation and flood extents in the 2017 data and could be used for hydraulic model calibration.

# 5 IDENTIFIED DATA GAPS

## 5.1 Spatial data and previous reports

As mentioned in Section 3.3, the following information has not yet been made available to NHC by the CoV:

- 2019 LiDAR data
- 2019 orthophoto data
- 2008 HEC-RAS model of upper B.X. Creek prepared by MMM
- Vertical datum of 2016 DEM data from CoV Open Data site
- Vertical datum of 2019 surveyed cross sections on B.X. Creek

## 5.2 Risk assessment

The risk assessment will use information to understand assets at risk of flooding including population, critical infrastructure, community facilities, buildings, environmentally sensitive areas and cultural assets. The risk assessment will use information available publicly through the CoV Open Data Catalogue, the GeoBC Data Catalogue and available through Statistics Canada. In addition to this data, the risk assessment will be improved through access to non-public CoV information including:

- Location of critical assets and community facilities such as schools, medical centres, water and wastewater treatment facilities, etc..
- BC Assessment data in spatial form.
- Emergency routes and EOCs.
- Building footprints.
- Population data that would be more detailed than census data.
- Information on culturally significant or environmentally sensitive areas.
- Location of contaminant storage (facilities which hold toxic materials).

NHC has reached out to the CoV GIS department to see if the above information is available. If this information is unavailable, more general provincial datasets can be substituted in some cases, or more general assumptions made.

# 6 SURVEY PLANNING

The quality of a floodplain map is directly related to the survey data collected to develop the hydraulic model used for mapping the inundation. NHC has survey technicians specialized in surveying of small creeks such as the ones being modelled for the current project. Vernon Creek and B.X. Creek will be primarily surveyed on foot using Trimble RTK GPS. Survey control will be established at the onset of the survey with benchmarks surveyed daily to provide confidence in combining multiple days of survey data. Overbank data points will be collected where there is clear coverage and consistent elevation to provide checkpoints for ensuring consistency between the field survey and the LiDAR data.

Cross sections have been identified by the hydraulic modelling team (see Figure 2). A total of 70 sections have been identified for Part 1 of the survey. Digital mapping of the targeted sections will be uploaded to the survey controller in CAD format to allow the surveyors to accurately collect the desired data.

While surveying the creeks, identifiable high water marks (such as staining or suspended debris) will be surveyed to assist in model calibration. Furthermore, other channel observations will be made, such as channel texture (substrate size), condition of bridges and other constrictions, and condition of existing flood mitigation works to support the subsequent tasks. Existing information on crossings will also be made available to surveyors for verification on the field. Geometry data for crossings will be surveyed only when necessary (missing or erroneous existing information).

The survey is set to start September 30th and Parts 1 and 2 will be completed uninterruptedly. It is expected that the survey will be completed by late October. This timing will provide the most favourable survey conditions, as water levels will be low and the vegetation less dense.

Survey will be collected in UTM coordinates based on the 2013 Canadian Geodetic Vertical Datum (CGVD 2013). The 2019 LiDAR data is most likely also in CGVD 2013, which will be confirmed upon receipt of the data. Past models are likely to be based on CGVD28. The difference in elevation data between these datums can be upwards of 0.60 m in the region. To minimize complications in comparison with historic data, NHC will survey local benchmarks since conversion between the historic and current datum is likely to not be a consistent shift across the study area.

Following data collection, the survey will be processed in AutoCAD Civil3D and then forwarded to the GIS specialist to combine with the LiDAR data.

# 7 CLOSURE

The purpose of this report is to provide an overview of NHC's data management approach, summarize the available data and identify data gaps for CoV Flood Mapping project. The report also presents an overview of survey planning, including cross section location for Part 1 of the survey (Upper B.X. Creek).

NHC is OQM certified under EGBC's OQM program and has established a system of quality control procedures that are initiated at the beginning of a project and are utilized throughout the development of the project. NHC proposes to manage spatial and survey data in GIS.

NHC has suggested an adjustment in the modelling extents which will have an impact on where our surveyors will be focusing their efforts. NHC requests that the CoV provide comment on the proposed survey cross sections immediately so that we can adjust as needed before the survey commences. If the CoV requires that the model be extended further upstream, NHC will adjust the survey cross sections to reflect that.

Overall, the proposed cross sectional survey together with 2019 LiDAR data to be received will result in an adequate representation of Lower and Upper B.X. Creek and Vernon Creek for modelling purposes. Existing data on crossings will be verified, thus completing the main geometric data inputs for the model.

Upon receipt of LiDAR and survey data, NHC expects to move forward with the tasks required to develop the hydraulic model.

We trust this document meets your immediate requirements, however feel free to contact the undersigned by telephone (250.851.9262) or email (mbroswick@nhcweb.com | acuetobergner@lasallenhc.com) with any questions.

Sincerely,

**Northwest Hydraulic Consultants Ltd.**

**Prepared by:**

*Unsigned document by …*

Arian Cueto Bergner, P. Eng.
Project Engineer

**Reviewed by:**

*Unsigned document by …*

Meg Broswick, P. Eng.
Project Manager

ENCLOSURE

Figure 1 – City of Vernon Floodplain Mapping Study Area

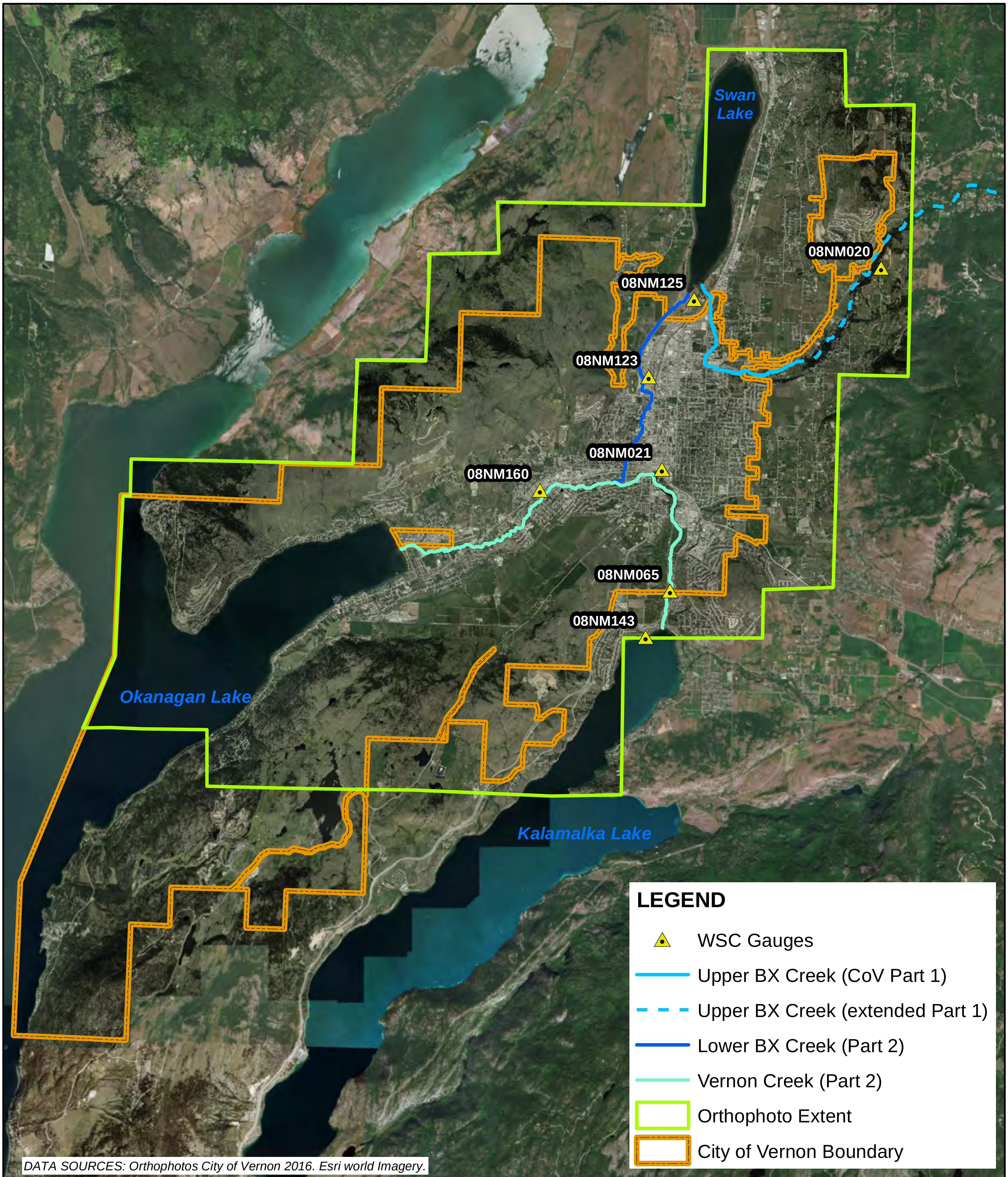
Figure 2 – Vernon Flood Mapping Survey Cross Sections, Upper B.X. Creek, Part 1

cc: Dale Muir, P.Eng. – Principal/NHC (dmuir@nhcweb.com)

## DISCLAIMER

This document has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of **the City of Vernon** for specific application to the **review of background information for the Flood Mapping, Risk Analysis and Mitigation of Upper and Lower B.X. Creek and Vernon Creek**. The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.** best professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation, and was prepared in accordance with generally accepted engineering practices.

Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by **the City of Vernon**, its officers and employees. **Northwest Hydraulic Consultants Ltd.** denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents.




CITY OF Vernon

nhc northwest hydraulic consultants

*SCALE - 1:105,000*

0 1 2 3 4 KM

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*Coordinate System: NAD 1983 UTM ZONE 11N*
*Units: METRES*

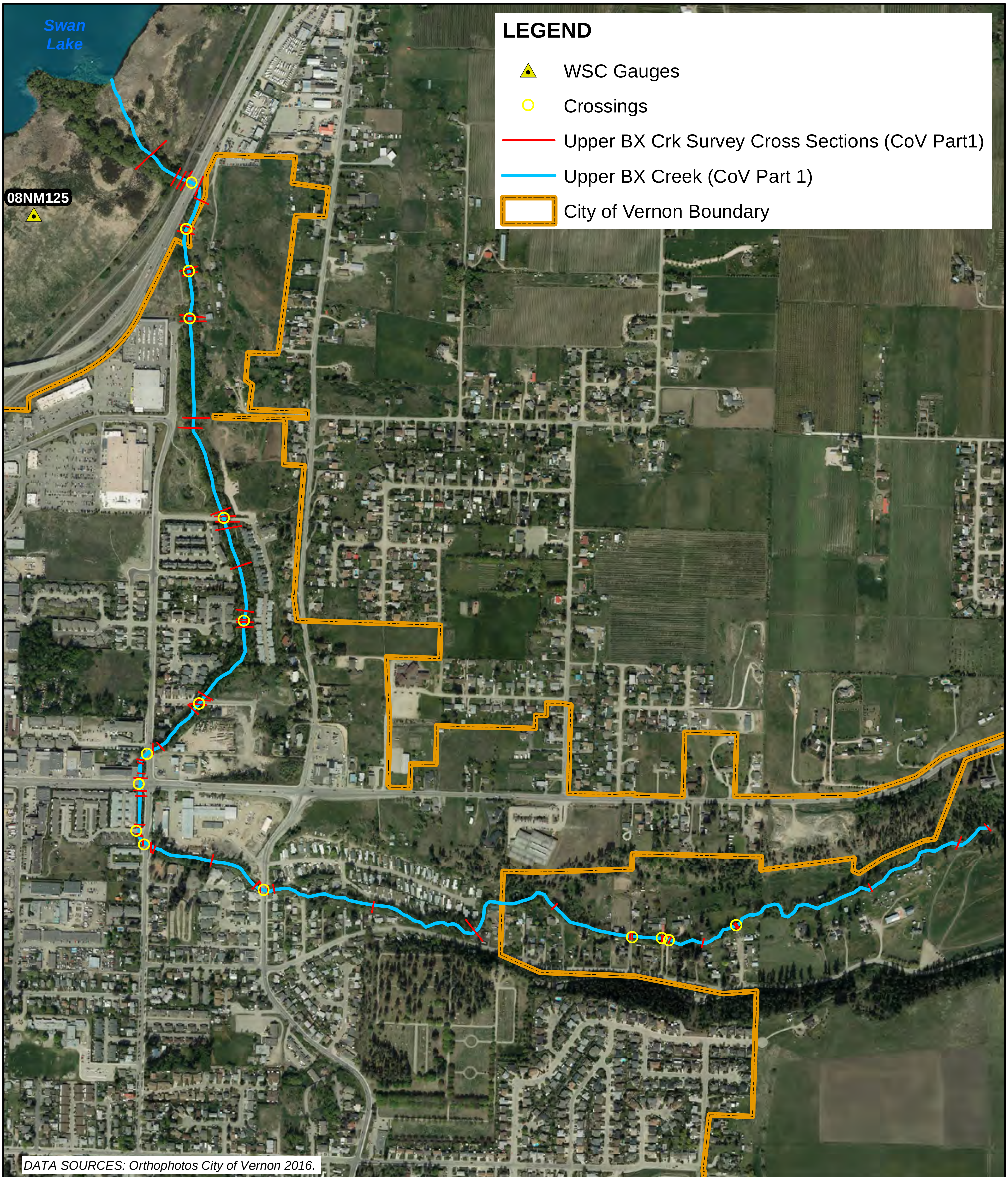
*Job: 3005032* | *Date: 17-SEP-2019*

*CITY OF VERNON FLOODPLAIN MAPPING STUDY AREA REFERENCE MAP*

*FIGURE 1*

RLM, \\mainfile-van\Projects\Active\3005032 Vernon Flood Mapping\95 GIS\3005032_ACB_BackgroundMemoPart1_R01.mxd

Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community




CITY OF Vernon

nhc northwest hydraulic consultants

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Coordinate System: NAD 1983 UTM ZONE 11N
Units: METRES

Job: 3005032 | Date: 17-SEP-2019

# CITY OF VERNON FLOODPLAIN MAPPING UPPER BX CREEK (PART 1) SURVEY CROSS SECTIONS

FIGURE 2

RLM, \\mainfile-van\Projects\Active\3005032 Vernon Flood Mapping\95 GIS\3005032_ACB_SurveyXS_Part1_R01.mxd

Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

# APPENDIX B Crossing Inventory

## CROSSING INVENTORY

| Crossing type | Station | Description | Height (m)* | Width (m)** | Culvert condition during 2019 survey | Culvert condition during 2015 inspection |
|---|---|---|---|---|---|---|
| Bridge | 3403 | Private wooden vehicle bridge | 1.7 | 7.2 | | |
| Culvert | 3236 | CSP arch open bottom Private driveway | 1.86 | 1.69 | 0 m blocked | Not inspected |
| Bridge | 3223 | Private wooden vehicle bridge | 1.9 | 3.5 | | |
| Culvert | 3152 | Box culvert modelled as bridge | 1.6 | 3.6 | 0 m blocked | Not inspected |
| Bridge | 2886 | Wooden bridge with log girders | 1.7 | 4.7 | | |
| Bridge | 2848 | Private wooden vehicle bridge | 2.3 | 7.5 | | |
| Bridge | 2838 | Private wooden vehicle bridge | 2.1 | 6.8 | | |
| Culvert | 2253 | CON SPAN culvert Pleasant Valley Rd. Crossing | 1.6 | 4.55 | 0 m blocked | 0 m blocked |
| Bridge | 1985 | Pedestrian bridge 20th St. Crossing | 2.7 | 17.7 | | |
| Culvert | 1970 | Arch - inlet 20th St. Crossing | 1.66 | 2.55 | 0 m blocked inlet | 0 m blocked inlet |
| Culvert | 1970 | Box culvert - outlet 20th St. Crossing | | | 0 m blocked outlet | 0 m blocked outlet |
| Culvert | 1936 | Box culvert Skyway Village Entrance | 2.42 | 2.42 | 0 m blocked inlet 0.06 m blocked outlet (2.5%) | Not inspected |
| Culvert | 1834 | Box culvert - inlet | 1.6 | 2.4 | 0.858 m blocked inlet (54%) | 0.690 m blocked inlet (43%) |
| Culvert | 1834 | Arc recessed under bridge - outlet 48th Ave. crossing | 1.7 | 2.5 | 0.427 m blocked outlet (25%) | 1.000 m blocked outlet (59%) |
| Culvert | 1764 | Box culvert 20th St. crossing | 2.4 | 3 | 0.357 m blocked inlet (15%) 0.552 m blocked outlet (23%) | 1.300 m blocked inlet (54%) 0.900 m blocked outlet (38%) |
| Bridge | 1602 | 50th Ave. crossing | 1.2 | 14.8 | | |
| Bridge | 1385 | 53rd Ave. crossing | 1.9 | 8.8 | | |
| Bridge | 1248 | Wooden pedestrian bridge 55th Ave. Extension crossing | 1.5 | 38.9 | | |

| Crossing type | Station | Description | Height (m)* | Width (m)** | Culvert condition during 2019 survey | Culvert condition during 2015 inspection |
|---|---|---|---|---|---|---|
| Culvert | 1154 | CON SPAN culvert Deleenheer Rd. Crossing | 1.68 | 7.4 | 0.328 m blocked inlet (20%)<br>0.113 m blocked outlet (7%) | Not inspected |
| Bridge | 930 | 58th Ave. Extension crossing | 1.8 | 14.2 | | |
| Culvert | 601 | CSP culvert under construction<br>20th St. Extension crossing | 3.84 | 6.23 | 0.78 m (as designed) | Not inspected |
| Bridge | 505 | Wooden pedestrian bridge in park | 2 | 10.5 | | |
| Culvert | 388 | Arch culvert<br>Highway 97 crossing | 2 | 3.4 | 0.969 m blocked inlet (48%)<br>0.75 m blocked outlet (38%) | Not inspected |

* Height for bridges measured from channel thalweg to bottom of deck at upstream face.

** Width of bridges measured at bottom of deck at upstream face.

nhc

# APPENDIX C Design Flow Estimation Technical Memo

400-235 1st Ave. | Kamloops, BC V2C 3J4 | 250.851.9262 | www.nhcweb.com

northwest hydraulic consultants ltd

NHC Ref. No. 3005032

14 January 2020

**City of Vernon**
Community Services Building
3001-32 Avenue
Vernon, BC
V1T 2L8

**Attention:** **Trevor Scott, PEng**
Infrastructure Engineer

**Via email:** tscott@vernon.ca

**Re:** **City of Vernon: Detailed Flood Mapping, Risk Analysis and Mitigation**
**Design Flow Estimation - Part 1 Upper B.X. Creek**

Dear Mr. Scott:

This memo contains our hydrologic analysis methods and results for the City of Vernon Part 1 – Upper B.X. Creek Flood Mapping project. The following describes how the design flow estimates for B.X. Creek where developed. Design flows are to be used for the hydraulic modeling of Upper B.X. Creek, above Swan Lake.

# 1 DESIGN FLOWS – B.X. CREEK

Design flows in B.X. Creek have been estimated using flood frequency analysis of Water Survey of Canada (WSC) gauge 08NM020 – B.X. Creek above Vernon Intake (WSC B.X.), located upstream of the model reach. Since WSC B.X. has been inactive since 1998, NHC has extended its record using data from an adjacent gauge, WSC 08NM142 – Coldstream Creek above Municipal Intake (WSC Coldstream). This adjacent gauge has a watershed of similar size and apparently similar vegetation and land use characteristics (Figure 3). A gauge summary is shown in Table 1.

**Table 1 WSC Gauges used in peak flow analysis. QPD = annual maximum daily flows, QPI = annual maximum instantaneous flows.**

| ID | 08NM020 (WSC B.X.) | 08NM142 (WSC Coldstream) |
|---|---|---|
| Name | B.X. Creek above Vernon Intake | Coldstream Creek above Municipal Intake |
| Area (km$^2$) | 53.2 (NHC delineated) | 60.6 (WSC delineated) |
| Reg. Status | Regulated | Unregulated |
| Activation status | Deactivated | Active |
| Annual Peak Flow (QPI) Record | 1977-1998 | 2003-2011 |
| # years QPI | 21 | 9 |
| Annual Max Daily Flow (QPD) Record | 1921-1998 | 1968-2018 (2015 and later is preliminary) |
| # years QPD | 46 | 50 |

Annual peak and maximum daily flows at both gauges occur almost exclusively in spring during the snowmelt freshet. The largest of these are usually enhanced by locally intense rainstorms that occur on top of an already melting snowpack. WSC B.X. experienced an event like this at the end of May 1996: 60 mm of rain fell in two days in the City of Vernon (and presumably more at higher elevation) causing extreme flows that were more than double any other annual peak measured flow at the gauge.

## 1.1 Regulation of flows at B.X. Creek Gauge 08NM020

Flows at WSC B.X. are flagged as regulated by WSC. Research indicates this was likely due to the former Dixon Lake reservoir, which was deactivated in 2000 (Mike Noseworthy, Senior Dam Safety Engineer, BC FLNRORD, pers. communication, November 2019). The location of the former reservoir is shown in yellow on Figure 3. We employed the methods of Moin and Shaw (1985) to assess whether the gauge data at WSC B.X. should be used for design flow estimation.

Moin and Shaw (1985) defined a regulation factor (RF) for determining whether a gauge record from a watershed that contained reservoirs could still be used in standard frequency analysis. The regulation factor is calculated as:

$$RF = \sum_{i=1}^{i=n} \frac{AC_i \times AR_i}{(AG)^2}$$

where *RF* = regulation factor, n = number of dams considered in the watershed, $AC_i$ = the area of the basin controlled by dam *i*, $AR_i$ = the surface area of reservoir *i*. Moin and Shaw define three categories for *RF*. An *RF* less than 0.03 means the gauge record can be used in flood frequency analysis as though it is an unregulated watershed. An *RF* of 0.03 to 0.1 means the gauge is moderately affected, and its flood frequency results should be grouped with gauges that have similar regulation. An RF above 0.1 is considered highly regulated and should be omitted from flood frequency analysis.

Using Google Earth[TM], we estimated the reservoir area (*AR*) of former Dixon Lake as 0.1 $km^2$ and its upstream drainage area (*AC*) as 5.8 $km^2$. This result gives an RF of 0.0002, well below the lowest category threshold of 0.03. Thus, we proceeded with analysis of the WSC B.X. data as though it was an unregulated gauge.

As a second check we calculated the unit mean annual flood ($m^3$/ s/ $km^2$) for both WSC B.X. and WSC Coldstream, and found that it was higher for WSC B.X. which supports the finding that regulation did not significantly impact flood flows on B.X. Creek.

## 1.2 Record extension

To extend the annual peak instantaneous flow (QPI) record for WSC B.X., we used a two step process known as the Maintenance of Variance Extension type 1 (MOVE.1) record extension technique (Hirsch, 1982), available in the United States Geological Survey (USGS) 'smwrStats' package[1] for the statistical programming language 'R' (Hornik, 2016). MOVE.1 is a regression technique which maintains the variance of the initial series in the extended series.

The first step was to extend the annual maximum daily flow (QPD) record for WSC B.X.[2] using the QPD record from WSC Coldstream. The QPD records have a Pearson correlation coefficient of 0.92 (maximum = 1) so are good candidates for extension. We included both approved data (1968-2014) and preliminary data (2015-2018) at WSC Coldstream in the analysis. However, investigation of the preliminary observations for 2018, including field data and rating curves supplied by WSC, indicated a high degree of uncertainty in the peak flow observation for 2018. Additionally, all 2018 preliminary observations were listed as "Estimated" by the WSC. Thus, this observation was only included for a rough estimate of the peak flow during the 2018 event, and was not used in the flood frequency analysis. Testing showed that inclusion/exclusion of this event did not significantly affect the MOVE.1 regression fit.

The extended QPD record for WSC B.X. is shown in Table 3 (Appendix A). A large data gap occurs between 1927 and 1959 since there were no observations from either gauge. The MOVE.1 regression equation is given as:

$$QPD_{BX} = 1.13 \cdot QPD_{Coldstream} + 0.43$$

The second step was to convert the extended WSC B.X. QPD record to a QPI record. Observed QPI and QPD data from the WSC B.X. have a Pearson correlation of 0.98 and hence are excellent candidates for this conversion. The MOVE.1 QPI extension equation for B.X. Creek is given as:

$$QPI_{BX} = 1.37 \cdot QPD_{BX} - 0.57$$

---

[1] https://github.com/USGS-R/smwrStats

[2] There is only a four year period of overlap between QPI records at WSC B.X. ad WSC Coldstream and hence direct extension of the QPI record is not possible.

The resulting 65 year QPI record for WSC B.X. is shown in Figure 1; the full table is shown in Appendix A (Table 3).

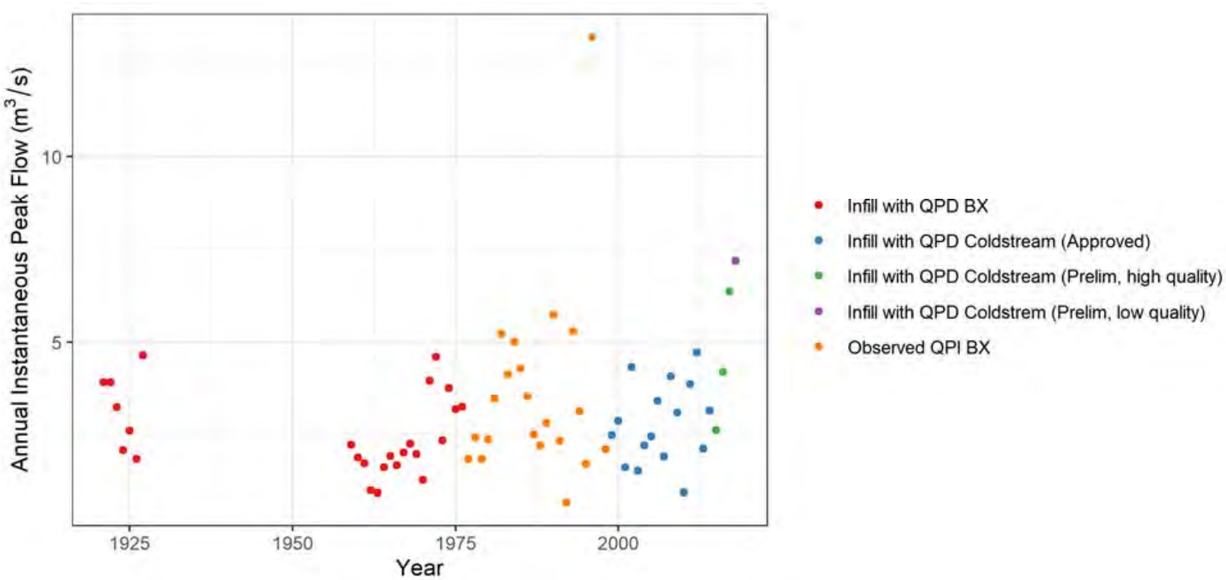



**Figure 1 Extended annual instantaneous peak flow (QPI) record for WSC B.X.**

## 1.3 Frequency Analysis

After record extension, quality checks were performed on the series to determine its suitability for frequency analysis (excluding the low quality 2018 peak flow estimate). First, a non-parametric Mann-Kendall trend test was performed on the record. Results showed no significant trend in the data at the 95% significance level ($\tau = 0.146$, $p = 0.087$).

Second, the Grubbs test for identifying outliers (Grubbs, 1969) was performed for both low and high outliers using the USGS 'smwrStats' R package. Results showed no low outliers ($G = 1.316$, $p = 1$) and one high outlier ($G = 5.651$, $p = 9.66 \times 10^{-10}$), the 1996 event. The USGS recommends removing low outliers from a peak flow series; however, high outliers are typically left in the series with the recognition that they will not necessarily fit well in the extreme value distribution. For design flow estimation, this more conservative approach is usually the most prudent. Thus, we left the 1996 value in the record.

Frequency analysis was performed by fitting the Generalized Extreme Value (GEV) distribution via l-moments in the 'lmomco' package for R[3]. Frequency analysis results are shown in Figure 2. Results show that the 1996 event has a return period above 500 years; estimates of recent peak flows in B.X.

[3] https://cran.r-project.org/web/packages/lmomco/index.html

Creek using Coldstream Creek (Appendix A) give return period flows of approximately 20 years for 2017 and 40 years for 2018.

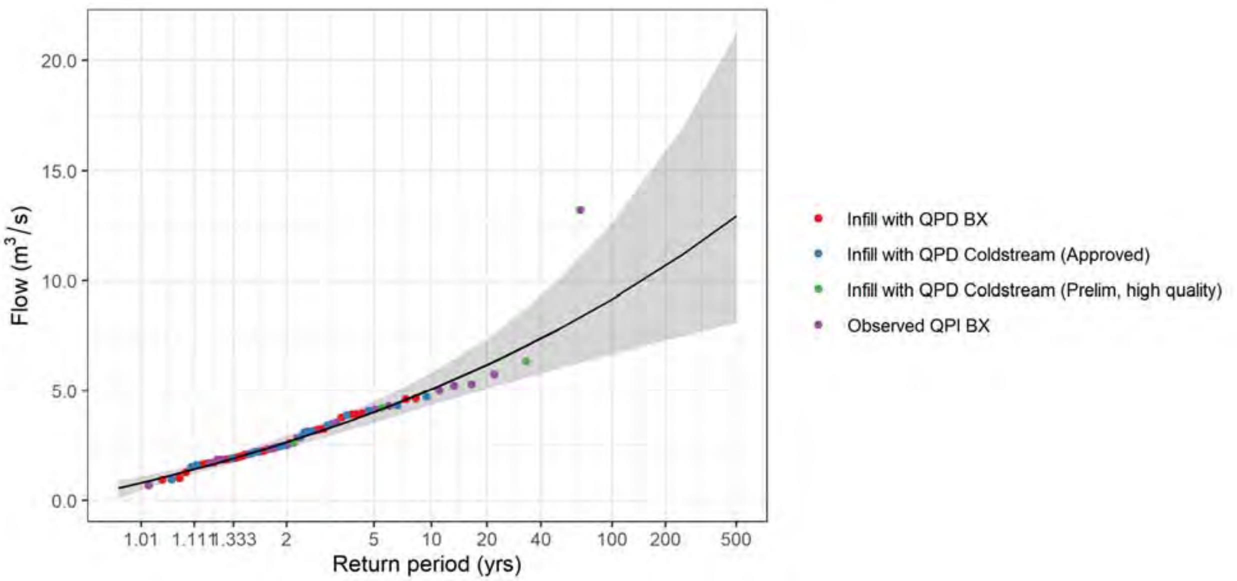



**Figure 2 Frequency analysis results for extended QPI record at WSC B.X., using the GEV distribution. Grey band indicates 90% confidence intervals.**

## 1.4 Design flows

After the frequency analysis was performed, we scaled the results to the upstream end of the study reach (71.5 $km^2$) using exponential, area-based scaling. Eaton et al (2003) recommend a generalized scaling exponent of 0.75 for peak flows in most of British Columbia, in particular snow-dominant interior peak flow areas. Thus we expect that this value is the most appropriate. The scaling equation is given as:

$$QPI_{Ungauged} = QPI_{Gauged}\left(\frac{A_{Ungauged}}{A_{Gauged}}\right)^{0.75}$$

Where $QPI_{ungauged}$ is the design flow (at any return period) needed for the point of interest, $QPI_{gauged}$ is the estimated design flow for the frequency analysis, $A_{ungauged}$ is the watershed area at the point of interest, and $A_{gauged}$ is the watershed area at the gauge location. The scaled design flow results are shown in Table 2. As a conservative approach, we assumed that the Vernon Intake, located downstream of WSC B.X., but above the upstream end of the model reach did not impact peak flows.

