THE CORPORATION OF THE CITY OF VERNON
REPORT TO COUNCIL

SUBMITTED BY: Mathew Keast, Water Resources Engineer
Mark Dowhaniuk, Infrastructure Manager

COUNCIL MEETING: REG ☐ COW ☒ I/C ☐
COUNCIL MEETING DATE: February 28, 2022
REPORT DATE: February 3, 2022
FILE: 5225-20-08

SUBJECT: FLOOD MAPPING, RISK ANALYSIS AND MITIGATION

PURPOSE:

To present the results and recommendations of the Flood Mapping, Risk Analysis and Mitigation study for Vernon Creek and BX Creek through the City. The recommendations of this the report will set the City of Vernon on the path to becoming a more flood resilient community.

RECOMMENDATION:

THAT Council direct Administration to create the Flood Response Plan as recommended and outlined in the report titled “Flood Mapping, Risk Analysis and Mitigation” dated February 3, 2022 and respectfully submitted by the Water Resource Engineer and Manager, Infrastructure;

AND FURTHER, that Council direct Administration to incorporate floodplain mapping into the Official Community Plan and develop a floodplain bylaw for its consideration;

AND FURTHER, that Council direct Administration to update the Sediment and Debris Management Plan as recommended in the report titled “Flood Mapping, Risk Analysis and Mitigation” dated February 3, 2022 and respectfully submitted by the Water Resource Engineer and Manager, Infrastructure, funded from the Storm Maintenance Various Location budget in the Infrastructure Program;

AND FURTHER, that Council direct Administration to complete feasibility assessments for the structural mitigation projects as recommended in the report titled “Flood Mapping, Risk Analysis and Mitigation” dated February 3, 2022 and respectfully submitted by the Water Resource Engineer and Manager, Infrastructure, to be funded from the Capital Design Budget in the Infrastructure Program;

AND FURTHER, that Council direct Administration to coordinate collaboration on mitigation opportunities with the Okanagan Indian Band as recommended in the report titled “Flood Mapping, Risk Analysis and Mitigation” dated February 3, 2022 and respectfully submitted by the Water Resource Engineer and Manager, Infrastructure;

AND FURTHER, that Council direct Administration to complete a Vernon Water Reclamation Center flood assessment and emergency plan funded from Capital Design funding in the 2023 Financial Plan;

AND FURTHER, that Council approve the change of the Water Resources Engineer to a permanent full time position in 2023 to be funded from the 1.9% Infrastructure Levy.

ALTERNATIVES & IMPLICATIONS:

The recommendations presented above provide direction to Administration to move forward with addressing an identified hazard and public safety concerns related to flooding. The recommendations all represent the best professional judgement and advice, as provided by Administration. Council support of the

recommendations will improve the flood resiliency of the community as the City moves towards implementation of both structural and non-structural mitigation. Coordination of the mitigation projects with Okanagan Indian band (OKIB) is a requirement for many of the approvals that will be required for the structural mitigation projects and City collaboration with OKIB on these projects could open additional funding opportunities.

ANALYSIS:

A. Committee Recommendations:

N/A

B. Rationale:

1. Background

The City of Vernon engaged Northwest Hydraulic Consultants (NHC) to undertake a Detailed Flood Mapping, Risk Analysis and Mitigation assessment to move the City towards a more flood resilient community. The study was broken into two parts. Part 1 (Attachment 1) focused on Upper BX Creek upstream of Swan Lake and Part 2 (Attachment 2) focused on Lower BX Creek and Vernon Creek within the City boundaries.

Figure 1 Project Area

The City of Vernon Detailed Flood Mapping, Risk Analysis and Mitigation assessment is complementary to the work recently completed by the Okanagan Basin Water Board (OBWB). The OBWB completed a large flood mapping project for the Okanagan mainstem system for the Okanagan Valley with technical work by NHC following record setting high flows and flooding in the Okanagan Valley in 2017. The OBWB flood mapping project was a regional undertaking including partnership with the British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD), the operator of the Okanagan Lake Regulation System (OLRS), as well as local communities within the Okanagan Valley.

2. Objective

The primary objective of the project was to prepare detailed floodplain and hazard maps for the study reaches within the Vernon city boundary; assess the associated flood risk; evaluate mitigation options; 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.

The flood maps and risk assessment provide the basis for the identification and implementation of mitigation measures to reduce flood risk.

3. Methodology

The project followed the latest version of the Engineers & Geoscientists of BC (EGBC) Flood Mapping in BC Professional Practice Guidelines and the Federal Flood Mapping Framework by Natural Resources Canada.

A standard design event for flood mapping or infrastructure design along watercourses is the 200-year event. However, in cases when an observed event has occurred that is larger than the 200-year event, this larger real event is used as the design event. In May 1996, water survey of Canada data and weather data recorded an event where 60mm of rain fell over two days in Vernon, on top of an already rapidly melting snowpack, causing extreme flows that were more than double any other annual peak flow measured on BX Creek. The 1996 flood event of record has a return period above the 500-year event. This event was used as the design event for Upper BX Creek.

Unlike Upper BX Creek, flows in both Lower BX Creek and Vernon Creek are regulated by lakes that act to reduce peak flows. As with Part 1, the 1996 flood of record (approximately a 500-year event) was used as the design event input to Swan Lake and Lower BX Creek. For Vernon Creek, the 200-year event outflow from Kalamalka Lake from the Okanagan mainstem hydrologic model was used as the design event, assuming dam gates were fully open. NHC expanded upon the hydrologic and reservoir operations model from the recent Okanagan Basin Water Board (OBWB) Okanagan mainstem floodplain mapping project to model Kalamalka Lake outflows to both present day and projected future (end of century) design conditions.

4. Floodplain Map and Hazard Maps

The Floodplain Maps developed for both part 1 and part 2 of the project show the inundation extents under the selected design scenarios and include a freeboard of 0.6m. An illustration of the Flood Construction Level and Freeboard can be seen in Figure 2 below:

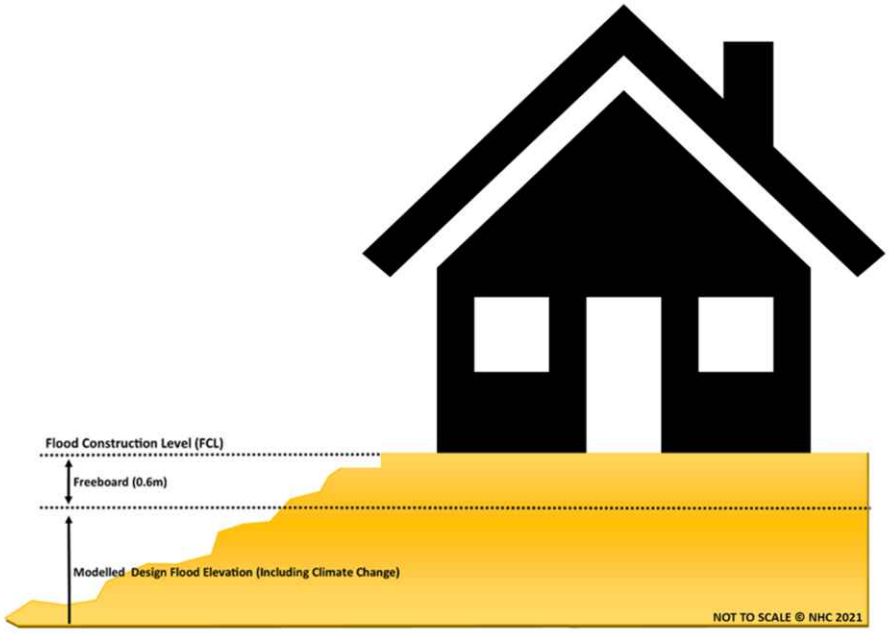

Figure 2 – Infographic of Flood Construction Level

A few key terms are important to understand when reading the Floodplain Maps:

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 floodwater.

Freeboard
A vertical offset from the design flood surface level to account for uncertainties and unpredictability regarding hydraulic, hydrologic and geomorphologic properties. A likely example would be a partially or fully blocked culvert due to vegetation and debris during flooding conditions resulting in higher than modelled water inundation.

Flood Fringe
The flood affected area outside of the main flow area (floodway), where velocities and water depths are lower. Includes a 0.6m freeboard.

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

Floodplain
The Flood plain would include the entire area of the Flood Fringe and the Floodway.