**Table 2 Frequency analysis results and design flow estimates for Upper B.X. Creek**

| Return Period | WSC B.X. ($m^3/s$) | Scaled to top of model reach ($m^3/s$) |
|---|---|---|
| 2-yr | 2.6 | 3.3 |
| 5-yr | 4.0 | 5.0 |
| 10-yr | 5.1 | 6.3 |
| 20-yr | 6.2 | 7.7 |
| 50-yr | 7.8 | 9.7 |
| 100-yr | 9.2 | 11.4 |
| 200-yr | 10.7 | 13.3 |
| 500-yr | 12.9 | 16.1 |

## 1.5 Climate change

The impacts of climate change on peak flows on Upper B.X. Creek will be evaluated following the completion of NHC's climate modelling of the full Okanagan basin through work with the Okanagan Basin Water Board (OBWB). This work is in progress at the present time (winter 2020) and expected to be completed March 2020.

# 2 REFERENCES


Eaton, B. C., Church, M., and Ham, D. (2003). Scaling and regionalization of flood flows in British Columbia. *2002*, 16(16), 3245–3263.

Grubbs, F. (1969). Procedures for Detecting Outlying Observations in Samples. *Technometrics*, 11(1), 1–21.

Hirsch, R. M. (1982). A comparison of four streamflow record extension techniques. *Water Resources Research*, 18(4), 1081–1088. doi:10.1029/WR018i004p01081.

Hornik, K. (2016). *The R FAQ*. [online] Available from: www.r-project.org.

Moin, S. M., and Shaw, M. A. (1985). *Regional Flood Frequency Analysis of Ontario Streams: Volume 1 Single Station Analysis and Index Method*. Environment Canada, Ottawa.

# 3 CLOSURE

The purpose of this report is to provide a summary of the hydrologic analysis completed on Upper B.X. Creek for Part 1 of the detailed flood mapping project. The design flows provided in this document have been used as input to the hydraulic model of Upper B.X. Creek, which is currently in the calibration phase.

We trust this document meets your immediate requirements, however feel free to contact the undersigned by telephone (250.851.9262) or email (mbroswick@nhcweb.com | jtrubilowicz@nhcweb.com) with any questions.

Sincerely,

**Northwest Hydraulic Consultants Ltd.**

| **Prepared by:** | **Reviewed by:** |
|---|---|
| *Unsigned document provided by* | *Unsigned document provided by* |
| Joel Trubilowicz, PhD, PEng<br>Project Hydrologist | Meg Broswick, PEng<br>Project Manager |

ENCLOSURE:

Appendix A: Additional Figures and Tables

cc: Dale Muir, P.Eng. – Principal/NHC (dmuir@nhcweb.com)

## DISCLAIMER

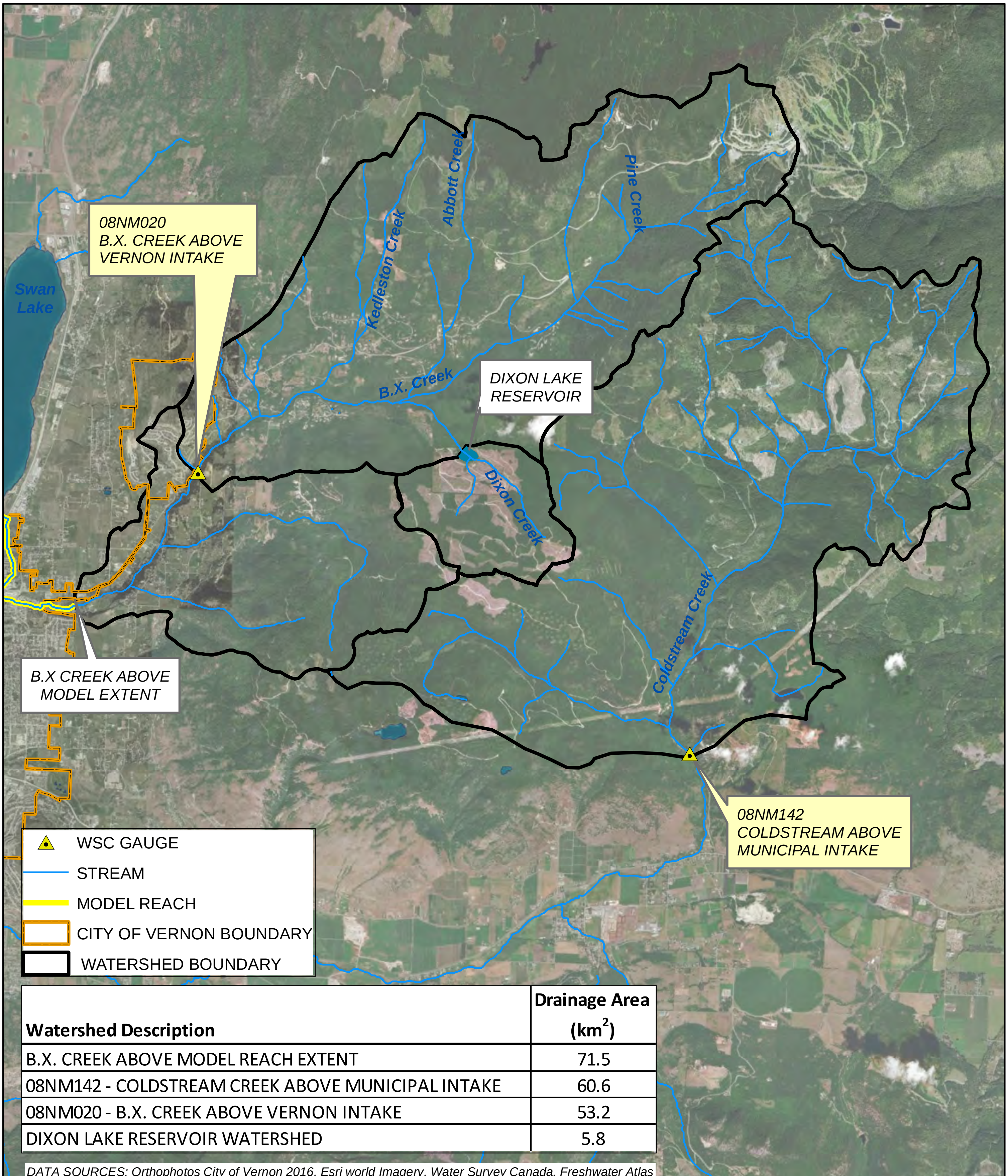
This document has been prepared by Northwest Hydraulic Consultants Ltd. for the benefit of the City of Vernon for specific application to floodplain mapping of B.X. Creek. The information and data contained herein represent Northwest Hydraulic Consultants Ltd. best professional judgment in light of the knowledge and information available to Northwest Hydraulic Consultants Ltd. at the time of preparation, and was prepared in accordance with generally accepted engineering practices.

Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by the City of Vernon, its officers and employees. Northwest Hydraulic Consultants Ltd. denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents.

# APPENDIX A

## Additional Figures and Tables

**Figure 3 Contributing watersheds for design flow estimation of Upper B.X. Creek**




| Watershed Description | Drainage Area ($km^2$) |
|---|---|
| B.X. CREEK ABOVE MODEL REACH EXTENT | 71.5 |
| 08NM142 - COLDSTREAM CREEK ABOVE MUNICIPAL INTAKE | 60.6 |
| 08NM020 - B.X. CREEK ABOVE VERNON INTAKE | 53.2 |
| DIXON LAKE RESERVOIR WATERSHED | 5.8 |

*DATA SOURCES: Orthophotos City of Vernon 2016. Esri world Imagery, Water Survey Canada, Freshwater Atlas*

CITY OF Vernon

nhc
northwest hydraulic consultants

*SCALE - 1:92,000*

0 1 2 4 KM

N

*Coordinate System: NAD 1983 UTM ZONE 11N*
*Units: METRES*

*Job: 3005032* | *Date: 14-JAN-2020*

*CONTRIBUTING WATERSHEDS FOR DESIGN FLOW ESTIMATION OF UPPER B.X. CREEK*

*FIGURE 3*

RLM, \\mainfile-van\Projects\Active\3005032 Vernon Flood Mapping\95 GIS\3005032_RLM_HydrologyMemo_R1.mxd

**Table 3 Extended record for WSC gauge 08NM020 – B.X. Creek above Vernon Intake. Only values shown in bold are direct observations at the gauge.**

| Year | QPD_BX ($m^3/s$) | QPI_BX ($m^3/s$) | Data type |
|---|---|---|---|
| 1921 | **3.3** | 3.9 | Infill with QPD BX |
| 1922 | **3.3** | 3.9 | Infill with QPD BX |
| 1923 | **2.8** | 3.2 | Infill with QPD BX |
| 1924 | **1.9** | 2.1 | Infill with QPD BX |
| 1925 | **2.3** | 2.6 | Infill with QPD BX |
| 1926 | **1.8** | 1.8 | Infill with QPD BX |
| 1927 | **3.8** | 4.6 | Infill with QPD BX |
| 1959 | **2.0** | 2.2 | Infill with QPD BX |
| 1960 | **1.8** | 1.9 | Infill with QPD BX |
| 1961 | **1.7** | 1.7 | Infill with QPD BX |
| 1962 | **1.1** | 1.0 | Infill with QPD BX |
| 1963 | **1.1** | 0.9 | Infill with QPD BX |
| 1964 | **1.6** | 1.6 | Infill with QPD BX |
| 1965 | **1.8** | 1.9 | Infill with QPD BX |
| 1966 | **1.6** | 1.7 | Infill with QPD BX |
| 1967 | **1.9** | 2.0 | Infill with QPD BX |
| 1968 | **2.1** | 2.2 | Infill with QPD BX |
| 1969 | **1.9** | 2.0 | Infill with QPD BX |
| 1970 | **1.3** | 1.3 | Infill with QPD BX |
| 1971 | **3.3** | 3.9 | Infill with QPD BX |
| 1972 | **3.8** | 4.6 | Infill with QPD BX |
| 1973 | **2.1** | 2.3 | Infill with QPD BX |
| 1974 | **3.2** | 3.8 | Infill with QPD BX |
| 1975 | **2.7** | 3.2 | Infill with QPD BX |
| 1976 | **2.8** | 3.2 | Infill with QPD BX |
| 1977 | **1.8** | **1.8** | Observed QPI BX |
| 1978 | **2.2** | **2.4** | Observed QPI BX |
| 1979 | **1.6** | **1.8** | Observed QPI BX |
| 1980 | **2.0** | **2.3** | Observed QPI BX |
| 1981 | **2.7** | **3.5** | Observed QPI BX |
| 1982 | **4.5** | **5.2** | Observed QPI BX |
| 1983 | **3.9** | **4.1** | Observed QPI BX |
| 1984 | **4.6** | **5.0** | Observed QPI BX |
| 1985 | **3.4** | **4.3** | Observed QPI BX |
| 1986 | **3.1** | **3.5** | Observed QPI BX |
| 1987 | **2.3** | **2.5** | Observed QPI BX |
| 1988 | **1.7** | **2.2** | Observed QPI BX |
| 1989 | **2.3** | **2.8** | Observed QPI BX |

| | | | |
|---|---|---|---|
| 1990 | **4.3** | **5.7** | Observed QPI BX |
| 1991 | **2.0** | **2.3** | Observed QPI BX |
| 1992 | **0.6** | **0.7** | Observed QPI BX |
| 1993 | **5.0** | **5.3** | Observed QPI BX |
| 1994 | **3.1** | **3.1** | Observed QPI BX |
| 1995 | **1.5** | **1.7** | Observed QPI BX |
| 1996 | **9.6** | **13.2** | Observed QPI BX |
| 1998 | **2.0** | **2.1** | Observed QPI BX |
| 1999 | 2.2 | 2.5 | Infill with QPD Coldstream (Approved) |
| 2000 | 2.5 | 2.9 | Infill with QPD Coldstream (Approved) |
| 2001 | 1.6 | 1.6 | Infill with QPD Coldstream (Approved) |
| 2002 | 3.6 | 4.3 | Infill with QPD Coldstream (Approved) |
| 2003 | 1.5 | 1.5 | Infill with QPD Coldstream (Approved) |
| 2004 | 2.0 | 2.2 | Infill with QPD Coldstream (Approved) |
| 2005 | 2.2 | 2.4 | Infill with QPD Coldstream (Approved) |
| 2006 | 2.9 | 3.4 | Infill with QPD Coldstream (Approved) |
| 2007 | 1.8 | 1.9 | Infill with QPD Coldstream (Approved) |
| 2008 | 3.4 | 4.1 | Infill with QPD Coldstream (Approved) |
| 2009 | 2.7 | 3.1 | Infill with QPD Coldstream (Approved) |
| 2010 | 1.1 | 0.9 | Infill with QPD Coldstream (Approved) |
| 2011 | 3.2 | 3.9 | Infill with QPD Coldstream (Approved) |
| 2012 | 3.9 | 4.7 | Infill with QPD Coldstream (Approved) |
| 2013 | 2.0 | 2.1 | Infill with QPD Coldstream (Approved) |
| 2014 | 2.7 | 3.1 | Infill with QPD Coldstream (Approved) |
| 2015 | 2.3 | 2.6 | Infill with QPD Coldstream (Prelim, high quality) |
| 2016 | 3.5 | 4.2 | Infill with QPD Coldstream (Prelim, high quality) |
| 2017 | 5.1 | 6.3 | Infill with QPD Coldstream (Prelim, high quality) |
| 2018 | 5.7* | 7.2* | Infill with QPD Coldstrem (Prelim, low quality) |

Notes:

- Values with an asterisk (*) were eliminated from the frequency analysis due to low confidence in the observation.

# APPENDIX D Map Panels

**Notes to Users:**

1. Please refer to **Disclaimer** below.
2. Please review the associated project report before using the floodplain and hazard maps:
   Northwest Hydraulic Consultants Ltd. (NHC). 2020. 'City of Vernon Detailed Flood Mapping, Risk Analysis and Mitigation Part 1 - Upper B.X. Creek'. Report prepared for the City of Vernon (CoV). 2020 August 25. NHC project number 3005032.
3. Map sheet layout shown on this map is consistent for both Floodplain and Hazard maps.
4. Floodplain maps delineate flood construction level (FCL) extents under the design flood event.
   a. The mapped FCLs include a freeboard allowance of 0.6 m added to the calculated flood water elevation. It has been added to account for local variations in water level, debris risk and uncertainty in channel conditions.
   b. FCL is shown on the map as smoothed isolines to create a user-friendly interpretation of FCL. **The upstream most face or point of any structure should be used to determine the structure's FCL. If an FCL isoline runs along this location its value can be taken as the FCL for the structure. If the structure is located between two isolines, the FCL can be either the next upstream isoline (next greatest) or calculated through interpolation by distance between the isoline upstream and downstream of the upstream face or point of the structure.**
5. Floodplain maps include the floodway and flood fringe. Floodway is considered the primary flow path during a flood event. Flood fringe is considered part of the floodplain where depth and velocity are generally low (< 1 m and < 1 m/s).
6. Hazard maps depict the flood depths and velocities during the design event. No freeboard has been added to flood depths. Hazard maps show modeled flood depths and velocities for both 1D and 2D areas. Velocities below 0.05 m/s have been omitted from hazard maps.
   a. Flood depths include a generalized description of the potential consequence. These descriptions are not altered to represent the exposure within the study area, and therefore may not directly be applicable.
7. Underlying hydraulic analysis assumes channel geometry is stationary. Erosion, deposition, degradation, and aggradation are expected to occur and may alter actual observed flood levels and extents. An estimate of obstructions, such as debris jams, at crossings has been made in this analysis. An increased or decreased level of obstruction will result in different flood extents and elevations for the same flow event. Local storm water inflows, temporary diking, drainage, and groundwater may further alter flood extents and elevations from that indicated on the maps.
8. Filtering was used to remove isolated inundation areas smaller than 100 $m^2$. Holes in the inundation extent with areas less than 100 $m^2$ were also removed. Isolated areas larger than 100 $m^2$ were retained for mapping if they were within 40 m of direct inundation.
9. The accuracy of simulated flood levels is limited by the reliability and extent of water level, flow, and climate data. The accuracy of the floodplain extents is limited by the accuracy of the design flood flow, the hydraulic model, and the digital surface representation of local topography. Localized areas above or below the FCL may be generalized by the inundation mapping. Therefore, floodplain maps should be considered an administrative tool that indicates flood elevations and floodplain boundaries for a designated flood. A Qualified Professional is to be consulted for site-specific engineering analysis. Accuracy of the maps may deteriorate with time as hydrology, channel and crossing geometry, and land use changes differ from that assessed.
10. Industry best practices have been followed to generate the floodplain maps. However, actual flood levels and extents may vary from those shown. Residual flood risk beyond that mapped exists for flood events more extreme than the design event. CoV and NHC do not assume any liability for variations of flood levels and extents from that shown.

**Data Sources and References:**

1. The design flood event is based on hydrologic modelling of the Upper B.X. Creek watershed. The design flood event is the instantaneous 1996 flood of record adjusted for end of century (2070-2100, including climate change), which is comparable to an instantaneous 500-year end of century flood event. The downstream boundary condition is the Swan Lake 500-year flood elevation of 390.08 m.
2. The hydraulic response is based on a coupled 1D/2D numerical model developed by NHC using HEC-RAS software, and ArcGIS software for pre and post processing.
3. The digital elevation model (DEM) used to develop the model and mapping is based on mosaiced, bare-earth (no buildings or structures) LiDAR (2018 & 2019, Emergency Management BC (EMBC)), channel survey (2019, NHC), and additional survey data (2019, SEL Survey). Contour lines are derived from the DEM.
4. Orthophoto imagery is from CoV (2016) and Esri (along with other base mapping), National Railway Network railway lines are from Natural Resources Canada, and highways, arterial roads, collector centerlines, and administrative boundaries are from CoV (2019).

**Disclaimer:**

This study has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of **City of Vernon** for specific application to the **Upper B.X. Creek Detailed Flood Mapping, Risk Analysis and Mitigation**. The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.** best professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation and was prepared in accordance with generally accepted engineering practices.
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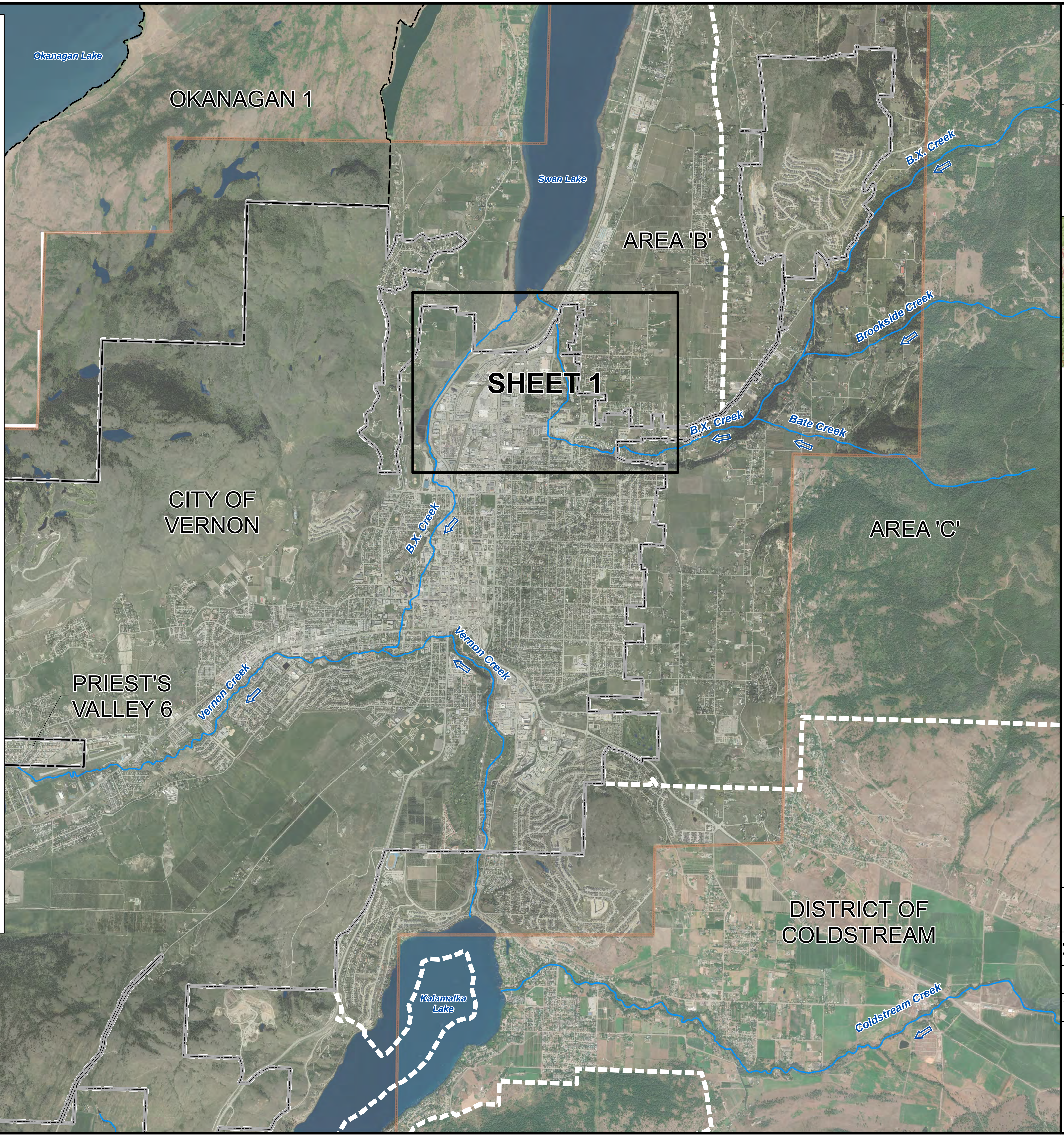
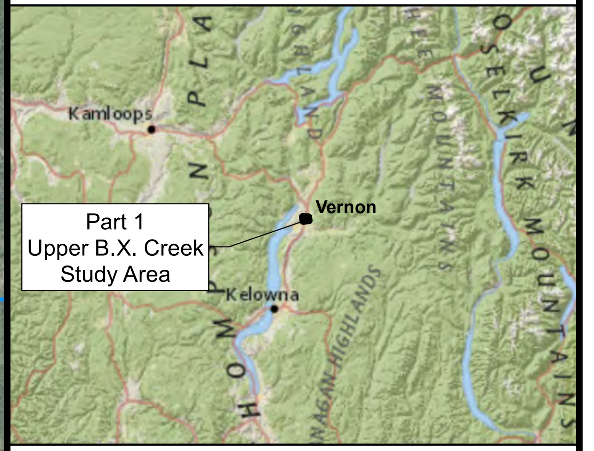



CITY OF Vernon

nhc
northwest hydraulic consultants
30 Gostick Place
North Vancouver, B.C. V7M 3G3
Canada
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com




CITY OF VERNON
FIRST NATIONS RESERVE
REGIONAL DISTRICT OF NORTH OKANAGAN SUB-AREA BOUNDARY
2016 ORTHOPHOTO EXTENT
FLOW DIRECTION
STREAM

SCALE - 1:25,000
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Coordinate System: NAD 1983 CSRS UTM ZONE 11N
Units: METRES; Vertical Datum: CGVD2013

| Engineer | GIS | Reviewer |
| --- | --- | --- |
| ACB | RLM | MB/DPM |

| Job Number | Date |
| --- | --- |
| 3005032 | 19-AUG-2020 |

CITY OF VERNON
FLOOD MAPPING
UPPER B.X. CREEK

SHEET INDEX

CITY OF Vernon
nhc
northwest hydraulic consultants
30 Gostick Place
North Vancouver, B.C. V7M 3G3
Canada
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com
Vernon
Sheet 1 Extent
Upper B.X. Creek
KALAMALKA LAKE
FLOW DIRECTION
CITY OF VERNON
TERRAIN SPOT ELEVATION
Labelled with elevation in metres
MAJOR CONTOUR AT 5 METRE INTERVAL
Labelled with elevation in metres
MINOR CONTOUR AT 1 METRE INTERVAL
STREAM
RAILWAY LINE
ROAD
LIMIT OF MAPPING
FLOOD CONSTRUCTION LEVEL (FCL)
Labelled with FCL in metres
INUNDATION EXTENT -
1996 DESIGN EVENT WITH FREEBOARD
FLOODWAY
15 m top of bank setback
FLOODWAY
30 m left bank and 15 m right bank top of bank setback
FLOOD FRINGE
PLEASE REFER TO NOTES ON SHEET INDEX
SCALE - 1:4,000
0 100 200 M
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Coordinate System: NAD 1983 CSRS UTM ZONE 11N
Units: METRES; Vertical Datum: CGVD2013
Engineer ACB
GIS RLM
Reviewer MB/DPM
Job Number 3005032
Date 21-AUG-2020
CITY OF VERNON
FLOOD MAPPING
UPPER B.X. CREEK
FLOODPLAIN
SHEET 1 OF 1
Swan Lake
Lower B.X. Creek
Upper B.X. Creek
AREA 'B'
AREA 'C'
CITY OF VERNON
VILLAGE GREEN CENTRE
NORTH VERNON PARK
BMX RANGER PARK
CEMETERY
KELOWNA PACIFIC RAILWAY
DELEENHEER RD
I.C.B.C.
A setback of 30 m from the top of bank should be applied to the left bank along this reach. A setback of 15 m should be applied to the right bank.
A setback of 30 m from the top of bank should be applied to the left bank along this reach. A setback of 15 m should be applied to the right bank.
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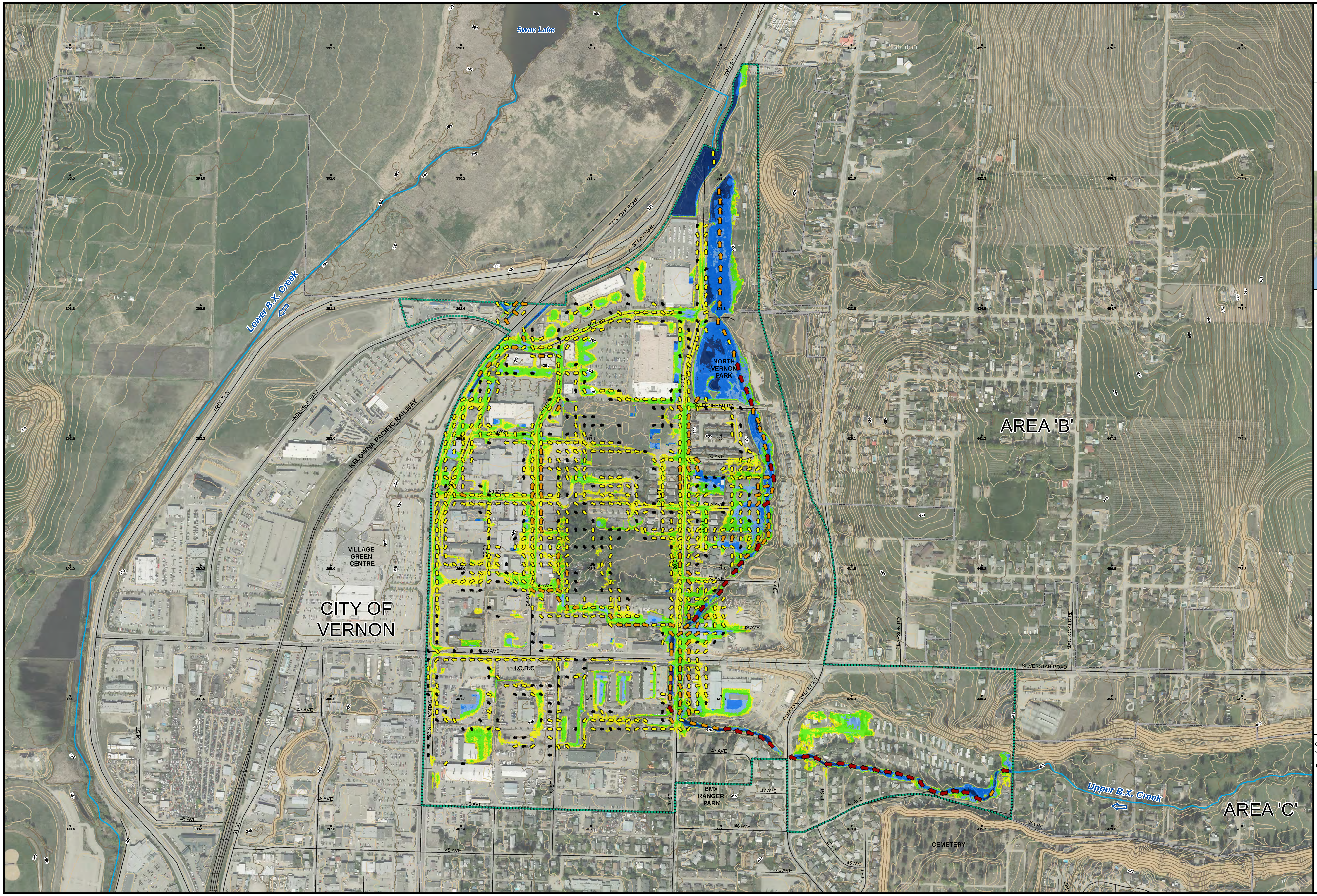