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

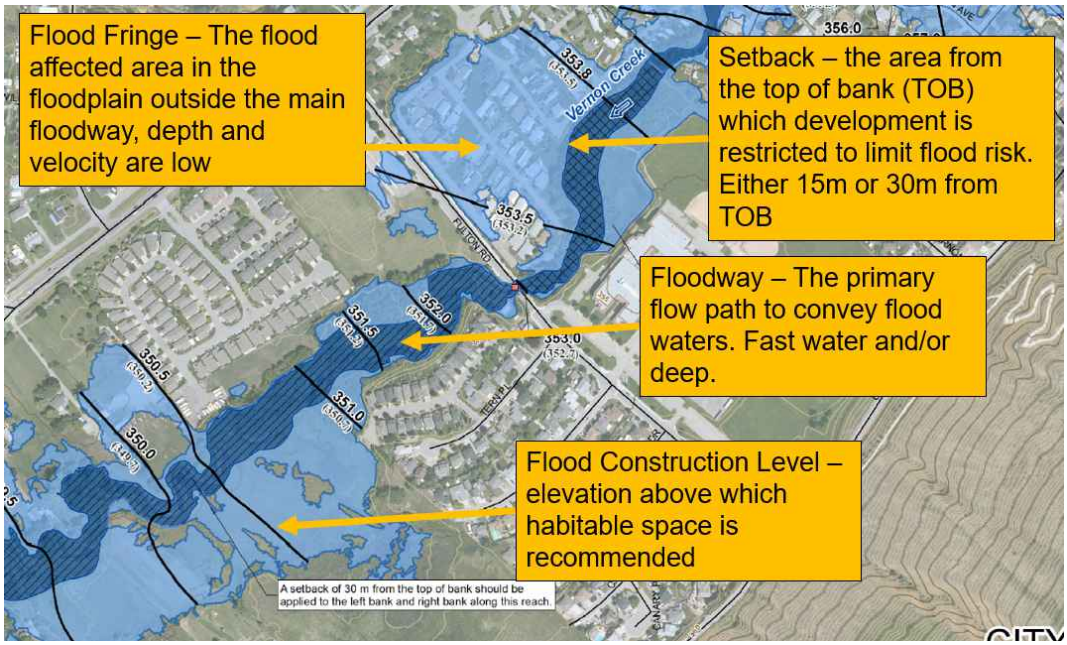

Figure 3 – Clip from Floodplain Maps

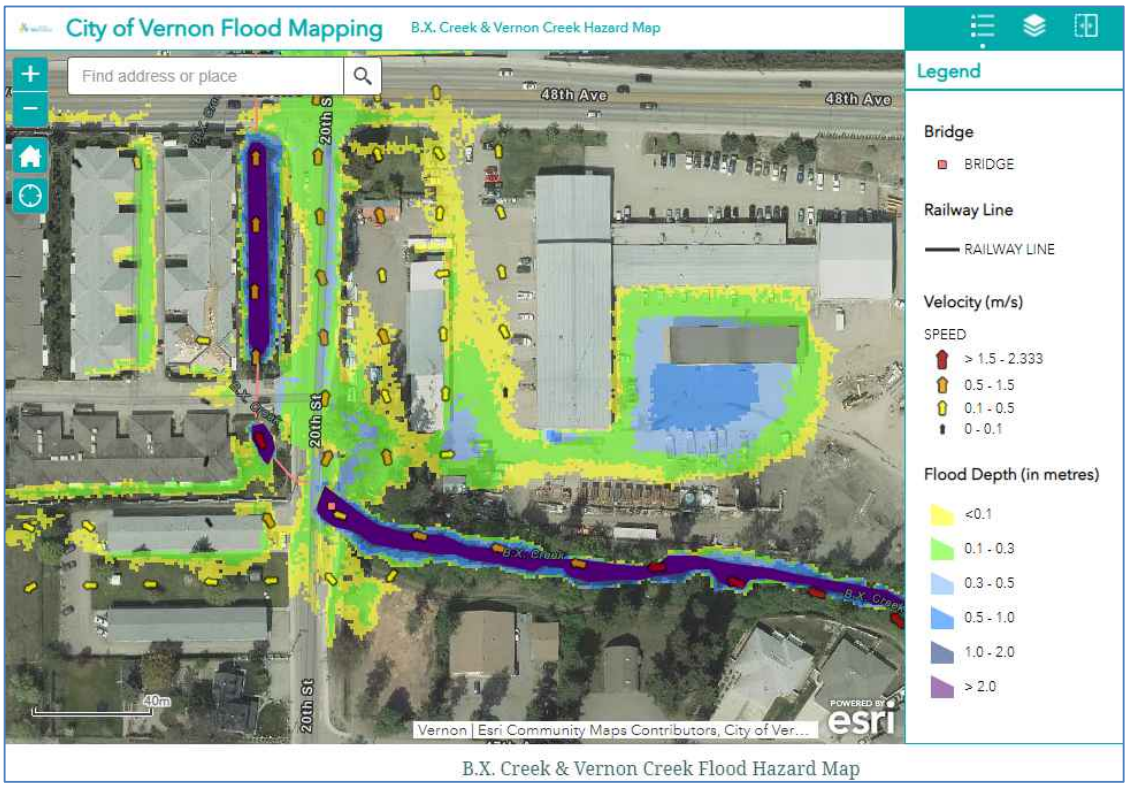

Figure 4 – Flood Hazard Map

Figure 4 shows a sample of the flood hazard mapping. The mapping represents the output from the flood modelling during the design event before adding freeboard. The different colors in the inundation area represent the depth of water while the different colored arrows show the varying flow velocities. These maps will be used by both Administration and the public for flood risk planning for emergency management, development and structural mitigation design.

5. Flood Risk Assessment

The Risk Classification is based on ratings provided in the Risk Assessment Information Template (RAIT) and flood risk matrix provided by the Engineers and Geoscientists of BC (EGBC, 2018). The project examined both the 20-year flood event, as well as the design flood event for each stream. For each of these events, modelled extent and depth results without freeboard were overlaid with existing GIS building footprint data to determine the potential impact to buildings and the number of residents displaced. The results of the Flood Risk Assessment are summarized in Table 1 below:

Table 1 - Estimated displaced population within City of Vernon boundaries

Estimated Vernon population displaced by flooding based on number of exposed dwellings			
	Factor	20-year Flood Event	Design Flood Event
BX Creek & Vernon Creek	Exposed Dwellings	623	1435
	Displaced Population (#)	1371	3136
	Displaced Population (%)	3%	7%

Section 7 of both Part 1 and Part 2 reports (attached) contains detailed results of the Flood Risk Assessment and key public/private facilities in the community that have been identified within the floodplain area.

a) <u>Priest Valley</u>

Priest Valley is located outside of the City limits as it is part of the Okanagan Indian Band. During the design event, Priest Valley residents are likely to be displaced into Vernon and use resources

available to them there. The results of the Flood Risk Assessment are summarized in Table 2 below:

Table 2 - Estimated displaced population within Priest's Valley boundaries

Estimated Priest's Valley population displaced by flooding based on number of exposed dwellings			
	Factor	20-year Flood Event	Design Flood Event
Priest's Valley	Exposed Dwellings	60	138
	Displaced Population (#)	126	290
	Displaced Population (%)	20%	46%

b) Vernon Water Reclamation Centre and Vernon Airport

An important finding from the flood risk assessment is that one of the buildings in the Vernon Water Reclamation Centre (VWRC) is exposed to both the design flood and 20-year flood events. Cascading infrastructure failure due to flooding such as lack of electricity should be considered. The risk assessment also found that groundwater saturation or non-connected ponding could affect the stability of runway surfaces at Vernon's airport. A site specific flood assessment is recommended for the VWRC site due to the critical nature of this infrastructure. The airport and all the other City facilities listed as vulnerable in the Part 1 and Part 2 reports would be considered in the development of a Flood Response Plan.

c) Estimates of economic impact and damage to structures was also estimated in the risk assessment. The risk assessment found that the economic impacts from both flood events (20 year and design flood event) are estimated to have "severe" or "catastrophic" economic consequences as per the example flood risk matrix, including severe building damage, several months of business interruption and greater than $1 million dollars of damage (EGBC, 2018). These estimates assume that private property is not protected by sandbags or other temporary emergency measures during flood events.

6. Prioritization of Mitigation

There is a variety of both structural and non-structural mitigation options that have been explored as part of this project. A prioritized list of 6 recommended mitigation options anticipated to have the largest benefit to the community are listed below. If directed by Council, Administration could start immediately on all recommended mitigation options (1 through 6) presented below.

One important note is that the structural mitigation recommendations presented in options 5 and 6 of the report assumed a clear span bridge to increase capacity. In some cases, this may not be the best or only way of increasing capacity and a further feasibility assessment of each crossing upgrade is recommended to determine the best method of increasing capacity and the potential impacts of each. The next step in implementing the structural mitigation options 4 to 6 would be to start a feasibility assessment and advance the engineering design. The feasibility assessment would identify additional methods to increase crossing capacities that may not have been explored as part of this project, provide a more in-depth analysis of environmental impacts, costs, permitting, and potential benefits beyond flood mitigation to the community such as trail networks. Proceeding with this work would also position the City well to take advantage of grant funding opportunities.

Recommended Mitigation Options:

1. Flood Response Plan (Entire City)

The recommended highest priority is to create a City Flood Response Plan that will guide Vernon through the response stage of a future flood event. Pre-planning the response to potential flooding

can help ensure an efficient, safe, and effective response. The following suggestions to be included in the Emergency Flood Response Plan:

- Identify key locations to monitor flows / water levels to trigger emergency plan actions;
- Pre-plan locations for temporary community flood barriers and operational activities during high-water events;
- Refine evacuation routes and plans based on updated flood hazard mapping; and
- Recovery planning for the post flood event.

Section 8.1.2 in Attachment 2 provides example recommendations for temporary flood barriers based on modelling which could form part of an Emergency Flood Response Plan. Figure 2 below is an example of a suggested emergency response plan measure for lower Vernon Creek utilizing temporary berms/dikes at strategic locations.

Funding for creating the Flood Response Plan as well as the purchase of flood response related equipment and supplies, could come from approved infrastructure funding from the Storm Maintenance at Various Locations project that is funded annually in the City's Financial Plan. Additional emergency planning work will be completed internally by Administration.