CITY OF Vernon

nhc
northwest hydraulic consultants

30 Gostick Place
North Vancouver, B.C. V7M 3G3
Canada
Office: 604.980.6011
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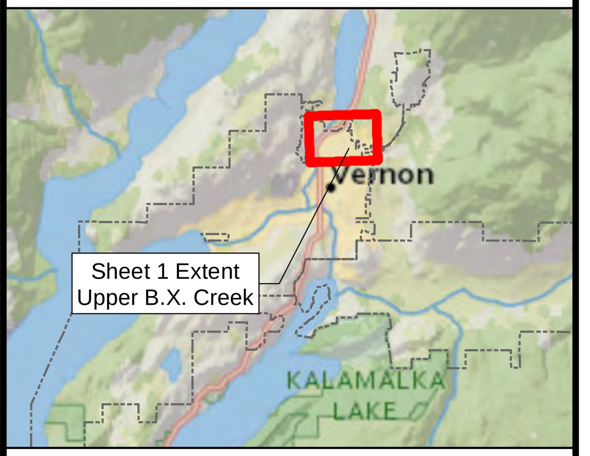


FLOW DIRECTION

CITY OF VERNON

*TERRAIN SPOT ELEVATION*
*Labelled with elevation in metres*

MAJOR CONTOUR AT 5 METRE INTERVAL
*Labelled with elevation in metres*

MINOR CONTOUR AT 1 METRE INTERVAL

STREAM

RAILWAY LINE

ROAD

LIMIT OF MAPPING

VELOCITY AND DEPTH - 1996 DESIGN EVENT WITHOUT FREEBOARD

VELOCITY (m/s)

- 0.05 - 0.1
- 0.1 - 0.5
- 0.5 - 1.5
- 1.5 - 3.5

*Velocities below 0.05 m/s have been removed from the map.*

DEPTH (m)

| | |
|---|---|
| < 0.1 | *Most buildings expected to be dry; underground infrastructure and basements may be flooded.* |
| 0.1 - 0.3 | *Water may enter buildings at grade, but most expected to be dry; walking in moving water or driving is potentially dangerous; underground infrastructure and basements may be flooded.* |
| 0.3 - 0.5 | *Water may enter ground floor of buildings; walking in moving or still water or driving is dangerous; underground infrastructure and basements may be flooded.* |
| 0.5 - 1.0 | *Water on ground floor; underground infrastructure and basements flooded; electricity failed; vehicles are commonly carried off roadways.* |
| 1.0 - 2.0 | *Ground floor flooded; residents and workers evacuate.* |
| > 2.0 | *First floor and often higher levels covered by water; residents and workers evacuate.* |

*PLEASE REFER TO NOTES ON SHEET INDEX*

*SCALE - 1:4,000*

*0 100 200 M*

N

*Coordinate System: NAD 1983 CSRS UTM ZONE 11N*
*Units: METRES; Vertical Datum: CGVD2013*

| *Engineer* | *GIS* | *Reviewer* |
|---|---|---|
| *ACB* | *RLM* | *MB/DPM* |

| *Job Number* | *Date* |
|---|---|
| *3005032* | *21-AUG-2020* |

*CITY OF VERNON*
*FLOOD MAPPING*
*UPPER B.X. CREEK*

*FLOOD HAZARD MAP*
*SHEET 1 OF 1*

apping\95 GIS\3005032_Map_HazardMap4_Landscape.mxd

# APPENDIX E Flood Risk Assessment Detailed Results

# FLOOD RISK ASSESSMENT DETAILED RESULTS

The tables in the following sections outline the stormwater, road, and building infrastructure components affected by the 20-year flood and the design flood (1996 flood of record with an adjustment for climate change).

- Stormwater pipe infrastructure data (Table E1 and Table E2) was obtained from the CoV Open Data Catalogue.
- Road segment data (Table E3 and Table E4) was provided to NHC by the CoV.
- Building data (Table E5 and Table E6) was provided to NHC by the CoV.

## Stormwater

**Table E1 Stormwater pipes inundated in 20-year flood.**

| Pipe ID | Diameter (mm) | Material | Facility ID | Location | Length (m) |
|---|---|---|---|---|---|
| 2983 | 450 | PVC | STMM002983 | 1994 48 Ave | 65.67 |
| 4481 | 250 | PVC | STMM004481 | 1700 55 Ave | 17.88 |
| 4482 | 375 | PVC | STMM004482 | | 34.52 |
| 5234 | 450 | CSP | STMM005234 | 6199 20 St | 12.14 |
| 5239 | 250 | PVC | STMM005239 | 2092 58 Ave | 89.78 |
| 5229 | 250 | PVC | STMM005229 | 1958 Deleenheer Rd | 100.43 |
| 5230 | 450 | PVC | STMM005230 | 5900 20 St | 62.79 |
| 5249 | 1050 | CONC | STMM005249 | 5680 24 St | 49.12 |
| 4483 | 375 | PVC | STMM004483 | | 62.92 |
| 8856 | 1850 | CSP | STMM008856 | 4876 20 St | 32.99 |
| 9233 | 300 | PVC | STMM009233 | 5392 20 St | 25 |
| 9234 | 300 | PVC | STMM009234 | 5502 20 St | 117.14 |
| 9235 | 300 | PVC | STMM009235 | 5402 20 St | 12.52 |
| 5223 | 450 | PVC | STMM005223 | 5714 20 St | 55.33 |
| 5232 | 300 | PVC | STMM005232 | 6198 20 St | 11.02 |
| 5224 | 300 | PVC | STMM009352 | 5596 20 St | 26.82 |

**Table E2 Stormwater pipes inundated in design flood (1996 flood with climate change)[1].**

| Pipe ID | Diameter (mm) | Material | Facility ID | Location | Length (m) |
|---|---|---|---|---|---|
| 2983 | 450 | PVC | STMM002983 | 1994 48 Ave | 65.67 |
| 2978 | 200 | AC | STMM002978 | | 58.15 |
| 2979 | 200 | AC | STMM002979 | | 36.29 |
| 2980 | 250 | AC | STMM002980 | | 59.92 |
| 2981 | 300 | AC | STMM002981 | | 53.22 |
| 2982 | 300 | AC | STMM002982 | | 58.11 |
| 2983 | 450 | PVC | STMM002983 | 1994 48 Ave | 65.67 |
| 2986 | 400 | AC | STMM002986 | 1936 48 Ave | 69.1 |
| 4479 | 300 | PVC | STMM004479 | 1813 55 Ave | 86.22 |
| 4480 | 300 | PVC | STMM004480 | 1704 55 Ave | 40.61 |
| 4481 | 250 | PVC | STMM004481 | 1700 55 Ave | 17.88 |
| 4482 | 375 | PVC | STMM004482 | | 34.52 |
| 4485 | 300 | PVC | STMM004485 | 1929 53 Ave | 35.75 |
| 4487 | 250 | PVC | STMM004487 | 1901 50 Ave | 49.17 |
| 4488 | 250 | PVC | STMM004488 | 1813 50 Ave | 25.25 |
| 4504 | 300 | AC | STMM004504 | 2568 48 Ave | 58.78 |
| 4505 | 350 | AC | STMM004505 | 2646 48 Ave | 56.09 |
| 4506 | 375 | PVC | STMM004506 | 2696 48 Ave | 15.53 |
| 4507 | 525 | CONC | STMM004507 | 4765 27 St | 123.98 |
| 2881 | 600 | AC | STMM002881 | 2355 53 Ave | 55.3 |
| 3853 | 600 | PVC | STMM003853 | | 65.17 |
| 3855 | 600 | PVC | STMM003855 | 2201 53 Ave | 47.86 |
| 3856 | 450 | PVC | STMM003856 | 2173 53 Ave | 1.75 |
| 3857 | 600 | PVC | STMM003857 | | 72.29 |
| 3858 | 600 | PVC | STMM003858 | 2137 53 Ave | 37.43 |
| 3860 | 250 | PVC | STMM003860 | 5350 21 St | 80.13 |
| 1205 | 600 | CMP | STMM001205 | 5247 27 St | 70.42 |
| 1206 | 600 | CMP | STMM001206 | 5145 27 St | 46.07 |
| 1318 | 200 | PVC | STMM001318 | 5434 26 St | 40.21 |
| 1349 | 200 | PVC | STMM001349 | 5404 26 St | 40.24 |
| 1350 | 200 | AC | STMM001350 | 2645 53 Ave | 25.09 |
| 1351 | 200 | AC | STMM001351 | 5268 26 St | 65.02 |
| 1352 | 200 | AC | STMM001352 | 5204 26 St | 40.04 |
| 2825 | 400 | AC | STMM002825 | 5239 24 St | 106.72 |
| 2827 | 900 | CONC | STMM002827 | 2429 58 Ave | 62.98 |

| Pipe ID | Diameter (mm) | Material | Facility ID | Location | Length (m) |
|---|---|---|---|---|---|
| 5227 | 250 | PVC | STMM005227 | 1896 Deleenheer Rd | 43.29 |
| 5226 | 300 | PVC | STMM005226 | 5526 20 St | 83.45 |
| 5225 | 300 | PVC | STMM005225 | 5564 20 St | 99.64 |
| 5234 | 450 | CSP | STMM005234 | 6199 20 St | 12.14 |
| 5239 | 250 | PVC | STMM005239 | 2092 58 Ave | 89.78 |
| 5237 | 750 | CONC | STMM005237 | 2374 58 Ave | 49.69 |
| 5238 | 525 | CONC | STMM005238 | 2292 58 Ave | 83.24 |
| 5231 | 525 | CONC | STMM005231 | 2194 58 Ave | 75.13 |
| 5229 | 250 | PVC | STMM005229 | 1958 Deleenheer Rd | 100.43 |
| 5228 | 600 | CONC | STMM005228 | 2438 58 Ave | 28.11 |
| 5230 | 450 | PVC | STMM005230 | 5900 20 St | 62.79 |
| 5240 | 1050 | CONC | STMM005240 | 2423 58 Ave | 38.8 |
| 5243 | 1200 | CONC | STMM005243 | 2435 58 Ave | 32.68 |
| 5244 | 600 | CONC | STMM005244 | 5675 27 St | 85.43 |
| 5246 | 600 | CONC | STMM005246 | 5645 27 St | 18.5 |
| 5245 | 1200 | CONC | STMM005245 | 5719 27 St | 7.53 |
| 5252 | 300 | PVC | STMM005252 | 2407 55 Ave | 18.91 |
| 5248 | 300 | PVC | STMM005248 | 2535 55 Ave | 63.3 |
| 5253 | 300 | PVC | STMM005253 | 2455 55 Ave | 50.58 |
| 5247 | 1050 | CONC | STMM005247 | 5632 24 St | 56.68 |
| 5249 | 1050 | CONC | STMM005249 | 5680 24 St | 49.12 |
| 5250 | 900 | CONC | STMM005250 | 5562 24 St | 87.79 |
| 5531 | 250 | PVC | STMM005531 | 4938 20 St | 22.25 |
| 5530 | 200 | PVC | STMM005530 | 2216 48 Ave | 25.41 |
| 2771 | 450 | PERMALOC | STMM002771 | 2356 48 Ave | 65.61 |
| 3003 | 450 | CONC | STMM003003 | 4790 23 St | 39.58 |
| 5419 | 450 | PVC | STMM005419 | 2272 48 Ave | 69.32 |
| 5549 | 300 | PVC | STMM005549 | 2178 48 Ave | 96.75 |
| 3859 | 375 | PVC | STMM003859 | 5248 21 St | 58.86 |
| 2878 | 300 | AC | STMM002878 | 2515 53 Ave | 48.09 |
| 2882 | 600 | AC | STMM002882 | 2445 53 Ave | 98.46 |
| 5241 | 1050 | CONC | STMM005241 | 2406 58 Ave | 45.33 |
| 2958 | 900 | CONC | STMM002958 | 5713 27 St | 18.5 |
| 4486 | 375 | PVC | STMM004486 | 5235 19 St | 62.08 |
| 1202 | 600 | CMP | STMM008106 | 5353 27 St | 89.15 |
| 4003 | 300 | PVC | STMM004003 | 5336 20 St | 95.95 |

| Pipe ID | Diameter (mm) | Material | Facility ID | Location | Length (m) |
|---|---|---|---|---|---|
| 6272 | 250 | PVC | STMM006272 | 5282 20 St | 49.74 |
| 4483 | 375 | PVC | STMM004483 | | 62.92 |
| 4484 | 375 | PVC | STMM004484 | 1853 53 Ave | 59.31 |
| 1204 | 600 | PVC-RIB | STMM001204 | 5493 27 St | 111.59 |
| 8640 | 600 | PVC-RIB | STMM008640 | 5592 26 St | 41.04 |
| 4502 | 600 | CMP | STMM004502 | 4865 27 St | 111.01 |
| 1207 | 600 | CMP | STMM008706 | 4985 27 St | 55.52 |
| 1207 | 600 | CMP | STMM008710 | 5033 27 St | 83.07 |
| 8764 | 250 | PVC | STMM008764 | | 16.5 |
| 4014 | 350 | PVC | STMM004014 | | 27.5 |
| 8856 | 1850 | CSP | STMM008856 | 4876 20 St | 32.99 |
| 8857 | 2400 | CONC | STMM008857 | 4741 20 St | 21.8 |
| 9233 | 300 | PVC | STMM009233 | 5392 20 St | 25 |
| 9234 | 300 | PVC | STMM009234 | 5502 20 St | 117.14 |
| 9235 | 300 | PVC | STMM009235 | 5402 20 St | 12.52 |
| 2830 | 750 | CONC | STMM002830 | 5397 24 St | 124 |
| 9236 | 750 | CONC | STMM009236 | 5499 24 St | 19.12 |
| 5223 | 450 | PVC | STMM005223 | 5714 20 St | 55.33 |
| 5242 | 450 | PVC | STMM005242 | 6110 20 St | 69.38 |
| 5232 | 300 | PVC | STMM005232 | 6198 20 St | 11.02 |
| 5222 | 450 | CSP | STMM005222 | 6199 20 St | 18.92 |
| 2826 | 400 | AC | STMM002826 | 5073 24 St | 103.43 |
| 5403 | 250 | PVC | STMM005403 | 2366 50 Ave | 31.56 |
| 5483 | 250 | PVC | STMM005483 | 4964 24 St | 60.51 |
| 9292 | 300 | PVC | STMM009292 | | 27.13 |
| 2772 | 450 | PERMALOC | STMM002772 | 2446 48 Ave | 70.23 |
| 2593 | 200 | AC | STMM002593 | | 54.26 |
| 5224 | 300 | PVC | STMM005224 | 5596 20 St | 23.24 |
| 5224 | 300 | PVC | STMM009352 | 5596 20 St | 26.82 |
| 2829 | 900 | CONC | STMM002829 | 5536 24 St | 26.12 |