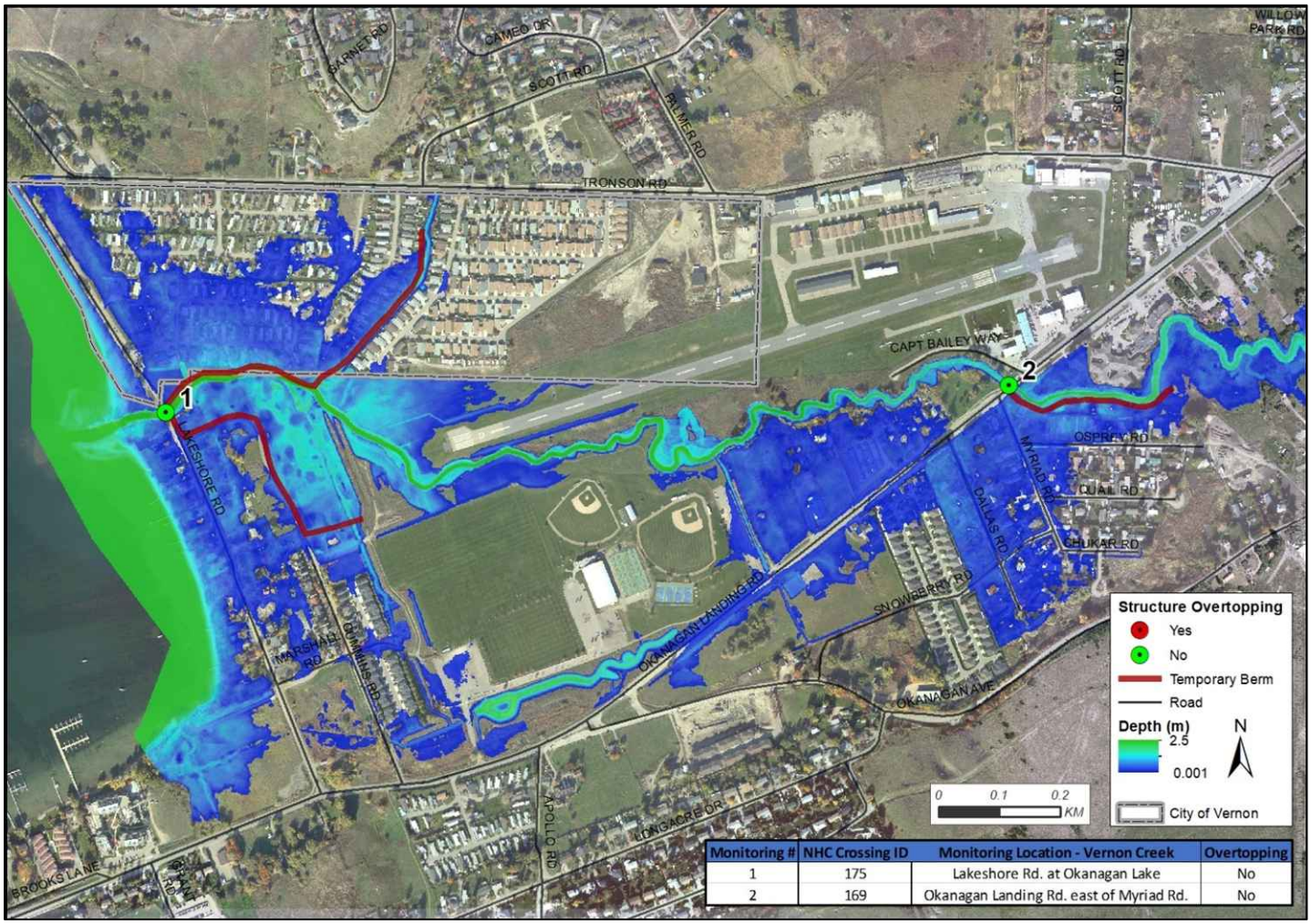

Figure 5 - Example of temporary berms that could be strategically located in a flooding emergency

2. OCP Amendment and Flood Plain Bylaw

The second non-structural mitigation option, which is of equal priority to the first, is to establish flood bylaws that provide guidance for development within the floodplain. The existing OCP must be

updated to incorporate restrictions to development within the floodplain and a floodplain bylaw developed utilizing the floodplain maps created as part of this project.

3. Sediment and Debris Management Plan (Upper BX Creek)

There is a well-documented history of sediment transport and the associated flood risk on Upper BX Creek. An update to the sediment and debris management plan is recommended that considers existing sediment loading on Upper BX Creek. Sediment basins have been constructed and maintained downstream of Pleasant Valley Road and between 48th Avenue and 20th Street crossings. There is also a sedimentation pond planned for 2022 in the BX Dog Park which will provide the community with increased protection from sediment transport into the City (Figure 6).

Figure 6 – BX Sediment Pond rendering

4. Diking between 20th Street and Deleenheer Road (Upper BX Creek)

The area between 20th Street and Deleenheer Road has experienced various degrees of flooding in 1996, 2008, 2017, 2018 and 2020. The left bank of Upper BX Creek along this reach has been identified as a concern during the 20-year, 200-year and design flood event which was further supported by the detailed modelling completed in this project (See Figure 7). This bank is low in some areas and during the higher flow events, flow is observed leaving the channel along this reach. Its anticipated that diking along this reach would likely provide effective flood mitigation. However, significant challenges exist due to the complex engineering, lengthy permitting process, ongoing maintenance required by the diking authority and land acquisition. Figure 7 shows the unmitigated flooding depth under the modelled scenario, and the flooding scenario with a potential riverside dike. The report recommends crossing upgrades be constructed around the same time to have the biggest impact on the area (option 6 below). Given the complexity of diking along Upper BX Creek, the report suggests that a feasibility study be completed first to aid in the decision making process.

Figure 7 - unmitigated flooding during design event along Upper BX Creek, mitigated (right)

5. Crossing upgrades on 43rd Street, Okanagan Landing Road, and Lakeshore Road (Lower Vernon Creek)

   The Part 1 Report identified that if the crossings at key locations had increased capacity, the flood risk to adjacent properties would be greatly reduced. To increase capacity, clear span bridges were assumed which allowed for a quick assessment of the potential impacts which crossings would have the largest impact on the flood risk. However, a clear span bridge is not the only method for increasing capacity. The three crossing upgrades recommended for lower Vernon Creek are all considered large capital projects that would likely require raising roads (and associated utilities), construction of large clear span structures that do not constrict the waterway, and possible property acquisitions. Despite the high costs, the improved crossings are anticipated to greatly reduce flood risk at all locations. Similar to option 4 above, this project requires a further feasibility assessment to determine the best method for increasing capacity and other complexities such as permitting, environmental impacts and opportunities for the public such as trail networks, etc. It's likely that any structural mitigation will take years before construction could start and would likely need to be phased over several years, however the feasibility study could start immediately.

   <u>43rd Street Crossing</u>

   The existing crossing at 43rd street is an open bottom arch culvert with concrete headwalls. The crossing is undersized and backwaters the upstream channel. Under design flood conditions, this results in overbank flooding on both sides of the channel (See Figure 8). On the right side (facing downstream), a larger corner property and social services buildings are inundated. On the left side, the overbank flooding extends onto 43rd Street, inundating the road southwest of the crossing as well as an industrial property. Flow on 43rd Street is conveyed further southwest and flooding directly affects approximately 50 homes. Flooding further affects six residential roads in the neighborhood, blocking access to additional homes before flows rejoin lower Vernon Creek around 16th Avenue.

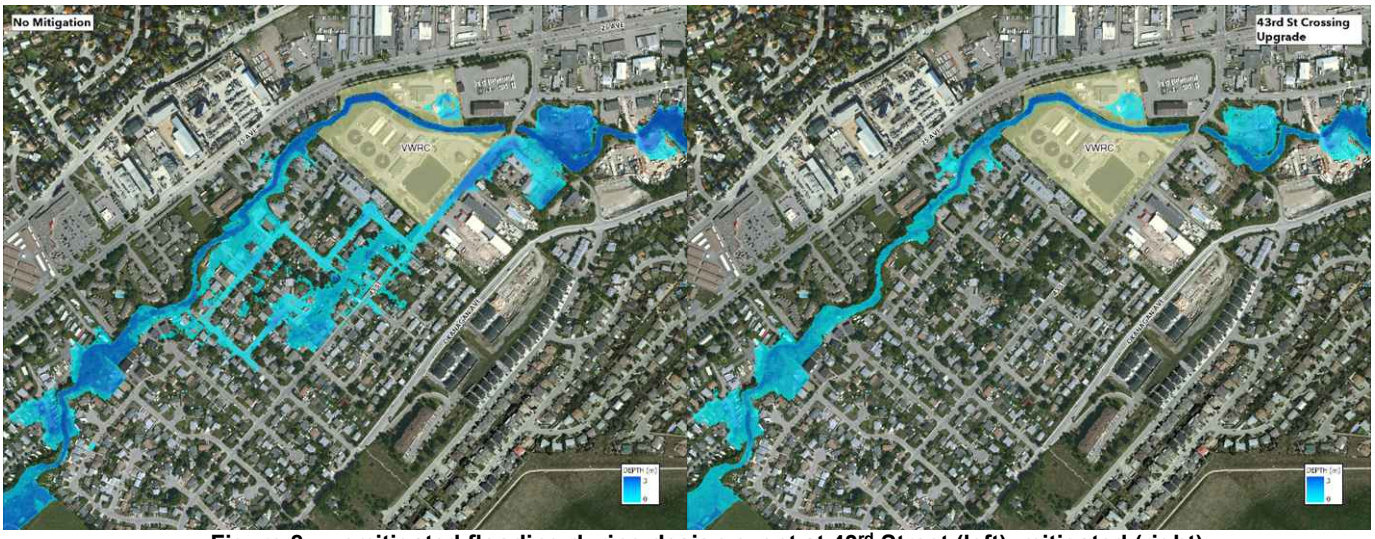

Figure 8 - unmitigated flooding during design event at 43rd Street (left), mitigated (right)

Okanagan Landing Road Crossing

The existing Okanagan Landing Road crossing is a 4.15m wide by 2.55m high elliptical corrugated metal culvert. The crossing is undersized and backwaters the upstream channel, causing overbank flooding on both banks under the modeled design flood conditions. The left overbank flooding directly impacts approximately 70 homes, as well as five residential roads, before overtopping Okanagan Landing Road. From there, the overland flow floods eight additional properties before rejoining lower Vernon Creek. The proposed crossing upgrade consists of replacing the culvert with a 19m clear span bridge. With the increased capacity, left overbank flooding is almost entirely avoided. Approximately 10 homes and properties remain impacted but the remaining level of inundation can likely be addressed through as-needed protection measures such as sandbagging.

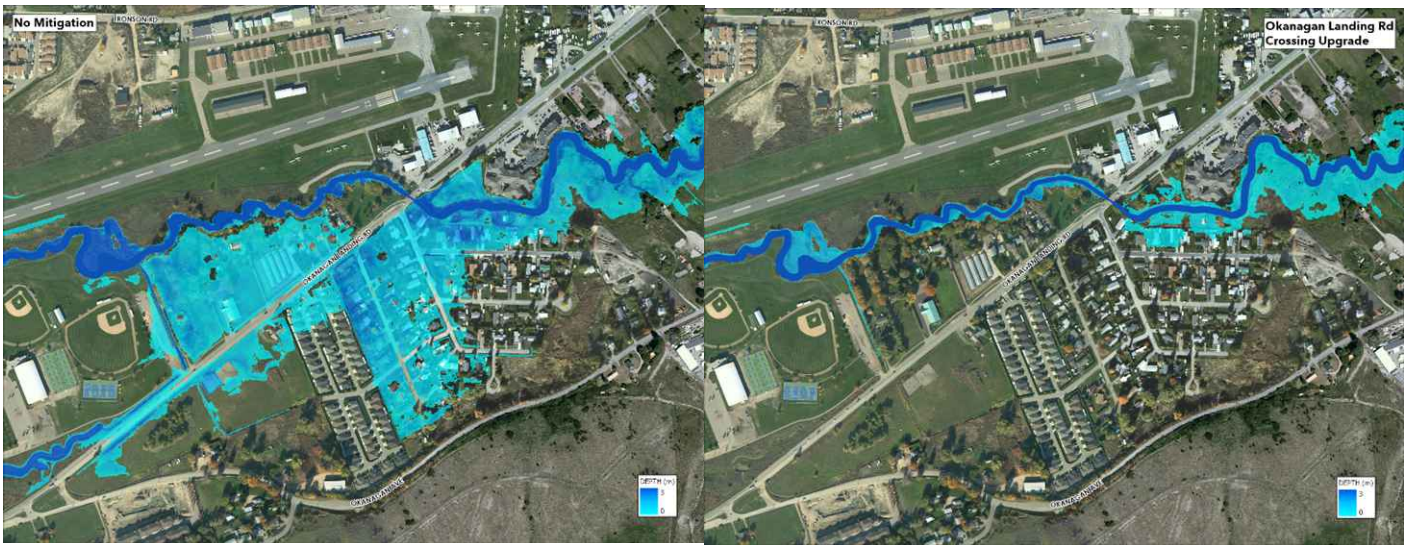

Figure 9 - unmitigated flooding during design event at Okanagan Landing Road (left), mitigated (right)

Lakeshore Road Crossing

The existing Lakeshore Road crossing is a 4.3m wide by 2.7m high arch culvert located at the outlet of Vernon Creek to Okanagan Lake and is undersized. To better understand the impacts resulting from Okanagan Lake shoreline flooding and backwatering versus overbank creek flooding from the undersized crossing, the crossing was modeled under four conditions for the design flow on lower Vernon Creek. The existing and proposed crossing were modeled under the design water level in

Okanagan Lake (343.9) as well as at a reduced water level to indicate no shoreline flooding (341.9); comparable to the lowest lake level likely to occur during freshet period. Modelling results are illustrated below:

Table 3 – Modelled conditions of Lakeshore Road crossing upgrade

Condition	Crossing Description	Okanagan Lake Water Level	Approx. Number of Flooded Homes
Condition 1	Existing culvert	343.9 m (design condition)	140
Condition 2	Proposed clear span bridge	343.9 m (design condition)	90
Condition 3	Existing culvert	341.9 m (2 m below design condition)	105
Condition 4	Proposed clear span bridge	341.9 m (2 m below design condition)	10

Figure 10 – Flooding scenarios at Lakeshore Road creek crossing

6. Crossing upgrades on 20th Street and 48th Avenue (Upper BX Creek)

   Like lower Vernon Creek crossing upgrades, the Upper BX Creek crossing upgrades at 20th Street and 48th Avenue are considered large capital projects that will have very high costs. The cost of this mitigation option is anticipated to be much higher than the downstream diking between 20th Street

and Deleenheer Road, and would have a similar reduction in flood risk. Design of this option should consider sediment transport, suitable clearance at crossings, existing channel constructions and channel improvements between crossings. Similar to option 5 above, the consultant considered only a clear span bridge to allow for a quick assessment comparing increased capacity to impacts on the flood risk to adjacent properties. A feasibility assessment will be required to further review and refine best methods for increasing capacity on each proposed crossing upgrade. Figure 11 below shows the comparison between existing conditions, option 6, and option 4 plus option 6.

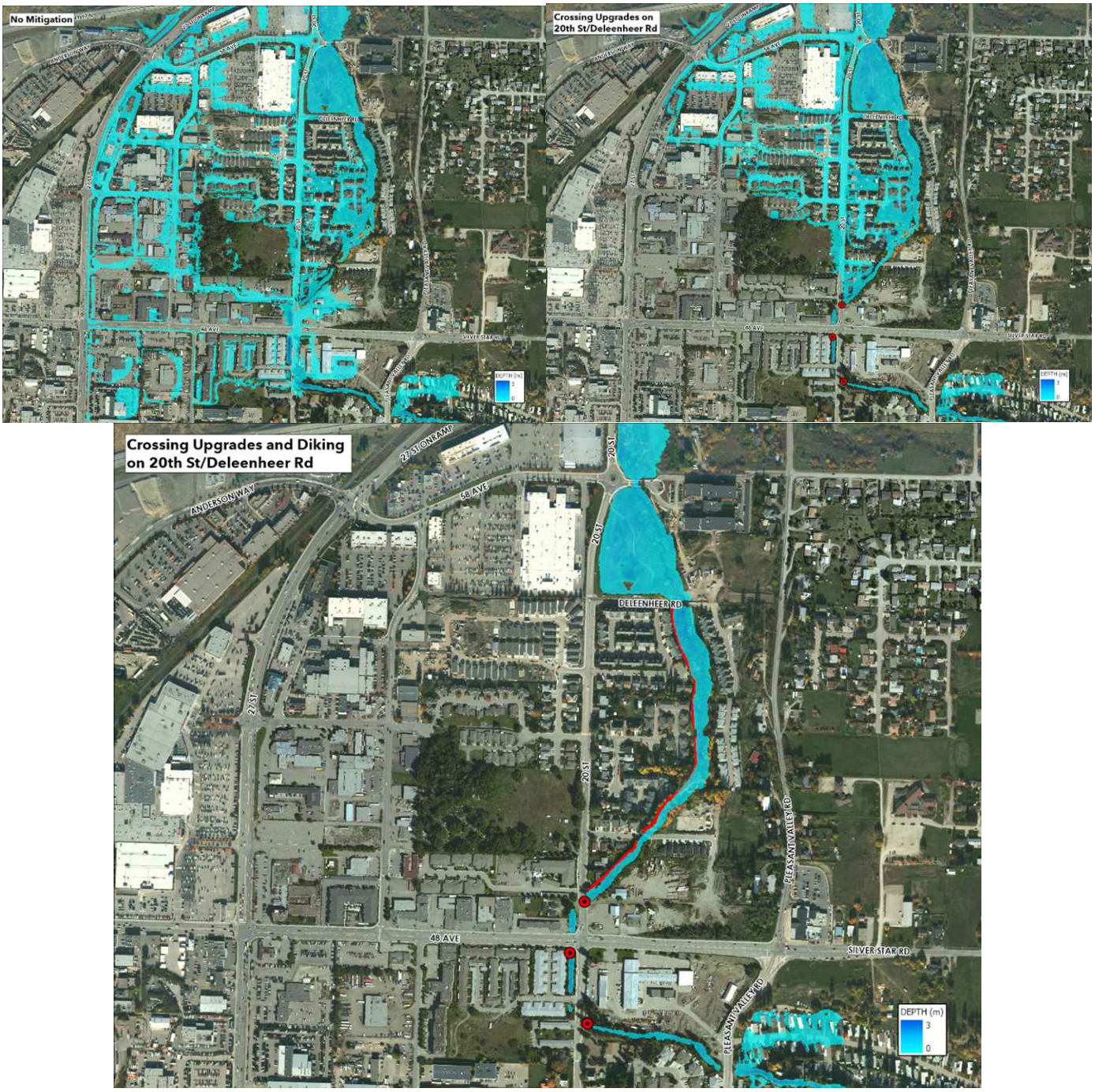

Figure 11 – Top left image is existing conditions. Top right is flooding depths after crossing upgrades are completed under mitigation option 6. Bottom image is crossing upgrades mitigation option 6 and diking between 20th Street and Deleenheer Road mitigation option 4 combined.

7. Public Engagement

The City has developed an interactive story map on the City's website to engage the public on Vernon's flood story. An interactive story map was deemed to be the best way to inform the public of the information developed through this project. The interactive story map provides detailed information on the work that was completed to identify the flood plain, the potential impacts to the community and the recommended mitigation projects. The story map contains interactive mapping that shows flood hazard mapping and the floodplain mapping in relation to individual properties. Additional information on the history of flooding, historical images, and flooding resources are also presented. The information in the interactive website mirrors the information contained in this Council report and accompanying presentation to Council.