## Roads

**Table E3 Road segments overtopped in 20-year flood.**

| Object ID | Max Flood Depth (m) | Mean Flood Depth (m) | Section ID | Road Name | From Street | To Street | Road Function Class | Bus Route | Number of Lanes | Facility ID | Road Width (m) | Road Segment Length (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.17 | 0.05 | 8540 | 24 ST | 55 AVE | 58 AVE | LOCAL | | 2 | TRDS008540 | 11.5 | 535.4 |
| 2 | 0.14 | 0.04 | 8550 | 58 AVE | 27 ST | 24 ST | COLLECTOR | BUS | 2 | TRDS008550 | 16.0 | 370.3 |
| 6 | 0.05 | 0.02 | 55918 | 21 ST | 53 AVE (N) | 55 AVE | LOCAL | | 2 | TRDS055918 | 8.9 | 112.0 |
| 7 | 0.26 | 0.11 | 56002 | ROUNDABOUT | 20 ST | 58 AVE | COLLECTOR | | 1 | TRDS056002 | 7.0 | 90.3 |
| 8 | 0.26 | 0.09 | 56003 | ROUNDABOUT | 58 AVE | 20 ST | COLLECTOR | | 1 | TRDS056003 | 7.0 | 78.7 |
| 9 | 0.25 | 0.09 | 56004 | ROUNDABOUT | 20 ST | 58 AVE | COLLECTOR | | 1 | TRDS056004 | 7.0 | 86.5 |
| 10 | 0.04 | 0.02 | 56005 | ROUNDABOUT | 58 AVE | 20 ST | COLLECTOR | | 1 | TRDS056005 | 7.0 | 94.3 |
| 11 | 0.26 | 0.03 | 6930 | 48 AVE | 20 ST | PLEASANT VALLEY RD | ARTERIAL | BUS | 3 | TRDS006930 | 19.2 | 790.6 |
| 12 | 1.88 | 0.14 | 6920 | 48 AVE | 23 ST | 20 ST | ARTERIAL | BUS | 4 | TRDS006920 | 19.0 | 671.9 |
| 13 | 0.60 | 0.07 | 7300 | DELEENHEER RD | 20 ST | CUL DE SAC | LOCAL | | 2 | TRDS007300 | 7.9 | 463.8 |
| 15 | 0.40 | 0.07 | 8520 | 55 AVE | 20 ST | CUL DE SAC | LOCAL | | 2 | TRDS008520 | 9.8 | 406.1 |
| 16 | 0.24 | 0.09 | 2090 | 24 ST | 53 AVE | 55 AVE | LOCAL | | 2 | TRDS002090 | 12.0 | 362.1 |
| 17 | 0.17 | 0.07 | 6960 | 55 AVE | 26 ST | 24 ST | LOCAL | | 2 | TRDS006960 | 11.5 | 376.4 |
| 23 | 0.01 | 0.00 | 6870 | 46 AVE | 1509 BX RD | 1257 BX RD | COLLECTOR | | 2 | TRDS006870 | 8.5 | 594.7 |
| 24 | 0.95 | 0.55 | 930 | 17 ST | 46 AVE | EOP (N) | LOCAL | | 2 | TRDS000930 | 7.0 | 305.1 |
| 25 | 0.09 | 0.03 | 8470 | 50 AVE | 20 ST | EOP (E) | LOCAL | | 2 | TRDS008470 | 7.5 | 254.8 |
| 28 | 0.77 | 0.10 | 1437 | 20 ST | 48 AVE | 49 AVE | COLLECTOR | BUS | 2 | TRDS001437 | 12.7 | 223.9 |
| 29 | 0.93 | 0.17 | 50870 | 49 AVE | 20 ST | EOP (E) | LOCAL | | 2 | TRDS050870 | 5.0 | 395.9 |
| 30 | 0.98 | 0.64 | 52930 | LANE W OF 17 ST (N OF 46 AVE) | 46 AVE | EOP (N) | LANE | | 1 | TRDS052930 | 3.5 | 360.4 |

| Object ID | Max Flood Depth (m) | Mean Flood Depth (m) | Section ID | Road Name | From Street | To Street | Road Function Class | Bus Route | Number of Lanes | Facility ID | Road Width (m) | Road Segment Length (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 0.47 | 0.22 | 52940 | LANE E OF 17 ST (N OF 46 AVE) | 46 AVE | EOP (N) | LANE | | 1 | TRDS052940 | 3.5 | 262.5 |
| 33 | 0.21 | 0.04 | 1441 | 20 ST | 49 AVE | 50 AVE | COLLECTOR | BUS | 2 | TRDS001441 | 11.4 | 297.2 |
| 34 | 0.10 | 0.03 | 1442 | 20 ST | 50 AVE | 53 AVE | COLLECTOR | BUS | 2 | TRDS001442 | 11.3 | 402.9 |
| 35 | 0.12 | 0.03 | 1443 | 20 ST | 53 AVE | 55 AVE | COLLECTOR | BUS | 2 | TRDS001443 | 13.8 | 312.6 |
| 41 | 0.65 | 0.24 | 53060 | SROW NE FROM 53 AVE | | | SROW | | 0 | TRDS053060 | 5.0 | 268.9 |
| 42 | 0.65 | 0.19 | 53070 | SROW E FROM 55 AVE | | | SROW | | 0 | TRDS053070 | 5.0 | 278.8 |
| 43 | 1.48 | 0.66 | 53100 | SROW FROM 20 ST W TO HWY | 20 ST | | SROW | | 0 | TRDS053100 | 5.0 | 283.9 |
| 45 | 0.12 | 0.04 | 1444 | 20 ST | 55 AVE | DELEENHEER RD | COLLECTOR | BUS | 2 | TRDS001444 | 8.5 | 291.6 |
| 47 | 0.30 | 0.11 | 8491 | 53 AVE | 19 ST | CUL DE SAC | LOCAL | | 2 | TRDS008491 | 13.5 | 210.4 |
| 60 | 0.22 | 0.03 | 55444 | 20 ST | 47 AVE | 48 AVE | COLLECTOR | | 2 | TRDS055444 | 9.1 | 486.1 |
| 62 | 1.63 | 1.37 | 55698 | PED BRIDGE XING | | | SROW | | 0 | TRDS055698 | 5.0 | 69.1 |
| 64 | 0.15 | 0.04 | 55909 | 55 AVE | 20 ST | 21 ST | LOCAL | | 2 | TRDS055909 | 8.9 | 155.6 |
| 66 | 0.47 | 0.16 | 8560 | 58 AVE | 24 ST | 20 ST | COLLECTOR | BUS | 2 | TRDS008560 | 11.5 | 724.5 |
| 67 | 0.25 | 0.06 | 1445 | 20 ST | DELEENHEER RD | 58 AVE | COLLECTOR | BUS | 2 | TRDS001445 | 10.0 | 467.0 |
| 68 | 1.70 | 0.81 | 53090 | 20 ST | 58 AVE | EOP | COLLECTOR | | 2 | TRDS053090 | 6.0 | 774.9 |
| 69 | 0.58 | 0.40 | 55926 | 58 AVE | CUL DE SAC | 20 ST | LOCAL | | 2 | TRDS055926 | 7.3 | 173.0 |

**Table E4 Road segments overtopped in design flood (1996 flood with climate change).**

| Object ID | Max Flood Depth (m) | Mean Flood Depth (m) | Section ID | Road Name | From Street | To Street | Road Function Class | Bus Route | Number of Lanes | Facility ID | Road Width (m) | Road Segment Length (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.40 | 0.13 | 8540 | 24 ST | 55 AVE | 58 AVE | LOCAL | | 2 | TRDS008540 | 11.5 | 535.4 |
| 2 | 0.52 | 0.15 | 8550 | 58 AVE | 27 ST | 24 ST | COLLECTOR | BUS | 2 | TRDS008550 | 16.0 | 370.3 |
| 3 | 0.16 | 0.04 | 6910 | 48 AVE | 24 ST | 23 ST | ARTERIAL | BUS | 4 | TRDS006910 | 19.5 | 252.9 |
| 4 | 0.29 | 0.08 | 6953 | 53 AVE | 27 ST | 26 ST | LOCAL | | 2 | TRDS006953 | 15.0 | 176.8 |
| 5 | 0.20 | 0.07 | 2575 | 26 ST | 53 AVE | EOP (N) | LOCAL | | 2 | TRDS002575 | 9.0 | 88.0 |
| 6 | 0.18 | 0.05 | 55918 | 21 ST | 53 AVE (N) | 55 AVE | LOCAL | | 2 | TRDS055918 | 8.9 | 112.0 |
| 7 | 0.40 | 0.16 | 56002 | ROUNDABOUT | 20 ST | 58 AVE | COLLECTOR | | 1 | TRDS056002 | 7.0 | 90.3 |
| 8 | 0.39 | 0.15 | 56003 | ROUNDABOUT | 58 AVE | 20 ST | COLLECTOR | | 1 | TRDS056003 | 7.0 | 78.7 |
| 9 | 0.42 | 0.13 | 56004 | ROUNDABOUT | 20 ST | 58 AVE | COLLECTOR | | 1 | TRDS056004 | 7.0 | 86.5 |
| 10 | 0.17 | 0.06 | 56005 | ROUNDABOUT | 58 AVE | 20 ST | COLLECTOR | | 1 | TRDS056005 | 7.0 | 94.3 |
| 11 | 1.01 | 0.14 | 6930 | 48 AVE | 20 ST | PLEASANT VALLEY RD | ARTERIAL | BUS | 3 | TRDS006930 | 19.2 | 790.6 |
| 12 | 2.28 | 0.17 | 6920 | 48 AVE | 23 ST | 20 ST | ARTERIAL | BUS | 4 | TRDS006920 | 19.0 | 671.9 |
| 13 | 1.20 | 0.13 | 7300 | DELEENHEER RD | 20 ST | CUL DE SAC | LOCAL | | 2 | TRDS007300 | 7.9 | 463.8 |
| 14 | 0.29 | 0.12 | 8500 | 19 ST | CUL DE SAC | 53 AVE | LOCAL | | 2 | TRDS008500 | 11.6 | 249.3 |
| 15 | 0.68 | 0.09 | 8520 | 55 AVE | 20 ST | CUL DE SAC | LOCAL | | 2 | TRDS008520 | 9.8 | 406.1 |
| 16 | 0.48 | 0.09 | 2090 | 24 ST | 53 AVE | 55 AVE | LOCAL | | 2 | TRDS002090 | 12.0 | 362.1 |
| 17 | 0.43 | 0.14 | 6960 | 55 AVE | 26 ST | 24 ST | LOCAL | | 2 | TRDS006960 | 11.5 | 376.4 |
| 18 | 0.22 | 0.06 | 8530 | 53 AVE | 24 ST | CUL DE SAC | LOCAL | | 2 | TRDS008530 | 16.3 | 234.5 |
| 19 | 0.33 | 0.12 | 6940 | 50 AVE | 24 ST | EOP | LOCAL | | 2 | TRDS006940 | 12.0 | 187.6 |
| 20 | 0.33 | 0.08 | 2080 | 24 ST | 50 AVE | 53 AVE | LOCAL | | 2 | TRDS002080 | 12.0 | 487.9 |
| 21 | 0.55 | 0.11 | 2070 | 24 ST | 48 AVE | 50 AVE | LOCAL | | 2 | TRDS002070 | 11.5 | 386.1 |
| 22 | 0.27 | 0.07 | 2560 | 26 ST | 50 AVE (APPROX) | 53 AVE | LOCAL | | 2 | TRDS002560 | 9.5 | 444.9 |
| 23 | 0.94 | 0.47 | 6870 | 46 AVE | 1509 BX RD | 1257 BX RD | COLLECTOR | | 2 | TRDS006870 | 8.5 | 594.7 |
| 24 | 1.79 | 0.40 | 930 | 17 ST | 46 AVE | EOP (N) | LOCAL | | 2 | TRDS000930 | 7.0 | 305.1 |

| Object ID | Max Flood Depth (m) | Mean Flood Depth (m) | Section ID | Road Name | From Street | To Street | Road Function Class | Bus Route | Number of Lanes | Facility ID | Road Width (m) | Road Segment Length (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 0.26 | 0.10 | 8470 | 50 AVE | 20 ST | EOP (E) | LOCAL | | 2 | TRDS008470 | 7.5 | 254.8 |
| 26 | 0.14 | 0.04 | 1920 | 23 ST | 46 AVE | 48 AVE | LOCAL | BUS | 2 | TRDS001920 | 8.5 | 758.7 |
| 27 | 0.19 | 0.05 | 2910 | 27 ST | 46 AVE | 48 AVE | ARTERIAL | | 4 | TRDS002910 | 19.5 | 833.0 |
| 28 | 1.55 | 0.26 | 1437 | 20 ST | 48 AVE | 49 AVE | COLLECTOR | BUS | 2 | TRDS001437 | 12.7 | 223.9 |
| 29 | 1.15 | 0.28 | 50870 | 49 AVE | 20 ST | EOP (E) | LOCAL | | 2 | TRDS050870 | 5.0 | 395.9 |
| 30 | 2.01 | 0.25 | 52930 | LANE W OF 17 ST (N OF 46 AVE) | 46 AVE | EOP (N) | LANE | | 1 | TRDS052930 | 3.5 | 360.4 |
| 31 | 1.16 | 0.60 | 52940 | LANE E OF 17 ST (N OF 46 AVE) | 46 AVE | EOP (N) | LANE | | 1 | TRDS052940 | 3.5 | 262.5 |
| 32 | 0.52 | 0.30 | 52960 | SRW NE FROM 47 AVE | 47 AVE | | SROW | | 0 | TRDS052960 | 5.0 | 142.8 |
| 33 | 0.46 | 0.07 | 1441 | 20 ST | 49 AVE | 50 AVE | COLLECTOR | BUS | 2 | TRDS001441 | 11.4 | 297.2 |
| 34 | 0.37 | 0.08 | 1442 | 20 ST | 50 AVE | 53 AVE | COLLECTOR | BUS | 2 | TRDS001442 | 11.3 | 402.9 |
| 35 | 0.32 | 0.10 | 1443 | 20 ST | 53 AVE | 55 AVE | COLLECTOR | BUS | 2 | TRDS001443 | 13.8 | 312.6 |
| 36 | 0.26 | 0.09 | 8480 | 53 AVE | 21 ST | 20 ST | LOCAL | | 2 | TRDS008480 | 8.4 | 149.9 |
| 37 | 0.18 | 0.05 | 8510 | 21 ST | 53 AVE | EOP (N 53 AVE) | LOCAL | | 2 | TRDS008510 | 8.5 | 156.9 |
| 38 | 0.27 | 0.10 | 8490 | 53 AVE | 19 ST | 20 ST | LOCAL | | 2 | TRDS008490 | 8.5 | 159.0 |
| 39 | 0.29 | 0.07 | 7433 | 27 ST | 50 AVE (APPROX) | 53 AVE | ARTERIAL | | 4 | TRDS007433 | 23.0 | 505.4 |
| 40 | 0.10 | 0.03 | 53050 | SROW 53 AVE | | | SROW | | 0 | TRDS053050 | 5.0 | 382.5 |
| 41 | 0.84 | 0.35 | 53060 | SROW NE FROM 53 AVE | | | SROW | | 0 | TRDS053060 | 5.0 | 268.9 |
| 42 | 0.88 | 0.21 | 53070 | SROW E FROM 55 AVE | | | SROW | | 0 | TRDS053070 | 5.0 | 278.8 |