Also, as the floodplain maps were being developed and draft maps being made available to the City, the City had been sharing the information with development applications that would have been impacted by the identified natural hazard. The City has been working with the development community while bylaws and policies are being developed, to complete site specific flood hazard assessments. This is a step that would not have been taken under previous development applications without having these floodplain maps. The City has shared the final report and mapping with the OKIB, Regional District of North Okanagan (RDNO), District of Coldstream, Okanagan Basin Water Board and Interior Health.

Along the downstream extent of Vernon Creek to Okanagan Lake sits Priest's Valley 6 which is part of the Okanagan Indian Band. In the event of a hazardous flood, Priest's Valley residents are likely to be displaced into Vernon. Through this project and working collaboratively with Okanagan Indian Band (OKIB), a flood risk assessment of Priest's Valley and hazard/inundation mapping had been completed for this area. The City has been working with OKIB to incorporate the inundation levels of Vernon Creek within the IR6 and to also assess potential mitigation measures along this downstream extent of Vernon Creek. The impacts to OKIB contributed to the recommended prioritization of mitigation measures which were explored as part of this project. Public input has, and will continue to provide, meaningful contributions to this project, which will result in a more flood resilient community.

C. Attachments:

Attachment 1 – Detailed Flood Mapping, Risk Analysis and Mitigation Part 1 – Upper BX Creek
Attachment 2 – Detailed Flood Mapping, Risk Analysis and Mitigation Part 1 – Upper BX Creek Mitigation Evaluation
Attachment 3 – Detailed Flood Mapping, Risk Analysis and Mitigation Part 2 – BX Creek below Swan Lake and Vernon Creek below Kalamalka Lake
Attachment 4 – Part 1 & 2 Combined Index Map
Attachment 5 – Part 1 & 2 Combined Floodplain Map
Attachment 6 – Part 1 & 2 Combined Hazard Map

D. Council's Strategic Plan 2019 - 2022 Goals/Action Items:

The proposed recommendation involve the following goals/action items in Council's Strategic Plan 2019 – 2022:

- Use public engagement tools for the flood mapping study
- Complete the Lower BX Creek detailed flood mapping, risk analysis and mitigation
- Complete Vernon Creek detailed flood mapping, risk and threat assessment and mitigation (grant funding secured)
- Complete Flood Risk Study with maps to set the basis for future bylaws
- Study the impacts of flooding and drainage and plan for it
- Present a drainage and water resources policy and bylaws gap analysis report to Council

E. Relevant Policy/Bylaws/Resolutions:

N/A

BUDGET/RESOURCE IMPLICATIONS:

All of the mitigation recommendations would be considered projects that will required a dedicated project manager with flood expertise. The Water Resources Engineer was a term position with the term set to expire in 2023. It is recommended that the Water Resources Engineer position be made permanent with funding from the 1.9% Infrastructure Levy. If this recommendation is approved it will be included in the 2023 Financial Plan in order for the City of Vernon to move forward with implementing the structural and non-structural mitigation projects as well as continue to advance the City's Priority Drainage Improvements (Financial Plan Projects).

The structural mitigation projects could be funded from the Infrastructure Program and the 1.9% Infrastructure Levy. This would be an additional cost to the program and would require several years being added to the program. The impact of these projects to the Infrastructure Program will be considered and reported back to Council when Administration has completed additional feasibility engineering work.

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REVIEWED WITH

- ☐ Corporate Services
  - ☐ Bylaw Compliance
  - ☐ Real Estate
- ☐ RCMP
- ☒ Fire & Rescue Services
- ☐ Human Resources
- ☐ Financial Services
- ☐ COMMITTEE:
- ☐ OTHER: Local Engineering / Environmental Firm
- ☒ Operations
  - ☐ Public Works/Airport
  - ☐ Facilities
  - ☐ Utilities
- ☐ Recreation Services
- ☒ Parks
- ☒ Current Planning
- ☒ Long Range Planning & Sustainability
- ☒ Building & Licensing
- ☒ Engineering Development Services
- ☒ Infrastructure Management
- ☒ Transportation
- ☐ Economic Development & Tourism

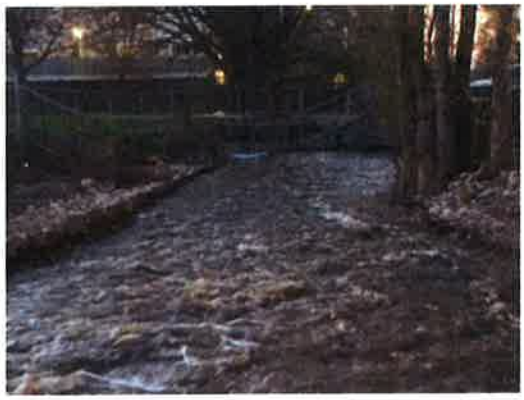
CITY OF VERNON
DETAILED FLOOD MAPPING, RISK ANALYSIS AND MITIGATION
PART 1 – UPPER B.X. CREEK

FINAL REPORT
Revision No. 0

Prepared for:

CITY OF Vernon

City of Vernon



25 August 2020

NHC Ref. No. 3005032

nhc
northwest hydraulic consultants
water resource specialists

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

FINAL REPORT

Prepared for:

City of Vernon
Vernon, BC

Prepared by:

Northwest Hydraulic Consultants Ltd.
Kamloops, BC

25 August 2020

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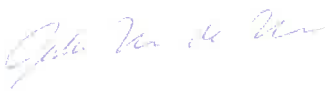

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DISCLAIMER

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:

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- Hydrologic Analysis (Joel Trubilowicz)
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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.

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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.

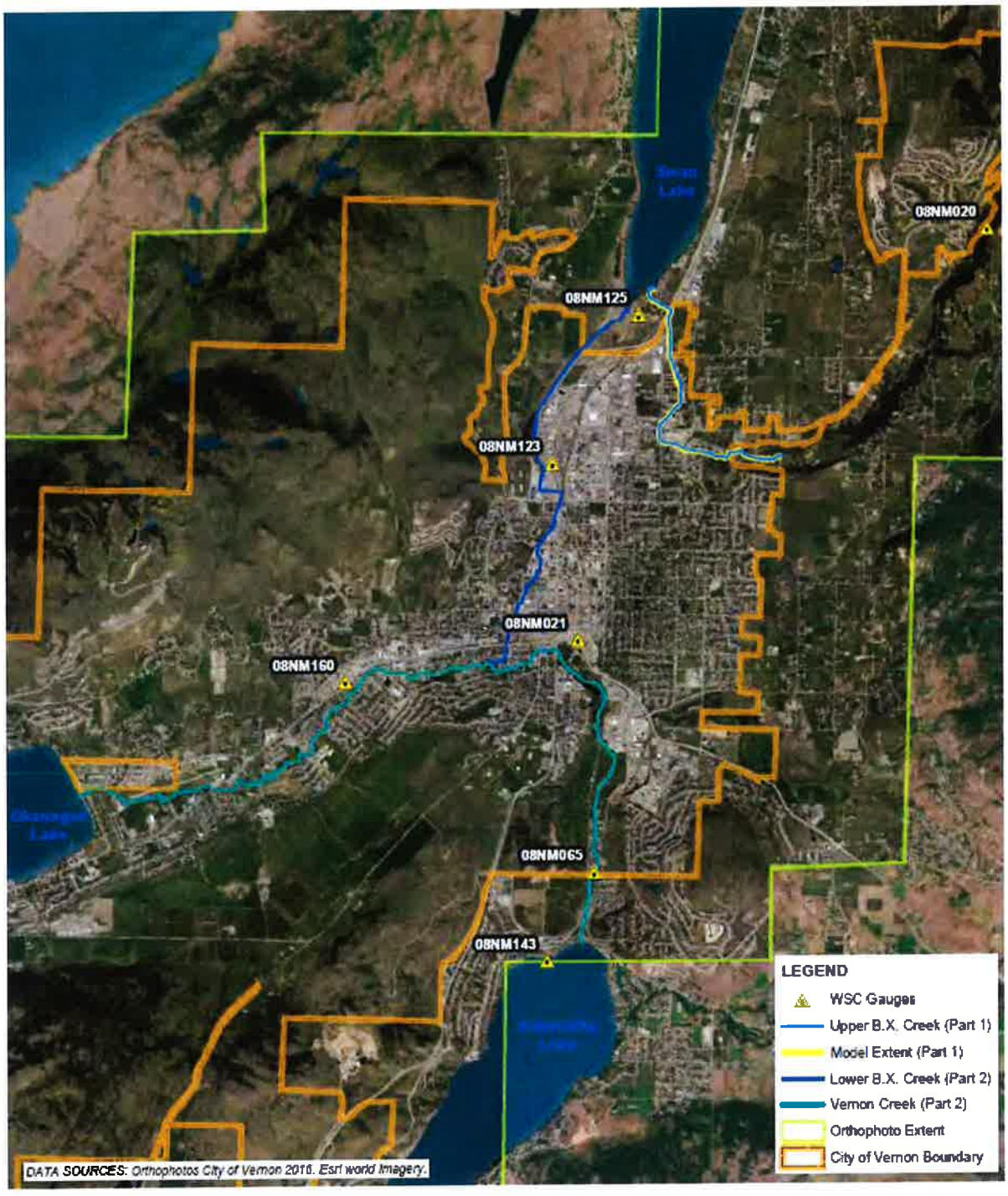


Figure 1.1 Project location for Parts 1 and 2.

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 28th to October 25th, 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.

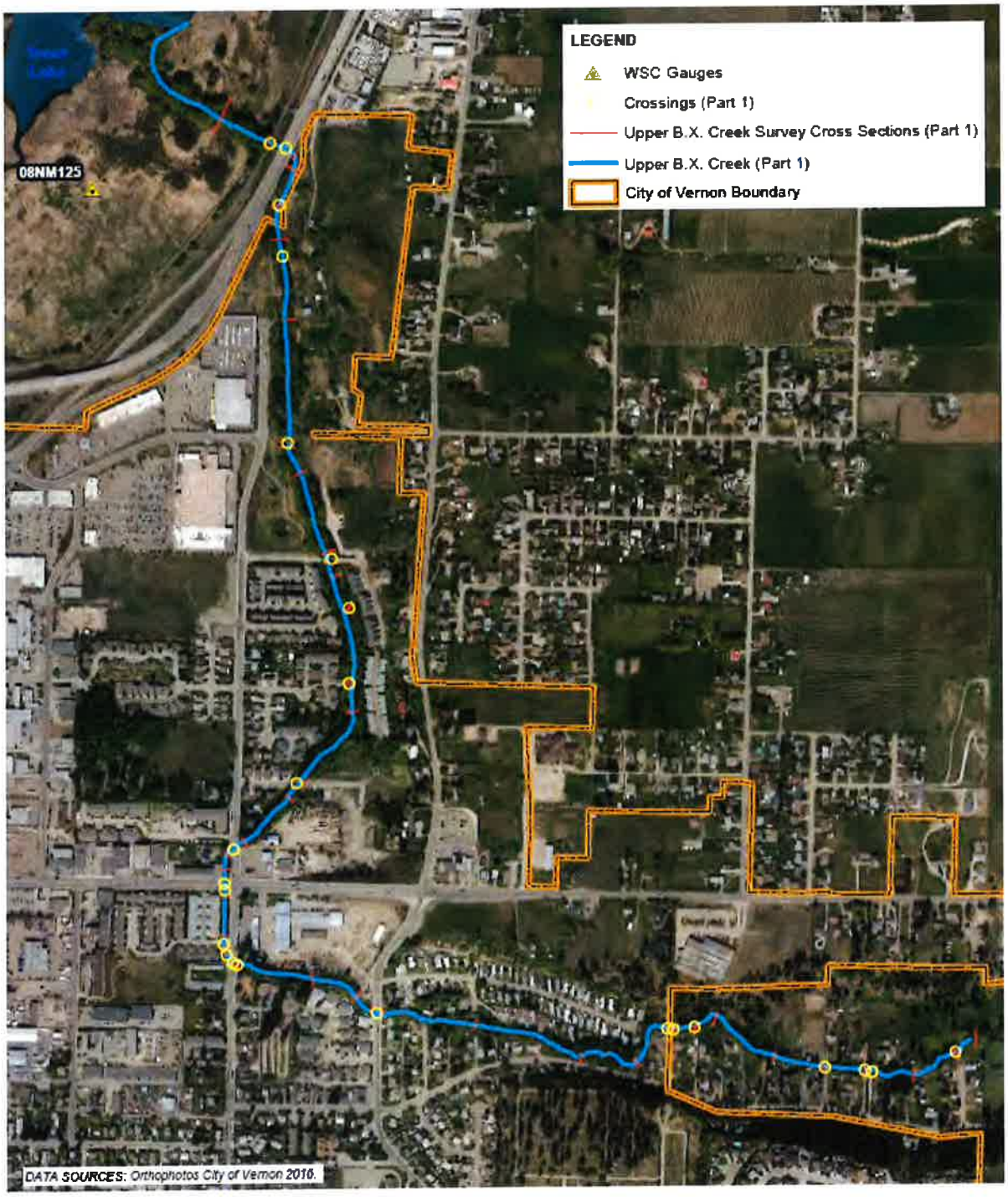


Figure 3.1 Survey extent Upper B.X. Creek.

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).

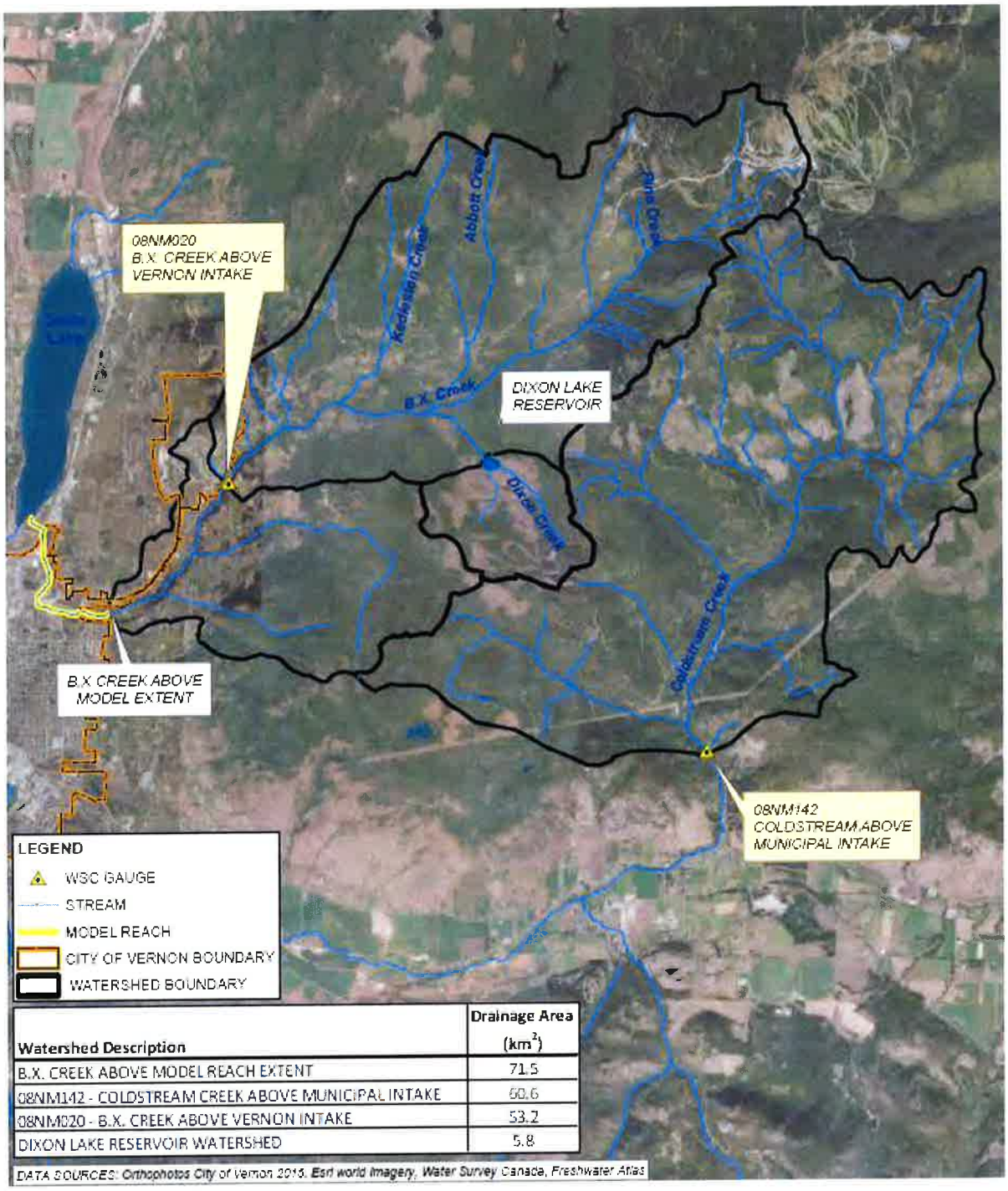
4.1 Design Flows at Upper B.X. Creek

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.

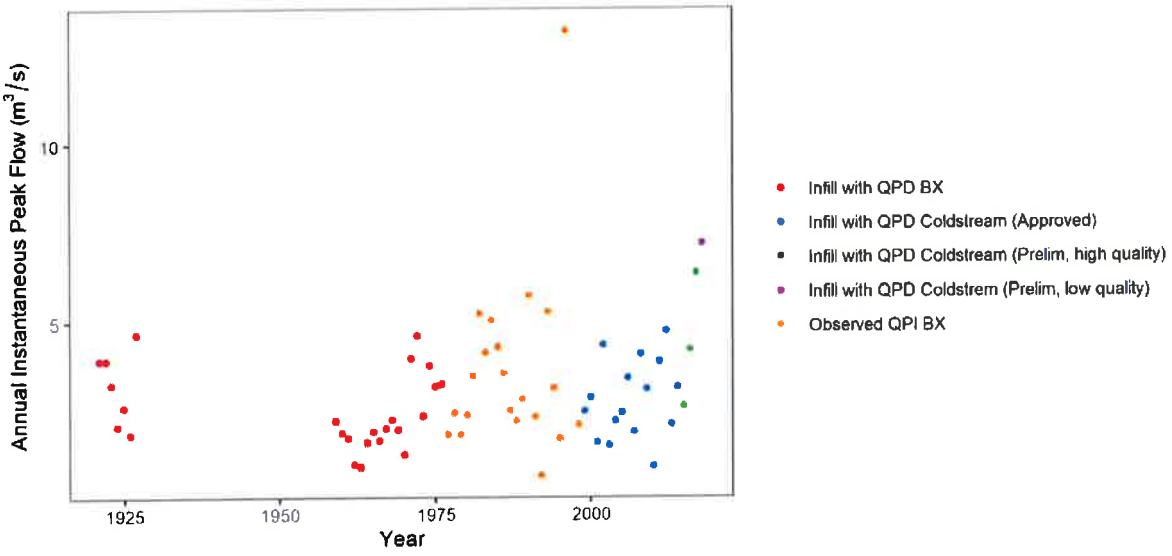


Figure 4.2 Extended annual instantaneous peak flow (QPI) record for WSC B.X.

[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.