| Object ID | Max Flood Depth (m) | Mean Flood Depth (m) | Section ID | Road Name | From Street | To Street | Road Function Class | Bus Route | Number of Lanes | Facility ID | Road Width (m) | Road Segment Length (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 | 1.59 | 0.65 | 53100 | SROW FROM 20 ST W TO HWY | 20 ST | | SROW | | 0 | TRDS053100 | 5.0 | 283.9 |
| 44 | 1.87 | 0.42 | 53110 | RAILWAY ROW | | | SROW | | 0 | TRDS053110 | 5.0 | 2444.9 |
| 45 | 0.35 | 0.18 | 1444 | 20 ST | 55 AVE | DELEENHEER RD | COLLECTOR | BUS | 2 | TRDS001444 | 8.5 | 291.6 |
| 46 | 0.33 | 0.07 | 8511 | 21 ST | 53 AVE | 55 AVE | LOCAL | | 2 | TRDS008511 | 8.5 | 223.1 |
| 47 | 0.51 | 0.14 | 8491 | 53 AVE | 19 ST | CUL DE SAC | LOCAL | | 2 | TRDS008491 | 13.5 | 210.4 |
| 48 | 0.33 | 0.05 | 8481 | 53 AVE | CUL DE SAC | 21 ST | LOCAL | | 2 | TRDS008481 | 14.0 | 201.2 |
| 49 | 0.29 | 0.10 | 6950 | 53 AVE | 26 ST | 24 ST | LOCAL | | 2 | TRDS006950 | 13.5 | 480.2 |
| 50 | 0.48 | 0.07 | 6913 | 48 AVE | 27 ST | 24 ST | ARTERIAL | BUS | 4 | TRDS006913 | 20.0 | 604.1 |
| 51 | 0.25 | 0.07 | 7430 | 27 ST | 48 AVE | 50 AVE | ARTERIAL | | 4 | TRDS007430 | 23.0 | 506.4 |
| 52 | 0.20 | 0.07 | 53150 | 25 ST | 53 AVE | EOP | LOCAL | | 2 | TRDS053150 | 5.0 | 376.8 |
| 53 | 0.21 | 0.07 | 6900 | 48 AVE | 29 ST | 27 ST | ARTERIAL | BUS | 4 | TRDS006900 | 20.5 | 605.5 |
| 54 | 1.63 | 0.18 | 7440 | 27 ST | 53 AVE | 58 AVE | ARTERIAL | | 4 | TRDS007440 | 21.1 | 966.3 |
| 55 | 1.77 | 0.44 | 7445 | 27 ST | 58 AVE | CITY LIMITS | ARTERIAL | | 4 | TRDS007445 | 25.2 | 359.1 |
| 56 | 0.30 | 0.09 | 2570 | 26 ST | 53 AVE | 55 AVE | LOCAL | | 2 | TRDS002570 | 11.5 | 373.0 |
| 57 | 0.47 | 0.15 | 53030 | SROW BX CREEK | | | SROW | | 0 | TRDS053030 | 5.0 | 546.5 |
| 58 | 0.44 | 0.21 | 52400 | PLEASANT VALLEY RD | 47 AVE | 48 AVE | COLLECTOR | BUS | 2 | TRDS052400 | 14.5 | 738.8 |
| 59 | 0.14 | 0.05 | 55085 | ANDERSON WAY | 5500 ANDERSON WAY | 27 ST | COLLECTOR | BUS | 2 | TRDS055085 | 12.5 | 1038.0 |
| 60 | 2.01 | 0.20 | 55444 | 20 ST | 47 AVE | 48 AVE | COLLECTOR | | 2 | TRDS055444 | 9.1 | 486.1 |
| 61 | 0.28 | 0.08 | 55522 | LANE E OF 25 ST & S OF 53 AVE | 25 ST | 24 ST | LANE | | 1 | TRDS055522 | 6.0 | 242.8 |
| 62 | 1.75 | 1.48 | 55698 | PED BRIDGE XING | | | SROW | | 0 | TRDS055698 | 5.0 | 69.1 |

| Object ID | Max Flood Depth (m) | Mean Flood Depth (m) | Section ID | Road Name | From Street | To Street | Road Function Class | Bus Route | Number of Lanes | Facility ID | Road Width (m) | Road Segment Length (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 63 | 0.22 | 0.04 | 55839 | 27 ST FRONTAGE | | | FRONTAG | | 1 | TRDS055839 | 5.0 | 462.5 |
| 64 | 0.33 | 0.12 | 55909 | 55 AVE | 20 ST | 21 ST | LOCAL | | 2 | TRDS055909 | 8.9 | 155.6 |
| 65 | 0.25 | 0.10 | 55922 | 50 AVE | 50 AVE CRK CROSSING | 18 ST | LOCAL | | 2 | TRDS055922 | 7.5 | 295.7 |
| 66 | 0.60 | 0.12 | 8560 | 58 AVE | 24 ST | 20 ST | COLLECTOR | BUS | 2 | TRDS008560 | 11.5 | 724.5 |
| 67 | 0.42 | 0.07 | 1445 | 20 ST | DELEENHEER RD | 58 AVE | COLLECTOR | BUS | 2 | TRDS001445 | 10.0 | 467.0 |
| 68 | 1.82 | 0.53 | 53090 | 20 ST | 58 AVE | EOP | COLLECTOR | | 2 | TRDS053090 | 6.0 | 774.9 |
| 69 | 0.91 | 0.46 | 55926 | 58 AVE | CUL DE SAC | 20 ST | LOCAL | | 2 | TRDS055926 | 7.3 | 173.0 |

## Buildings

**Table E5 Buildings damaged in 20-year flood.**

| Object ID | Maximum Flood Depth (m) | Ground Floor Elevation (m) | OCP Designation | Damage Curve | Dwelling Units (#) | Structure Damage (%) | Contents Damage (%) |
|---|---|---|---|---|---|---|---|
| 43 | 0.24 | 400.40 | OCP-RMD | Single Family Dwelling | 3 | 20.5 | 17.5 |
| 44 | 0.35 | 400.37 | OCP-RMD | Single Family Dwelling | 2 | 31.8 | 33.1 |
| 45 | 0.49 | 400.80 | OCP-RMD | Single Family Dwelling | 2 | 34.0 | 36.3 |
| 46 | 0.03 | 400.88 | OCP-RMD | Single Family Dwelling | 2 | 19.2 | 16.2 |
| 47 | 0.44 | 400.82 | OCP-RMD | Single Family Dwelling | 2 | 33.1 | 35.0 |
| 48 | 0.47 | 400.68 | OCP-RMD | Single Family Dwelling | 2 | 33.7 | 35.7 |
| 49 | 0.27 | 400.88 | OCP-RMD | Single Family Dwelling | 4 | 20.8 | 17.8 |
| 50 | 0.09 | 400.54 | OCP-RMD | Single Family Dwelling | 2 | 19.6 | 16.6 |
| 52 | 0.64 | 398.81 | OCP-RMD | Single Family Dwelling | 2 | 38.3 | 41.4 |
| 62 | 0.25 | 401.75 | OCP-RMD | Single Family Dwelling | 2 | 20.7 | 17.7 |
| 63 | 0.33 | 401.73 | OCP-RMD | Single Family Dwelling | 2 | 31.5 | 32.6 |
| 65 | 0.31 | 401.73 | OCP-RMD | Single Family Dwelling | 2 | 31.1 | 32.1 |
| 66 | 0.25 | 402.22 | OCP-RMD | Single Family Dwelling | 2 | 20.7 | 17.7 |
| 68 | 0.04 | 404.43 | OCP-RMD | Single Family Dwelling | 1 | 19.2 | 16.2 |
| 69 | 0.17 | 404.53 | OCP-RMD | Single Family Dwelling | 1 | 20.1 | 17.1 |
| 70 | 0.03 | 404.55 | OCP-RMD | Single Family Dwelling | 1 | 19.2 | 16.2 |
| 71 | 0.06 | 404.82 | OCP-RMD | Single Family Dwelling | 1 | 19.4 | 16.4 |
| 75 | 0.09 | 400.13 | OCP-RMD | Single Family Dwelling | 1 | 19.6 | 16.6 |
| 76 | 0.01 | 400.18 | OCP-RMD | Single Family Dwelling | 1 | 19.0 | 16.0 |
| 80 | 0.47 | 399.56 | OCP-RMD | Single Family Dwelling | 1 | 33.7 | 35.8 |
| 81 | 0.30 | 399.28 | OCP-RMD | Single Family Dwelling | 1 | 20.9 | 17.9 |
| 82 | 0.52 | 399.38 | OCP-RMD | Single Family Dwelling | 1 | 34.6 | 37.0 |
| 123 | 0.13 | 399.86 | OCP-RMD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 124 | 0.13 | 400.11 | OCP-RMD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 125 | 0.20 | 395.86 | OCP-CCOM | Retail Trade | | 6.3 | 18.0 |
| 126 | 1.14 | 396.46 | OCP-CCOM | Retail Trade | | 29.5 | 136.9 |
| 127 | 0.18 | 395.07 | OCP-RMD | Light Industry | | 5.6 | 5.2 |
| 168 | 0.19 | 406.15 | OCP-CCOM | Light Industry | | 5.9 | 5.5 |
| 171 | 0.12 | 405.33 | OCP-RMD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 208 | 0.41 | 401.79 | OCP-RMD | Single Family Dwelling | 1 | 32.7 | 34.4 |
| 227 | 0.21 | 419.29 | OCP-RLD | Single Family Dwelling | 1 | 20.4 | 17.4 |

**Table E6 Buildings damaged in design flood (1996 flood with climate change).**

| Object ID | Maximum Flood Depth (m) | Ground Floor Elevation (m) | OCP Designation | Damage Curve | Dwelling Units (#) | Structure Damage (%) | Contents Damage (%) |
|---|---|---|---|---|---|---|---|
| 1 | 0.83 | 410.87 | OCP-PUBINS | Light Industry | | 28.2 | 79.8 |
| 2 | 0.04 | 411.01 | OCP-PUBINS | Light Industry | | 2.0 | 1.1 |
| 3 | 0.16 | 410.92 | OCP-PUBINS | Light Industry | | 5.3 | 4.8 |
| 5 | 0.06 | 402.00 | OCP-LINDSC | Light Industry | | 2.7 | 1.9 |
| 6 | 0.17 | 399.89 | OCP-CCOM | Retail Trade | | 5.5 | 15.5 |
| 7 | 0.04 | 399.33 | OCP-CCOM | Retail Trade | | 2.0 | 5.1 |
| 8 | 0.10 | 398.75 | OCP-CCOM | Retail Trade | | 3.6 | 9.9 |
| 9 | 0.12 | 400.15 | OCP-CCOM | Retail Trade | | 4.2 | 11.7 |
| 10 | 0.02 | 402.26 | OCP-CCOM | Retail Trade | | 1.5 | 3.6 |
| 11 | 0.09 | 401.73 | OCP-CCOM | Retail Trade | | 3.3 | 9.0 |
| 15 | 0.46 | 406.51 | OCP-RMD | Retail Trade | | 21.6 | 66.3 |
| 16 | 0.23 | 407.42 | OCP-RMD | Single Family Dwelling | 6 | 20.5 | 17.5 |
| 17 | 0.20 | 407.70 | OCP-RMD | Single Family Dwelling | 5 | 20.3 | 17.3 |
| 19 | 0.82 | 400.63 | OCP-RMD | Single Family Dwelling | 1 | 40.1 | 43.7 |
| 20 | 0.64 | 400.39 | OCP-RMD | Single Family Dwelling | 1 | 38.3 | 41.3 |
| 21 | 0.21 | 400.67 | OCP-RMD | Single Family Dwelling | 1 | 20.4 | 17.4 |
| 22 | 0.20 | 400.63 | OCP-RMD | Single Family Dwelling | 1 | 20.3 | 17.3 |
| 23 | 0.12 | 400.04 | OCP-RMD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 24 | 0.13 | 400.19 | OCP-RMD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 25 | 0.08 | 400.24 | OCP-RMD | Single Family Dwelling | 1 | 19.5 | 16.5 |
| 28 | 0.18 | 400.72 | OCP-RMD | Single Family Dwelling | 1 | 20.2 | 17.2 |
| 29 | 0.22 | 400.71 | OCP-RMD | Single Family Dwelling | 1 | 20.4 | 17.4 |
| 30 | 0.07 | 402.17 | OCP-RMD | Single Family Dwelling | 1 | 19.5 | 16.5 |
| 31 | 0.12 | 398.76 | OCP-RMD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 32 | 0.07 | 399.45 | OCP-RMD | Single Family Dwelling | 2 | 19.5 | 16.5 |
| 33 | 0.03 | 398.80 | OCP-RMD | Single Family Dwelling | 2 | 19.2 | 16.2 |
| 34 | 0.05 | 398.75 | OCP-RMD | Single Family Dwelling | 2 | 19.3 | 16.3 |
| 35 | 0.30 | 398.34 | OCP-RMD | Single Family Dwelling | 2 | 21.0 | 18.0 |
| 36 | 0.12 | 398.46 | OCP-RMD | Single Family Dwelling | 2 | 19.8 | 16.8 |
| 37 | 0.13 | 398.47 | OCP-RMD | Single Family Dwelling | 2 | 19.9 | 16.9 |
| 38 | 0.31 | 398.25 | OCP-RMD | Single Family Dwelling | 2 | 31.1 | 32.1 |
| 39 | 0.17 | 398.58 | OCP-RMD | Single Family Dwelling | 2 | 20.1 | 17.1 |
| 40 | 0.16 | 398.99 | OCP-RMD | Single Family Dwelling | 2 | 20.1 | 17.1 |
| 41 | 0.10 | 399.27 | OCP-RMD | Single Family Dwelling | 2 | 19.6 | 16.6 |