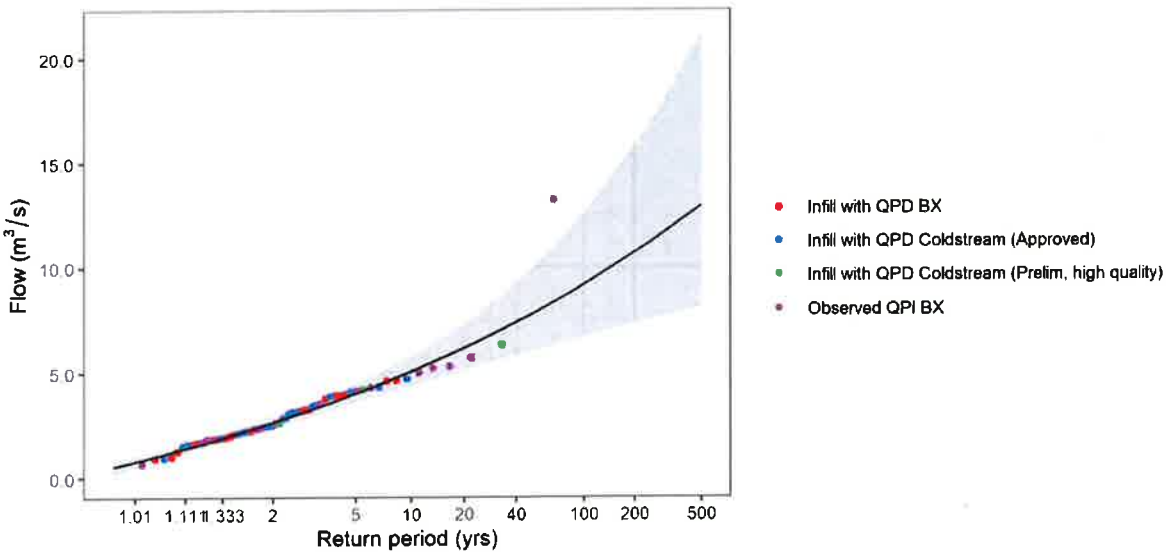


Figure 4.3 Frequency analysis results for extended QPI record at WSC B.X., using the GEV distribution. Grey band indicates 90 % confidence intervals.

[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/m² (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.

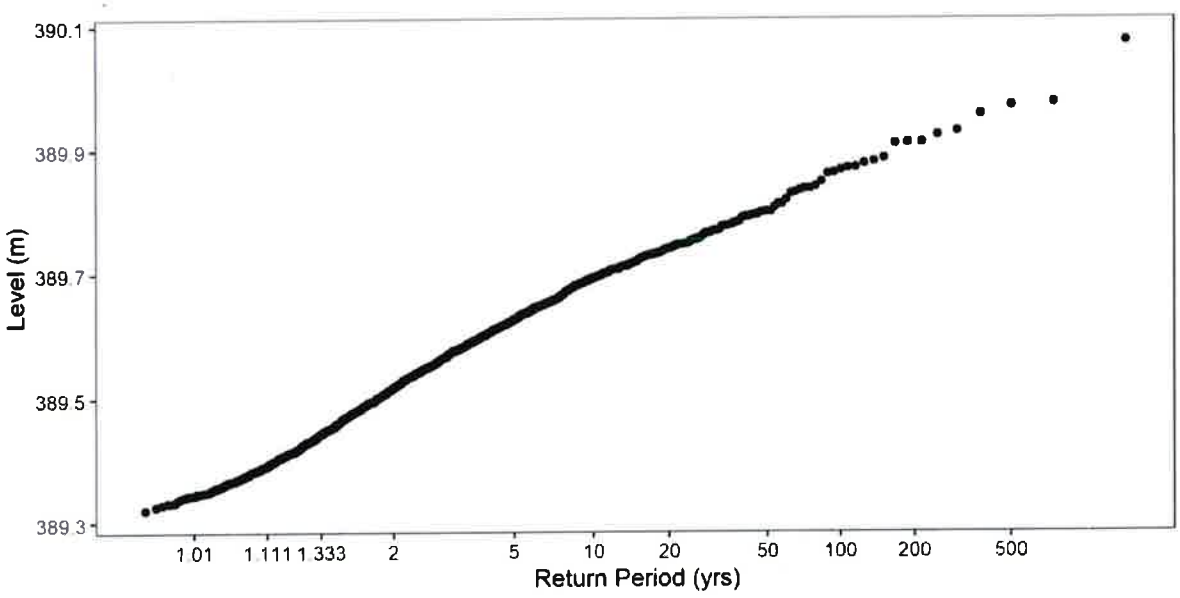


Figure 4.4 Example empirical frequency analysis for Swan Lake 2006-2035 annual maximum levels from ensemble hydrologic modelling.

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.

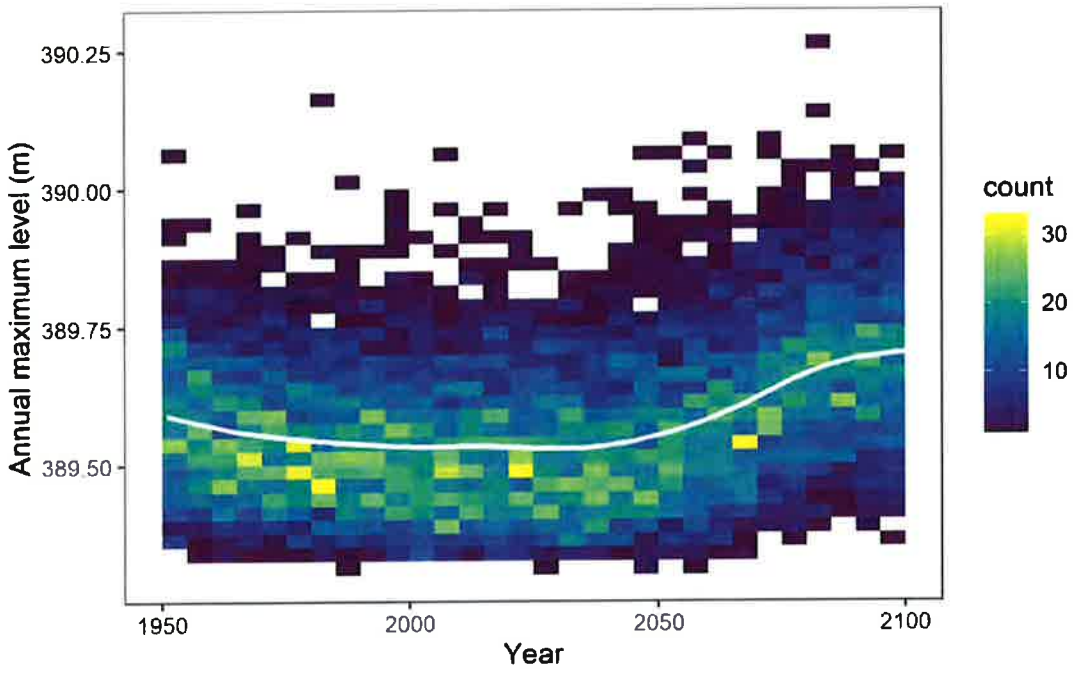


Figure 4.5 **Swan Lake ensemble simulation results, showing the maximum reservoir level reached per year as a 2D histogram. White line is a smoothed line showing the general trend over time.**

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 20th Street, composed of an arch culvert followed by a box culvert, and the crossing at 48th 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 (average of inlet and outlet infilling)	39 (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.

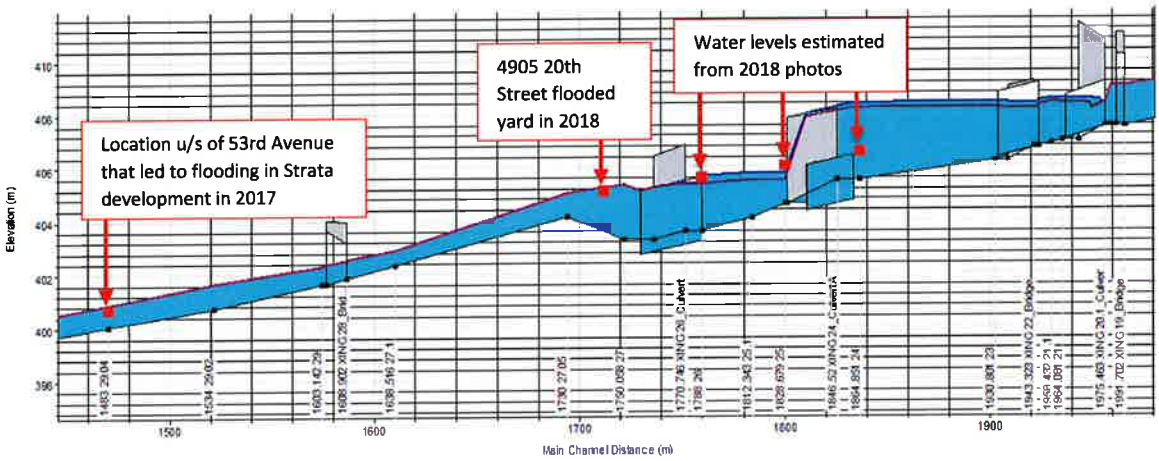


Figure 5.2 Calibration results for the 2018 and 2017 spring flood with 2015 (light blue infill profile) and 2019 (purple profile) infilling levels.

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).