| Object ID | Maximum Flood Depth (m) | Ground Floor Elevation (m) | OCP Designation | Damage Curve | Dwelling Units (#) | Structure Damage (%) | Contents Damage (%) |
|---|---|---|---|---|---|---|---|
| 42 | 0.34 | 397.99 | OCP-CCOM | Retail Trade | | 19.5 | 59.7 |
| 43 | 0.40 | 400.40 | OCP-RMD | Single Family Dwelling | 3 | 32.6 | 34.2 |
| 44 | 0.49 | 400.37 | OCP-RMD | Single Family Dwelling | 2 | 34.0 | 36.2 |
| 45 | 0.68 | 400.80 | OCP-RMD | Single Family Dwelling | 2 | 38.7 | 41.9 |
| 46 | 0.24 | 400.88 | OCP-RMD | Single Family Dwelling | 2 | 20.6 | 17.6 |
| 47 | 0.63 | 400.82 | OCP-RMD | Single Family Dwelling | 2 | 38.2 | 41.2 |
| 48 | 0.66 | 400.68 | OCP-RMD | Single Family Dwelling | 2 | 38.5 | 41.6 |
| 49 | 0.45 | 400.88 | OCP-RMD | Single Family Dwelling | 4 | 33.5 | 35.4 |
| 50 | 0.25 | 400.54 | OCP-RMD | Single Family Dwelling | 2 | 20.6 | 17.6 |
| 52 | 0.78 | 398.81 | OCP-RMD | Single Family Dwelling | 2 | 39.7 | 43.3 |
| 53 | 0.13 | 401.48 | OCP-RMD | Single Family Dwelling | 1 | 19.9 | 16.9 |
| 54 | 0.09 | 401.53 | OCP-RMD | Single Family Dwelling | 1 | 19.6 | 16.6 |
| 55 | 0.13 | 401.83 | OCP-RMD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 56 | 0.13 | 401.58 | OCP-RMD | Single Family Dwelling | 1 | 19.9 | 16.9 |
| 57 | 0.15 | 401.46 | OCP-RMD | Single Family Dwelling | 1 | 20.0 | 17.0 |
| 58 | 0.04 | 401.55 | OCP-RMD | Single Family Dwelling | 1 | 19.3 | 16.3 |
| 59 | 0.21 | 402.05 | OCP-RMD | Single Family Dwelling | 1 | 20.3 | 17.3 |
| 60 | 0.16 | 402.31 | OCP-RMD | Single Family Dwelling | 1 | 20.0 | 17.0 |
| 61 | 0.10 | 402.48 | OCP-RMD | Single Family Dwelling | 1 | 19.6 | 16.6 |
| 62 | 0.58 | 401.75 | OCP-RMD | Single Family Dwelling | 2 | 35.6 | 38.4 |
| 63 | 0.64 | 401.73 | OCP-RMD | Single Family Dwelling | 2 | 38.3 | 41.4 |
| 64 | 0.36 | 401.96 | OCP-RMD | Single Family Dwelling | 2 | 31.9 | 33.3 |
| 65 | 0.64 | 401.73 | OCP-RMD | Single Family Dwelling | 2 | 38.3 | 41.4 |
| 66 | 0.56 | 402.22 | OCP-RMD | Single Family Dwelling | 2 | 35.2 | 37.9 |
| 67 | 0.18 | 402.42 | OCP-RMD | Single Family Dwelling | 2 | 20.2 | 17.2 |
| 68 | 0.21 | 404.43 | OCP-RMD | Single Family Dwelling | 1 | 20.4 | 17.4 |
| 69 | 0.32 | 404.53 | OCP-RMD | Single Family Dwelling | 1 | 31.3 | 32.4 |
| 70 | 0.14 | 404.55 | OCP-RMD | Single Family Dwelling | 1 | 19.9 | 16.9 |
| 71 | 0.26 | 404.82 | OCP-RMD | Single Family Dwelling | 1 | 20.7 | 17.7 |
| 72 | 0.45 | 405.89 | OCP-RMD | Nursing Home | 27.7 | 14.5 | 92.8 |
| 73 | 1.26 | 406.04 | OCP-MDCOMRES | Retail Trade | | 34.3 | 149.4 |
| 74 | 0.18 | 406.72 | OCP-MDCOMRES | Retail Trade | | 5.7 | 16.0 |
| 75 | 0.18 | 400.13 | OCP-RMD | Single Family Dwelling | 1 | 20.2 | 17.2 |
| 76 | 0.11 | 400.18 | OCP-RMD | Single Family Dwelling | 1 | 19.7 | 16.7 |
| 77 | 0.12 | 400.27 | OCP-RMD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 78 | 0.16 | 400.21 | OCP-RMD | Single Family Dwelling | 1 | 20.0 | 17.0 |
| 79 | 0.04 | 400.42 | OCP-RMD | Single Family Dwelling | 1 | 19.3 | 16.3 |

| Object ID | Maximum Flood Depth (m) | Ground Floor Elevation (m) | OCP Designation | Damage Curve | Dwelling Units (#) | Structure Damage (%) | Contents Damage (%) |
|---|---|---|---|---|---|---|---|
| 80 | 0.61 | 399.56 | OCP-RMD | Single Family Dwelling | 1 | 38.0 | 41.0 |
| 81 | 0.44 | 399.28 | OCP-RMD | Single Family Dwelling | 1 | 33.2 | 35.1 |
| 82 | 0.66 | 399.38 | OCP-RMD | Single Family Dwelling | 1 | 38.5 | 41.7 |
| 83 | 0.33 | 400.39 | OCP-RMD | Single Family Dwelling | 1 | 31.3 | 32.5 |
| 84 | 0.14 | 399.76 | OCP-RMD | Single Family Dwelling | 1 | 19.9 | 16.9 |
| 87 | 1.11 | 404.33 | OCP-RMD | Single Family Dwelling | 1 | 62.2 | 55.6 |
| 88 | 0.18 | 402.93 | OCP-LINDSC | Retail Trade | | 5.7 | 16.2 |
| 89 | 0.27 | 404.93 | OCP-RMD | Single Family Dwelling | 2 | 20.8 | 17.8 |
| 90 | 0.23 | 404.40 | OCP-RMD | Single Family Dwelling | 2 | 20.5 | 17.5 |
| 91 | 0.19 | 403.96 | OCP-RMD | Single Family Dwelling | 2 | 20.3 | 17.3 |
| 92 | 0.14 | 406.11 | OCP-MDCOMRES | Retail Trade | | 4.7 | 13.1 |
| 93 | 0.11 | 404.88 | OCP-RMD | Single Family Dwelling | 2 | 19.7 | 16.7 |
| 94 | 0.17 | 404.38 | OCP-RMD | Single Family Dwelling | 2 | 20.1 | 17.1 |
| 95 | 0.16 | 403.77 | OCP-RMD | Single Family Dwelling | 2 | 20.0 | 17.0 |
| 96 | 0.23 | 400.99 | OCP-LINDSC | Retail Trade | | 7.0 | 20.0 |
| 97 | 0.15 | 400.15 | OCP-LINDSC | Retail Trade | | 5.0 | 13.9 |
| 98 | 0.08 | 398.50 | OCP-CCOM | Retail Trade | | 3.2 | 8.6 |
| 99 | 0.10 | 400.82 | OCP-LINDSC | Retail Trade | | 3.7 | 10.0 |
| 100 | 1.13 | 399.72 | OCP-LINDSC | Retail Trade | | 29.4 | 136.3 |
| 102 | 0.12 | 396.10 | OCP-CCOM | Retail Trade | | 4.1 | 11.3 |
| 103 | 0.97 | 395.94 | OCP-CCOM | Retail Trade | | 28.4 | 130.4 |
| 104 | 0.43 | 395.84 | OCP-CCOM | Retail Trade | | 21.1 | 64.8 |
| 105 | 0.33 | 396.53 | OCP-CCOM | Retail Trade | | 19.4 | 59.1 |
| 106 | 0.09 | 397.32 | OCP-CCOM | Retail Trade | | 3.3 | 9.0 |
| 107 | 0.96 | 397.97 | OCP-CCOM | Retail Trade | | 28.3 | 129.9 |
| 108 | 0.05 | 397.66 | OCP-CCOM | Retail Trade | | 2.2 | 5.6 |
| 109 | 0.21 | 395.65 | OCP-CCOM | Retail Trade | | 6.6 | 18.9 |
| 110 | 0.31 | 394.73 | OCP-CCOM | Retail Trade | | 19.0 | 58.1 |
| 111 | 0.03 | 395.39 | OCP-CCOM | Retail Trade | | 1.7 | 4.1 |
| 112 | 0.05 | 394.94 | OCP-CCOM | Retail Trade | | 2.3 | 5.9 |
| 113 | 0.07 | 394.70 | OCP-CCOM | Retail Trade | | 2.8 | 7.5 |
| 114 | 0.07 | 394.73 | OCP-CCOM | Retail Trade | | 3.0 | 7.9 |
| 115 | 0.10 | 395.05 | OCP-CCOM | Retail Trade | | 3.6 | 9.7 |
| 118 | 0.04 | 406.93 | OCP-MDCOMRES | Single Family Dwelling | 1 | 19.2 | 16.2 |
| 122 | 0.09 | 399.96 | OCP-RMD | Single Family Dwelling | 3 | 19.6 | 16.6 |
| 123 | 0.21 | 399.86 | OCP-RMD | Single Family Dwelling | 1 | 20.4 | 17.4 |
| 124 | 0.19 | 400.11 | OCP-RMD | Single Family Dwelling | 1 | 20.2 | 17.2 |

| Object ID | Maximum Flood Depth (m) | Ground Floor Elevation (m) | OCP Designation | Damage Curve | Dwelling Units (#) | Structure Damage (%) | Contents Damage (%) |
|---|---|---|---|---|---|---|---|
| 125 | 0.25 | 395.86 | OCP-CCOM | Retail Trade | | 7.5 | 21.4 |
| 126 | 1.26 | 396.46 | OCP-CCOM | Retail Trade | | 34.3 | 149.4 |
| 127 | 0.42 | 395.07 | OCP-RMD | Light Industry | | 20.9 | 42.3 |
| 128 | 0.30 | 394.64 | OCP-RMD | Light Industry | | 8.9 | 8.9 |
| 129 | 0.10 | 418.22 | OCP-RLD | Single Family Dwelling | 1 | 19.7 | 16.7 |
| 130 | 0.31 | 417.68 | OCP-RLD | Single Family Dwelling | 1 | 31.1 | 32.1 |
| 131 | 0.19 | 423.65 | OCP-RLD | Single Family Dwelling | 1 | 20.3 | 17.3 |
| 132 | 0.11 | 416.08 | OCP-RLD | Single Family Dwelling | 1 | 19.7 | 16.7 |
| 133 | 0.25 | 416.35 | OCP-RLD | Single Family Dwelling | 1 | 20.6 | 17.6 |
| 134 | 0.25 | 416.59 | OCP-RLD | Single Family Dwelling | 1 | 20.6 | 17.6 |
| 135 | 0.30 | 416.66 | OCP-RLD | Single Family Dwelling | 1 | 20.9 | 17.9 |
| 136 | 0.42 | 416.83 | OCP-RLD | Single Family Dwelling | 1 | 33.0 | 34.7 |
| 137 | 0.45 | 416.99 | OCP-RLD | Single Family Dwelling | 1 | 33.4 | 35.4 |
| 138 | 0.51 | 417.24 | OCP-RLD | Single Family Dwelling | 1 | 34.3 | 36.6 |
| 139 | 0.29 | 417.77 | OCP-RLD | Single Family Dwelling | 1 | 20.9 | 17.9 |
| 140 | 0.12 | 416.89 | OCP-RLD | Single Family Dwelling | 1 | 19.8 | 16.8 |
| 141 | 0.14 | 416.94 | OCP-RLD | Single Family Dwelling | 1 | 19.9 | 16.9 |
| 142 | 0.10 | 417.09 | OCP-RLD | Single Family Dwelling | 1 | 19.6 | 16.6 |
| 148 | 0.31 | 408.75 | OCP-RMD | Single Family Dwelling | 4 | 31.0 | 32.0 |
| 149 | 0.19 | 409.09 | OCP-RMD | Single Family Dwelling | 4 | 20.2 | 17.2 |
| 150 | 0.20 | 408.55 | OCP-RMD | Single Family Dwelling | 5 | 20.3 | 17.3 |
| 151 | 0.24 | 408.45 | OCP-RMD | Single Family Dwelling | 5 | 20.6 | 17.6 |
| 152 | 0.17 | 408.42 | OCP-RMD | Single Family Dwelling | 2 | 20.1 | 17.1 |
| 153 | 0.29 | 409.41 | OCP-RMD | Single Family Dwelling | 4 | 20.9 | 17.9 |
| 154 | 0.30 | 409.90 | OCP-RMD | Single Family Dwelling | 3 | 20.9 | 17.9 |
| 156 | 0.79 | 410.31 | OCP-PUBINS | Light Industry | | 27.8 | 78.3 |
| 157 | 0.16 | 415.93 | OCP-RLD | Single Family Dwelling | 1 | 20.1 | 17.1 |
| 158 | 0.21 | 416.06 | OCP-RLD | Single Family Dwelling | 1 | 20.4 | 17.4 |
| 159 | 0.25 | 416.23 | OCP-RLD | Single Family Dwelling | 1 | 20.7 | 17.7 |
| 161 | 0.25 | 416.48 | OCP-RLD | Single Family Dwelling | 1 | 20.7 | 17.7 |
| 162 | 0.11 | 416.66 | OCP-RLD | Single Family Dwelling | 1 | 19.7 | 16.7 |
| 163 | 0.03 | 416.59 | OCP-RLD | Single Family Dwelling | 1 | 19.2 | 16.2 |
| 164 | 0.15 | 417.13 | OCP-RLD | Single Family Dwelling | 1 | 20.0 | 17.0 |
| 165 | 0.18 | 416.38 | OCP-RLD | Single Family Dwelling | 1 | 20.2 | 17.2 |
| 167 | 0.45 | 406.28 | OCP-RMD | Light Industry | | 21.4 | 43.8 |
| 168 | 0.50 | 406.15 | OCP-CCOM | Light Industry | | 22.3 | 46.1 |
| 169 | 0.24 | 406.28 | OCP-CCOM | Light Industry | | 7.2 | 7.0 |
| 170 | 0.11 | 407.33 | OCP-CCOM | Single Family Dwelling | 1 | 19.7 | 16.7 |

| Object ID | Maximum Flood Depth (m) | Ground Floor Elevation (m) | OCP Designation | Damage Curve | Dwelling Units (#) | Structure Damage (%) | Contents Damage (%) |
|---|---|---|---|---|---|---|---|
| 171 | 0.34 | 405.33 | OCP-RMD | Single Family Dwelling | 1 | 31.5 | 32.7 |
| 173 | 0.15 | 401.97 | OCP-CCOM | Retail Trade | | 4.8 | 13.5 |
| 175 | 0.60 | 401.25 | OCP-CCOM | Retail Trade | | 23.9 | 73.5 |
| 176 | 0.17 | 402.39 | OCP-CCOM | Retail Trade | | 5.6 | 15.7 |
| 177 | 0.05 | 405.06 | OCP-LINDSC | Retail Trade | | 2.3 | 5.8 |
| 178 | 0.05 | 404.59 | OCP-LINDSC | Retail Trade | | 2.2 | 5.6 |
| 185 | 0.18 | 416.14 | OCP-RLD | Single Family Dwelling | 1 | 20.2 | 17.2 |
| 188 | 0.36 | 424.34 | OCP-RLD | Single Family Dwelling | 1 | 31.8 | 33.2 |
| 189 | 0.05 | 407.58 | OCP-RMD | Single Family Dwelling | 1 | 19.3 | 16.3 |
| 195 | 0.10 | 400.32 | OCP-RMD | Single Family Dwelling | 1 | 19.7 | 16.7 |
| 208 | 0.74 | 401.79 | OCP-RMD | Single Family Dwelling | 1 | 39.3 | 42.7 |
| 220 | 0.17 | 396.43 | OCP-CCOM | Retail Trade | | 5.6 | 15.7 |
| 221 | 0.91 | 395.91 | OCP-CCOM | Retail Trade | | 24.0 | 111.8 |
| 223 | 0.15 | 406.58 | OCP-CCOM | Light Industry | | 4.9 | 4.4 |
| 224 | 0.13 | 408.58 | OCP-RMD | Single Family Dwelling | 3 | 19.9 | 16.9 |
| 225 | 0.08 | 395.94 | OCP-CCOM | Single Family Dwelling | 3 | 19.5 | 16.5 |
| 227 | 0.76 | 419.29 | OCP-RLD | Single Family Dwelling | 1 | 39.5 | 43.0 |
| 229 | 0.27 | 406.54 | OCP-RMD | Nursing Home | 22.7 | 6.2 | 33.8 |
| 230 | 0.04 | 402.27 | OCP-CCOM | Retail Trade | | 2.1 | 5.2 |
| 231 | 0.34 | 417.43 | OCP-RLD | Single Family Dwelling | 1 | 31.6 | 32.8 |
| 232 | 0.17 | 417.41 | OCP-RLD | Single Family Dwelling | 1 | 20.1 | 17.1 |
| 252 | 0.46 | 424.46 | OCP-RLD | Retail Trade | | 21.6 | 66.2 |