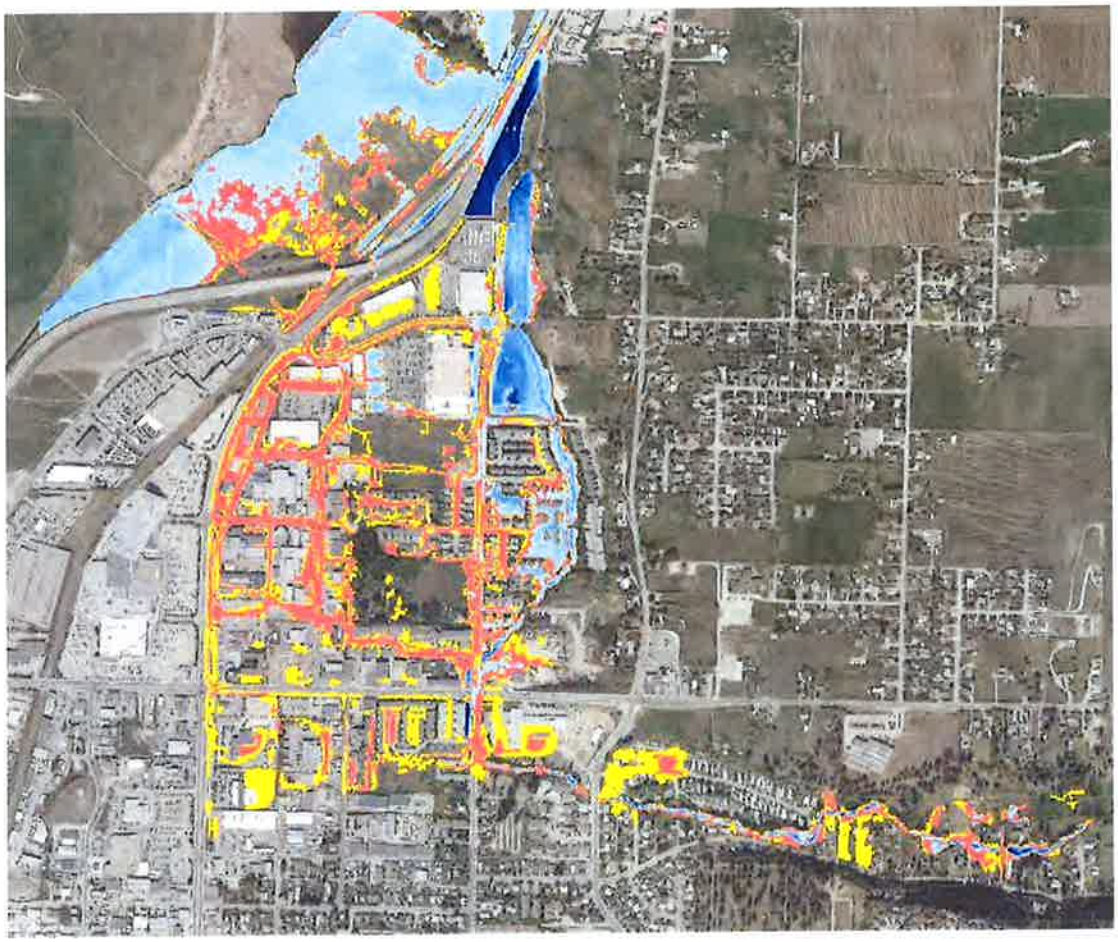


Figure 5.5 **Comparison of flood extents with Condition 1 for the design flood event (yellow + red + blue), the 200-year flow with climate change (red + blue) and the 20-year flood (blue).**

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.

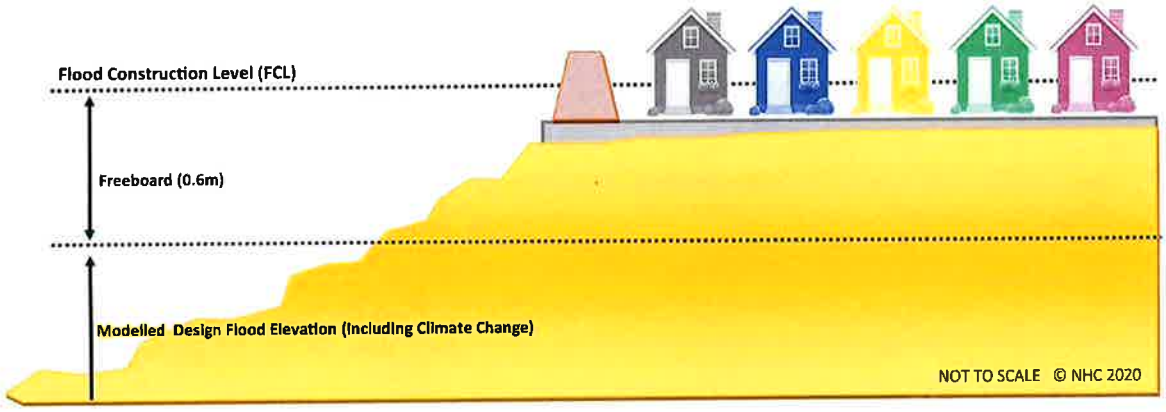


Figure 6.1 FCL schematic for rivers.

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).

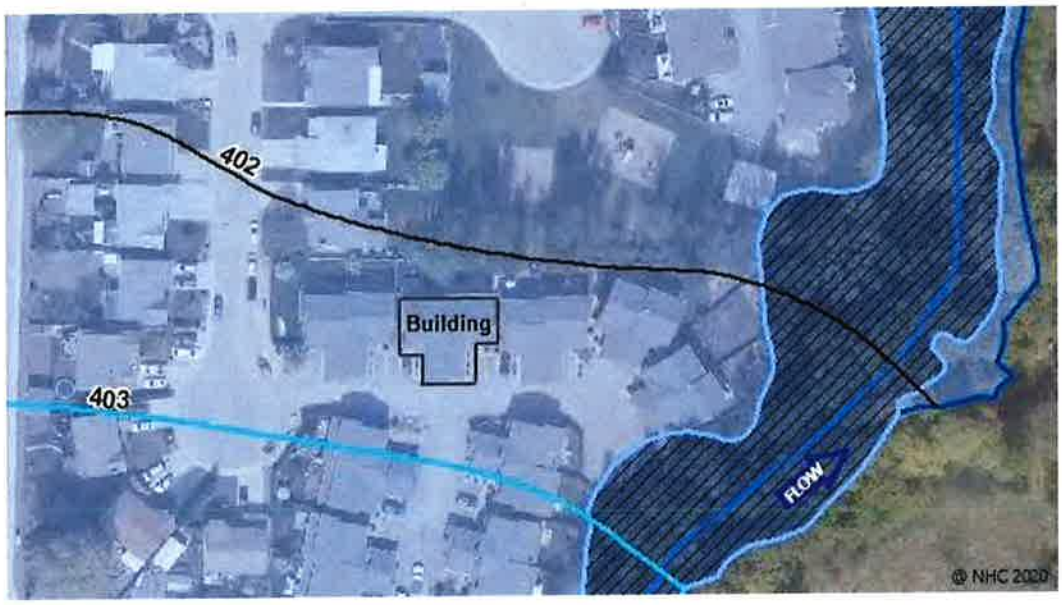


Figure 6.2 Example of FCL line calculation.

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.

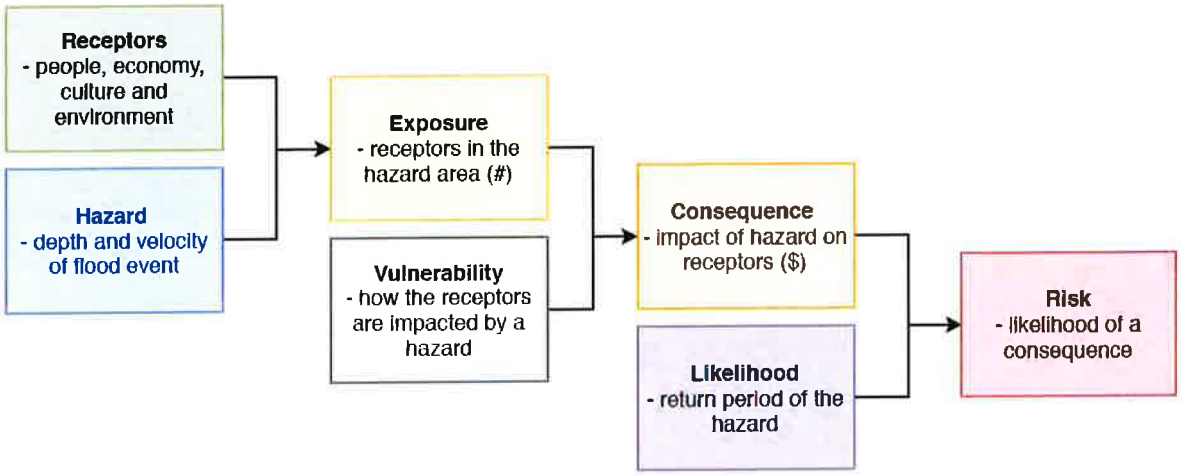


Figure 7.1 Terminology and Concept Diagram.

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
		Length (m)	776	5422
BC Hydro	Underground hydro distribution (secondary lines)	Count	32	207
		Length (m)	650	4,734
	Underground hydro distribution (primary lines)	Count	0	91
		Length (m)	0	5,797
	Overhead hydro distribution (secondary lines)	Count	12	71
		Length (m)	351	1,998
	Overhead hydro distribution (primary lines)	Count	8	61
		Length (m)	295	2,583
	Hydro poles	Count	2	45
	Hydro junction boxes	Count	3	15
	Hydro underground transformer	Count	1	1
FortisBC Gas	Distribution valves	Count	0	1
	Distribution pipes	Count	59	187
		Length (m)	2,739	8,646
Shaw Telecom Infrastructure	Facility	Count	10	10
	Pole	Count	4	70
	Underground line	Count	52	246
		Length (m)	3,312	12,141
Telus Telecom Infrastructure	Facility	Count	0	2
	Poles and manholes	Count	1	73
	Cable wire	Count	76	356
		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 27th 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 *Reducing Exposure & Vulnerability*	Structural *Reducing Flood Hazard*

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

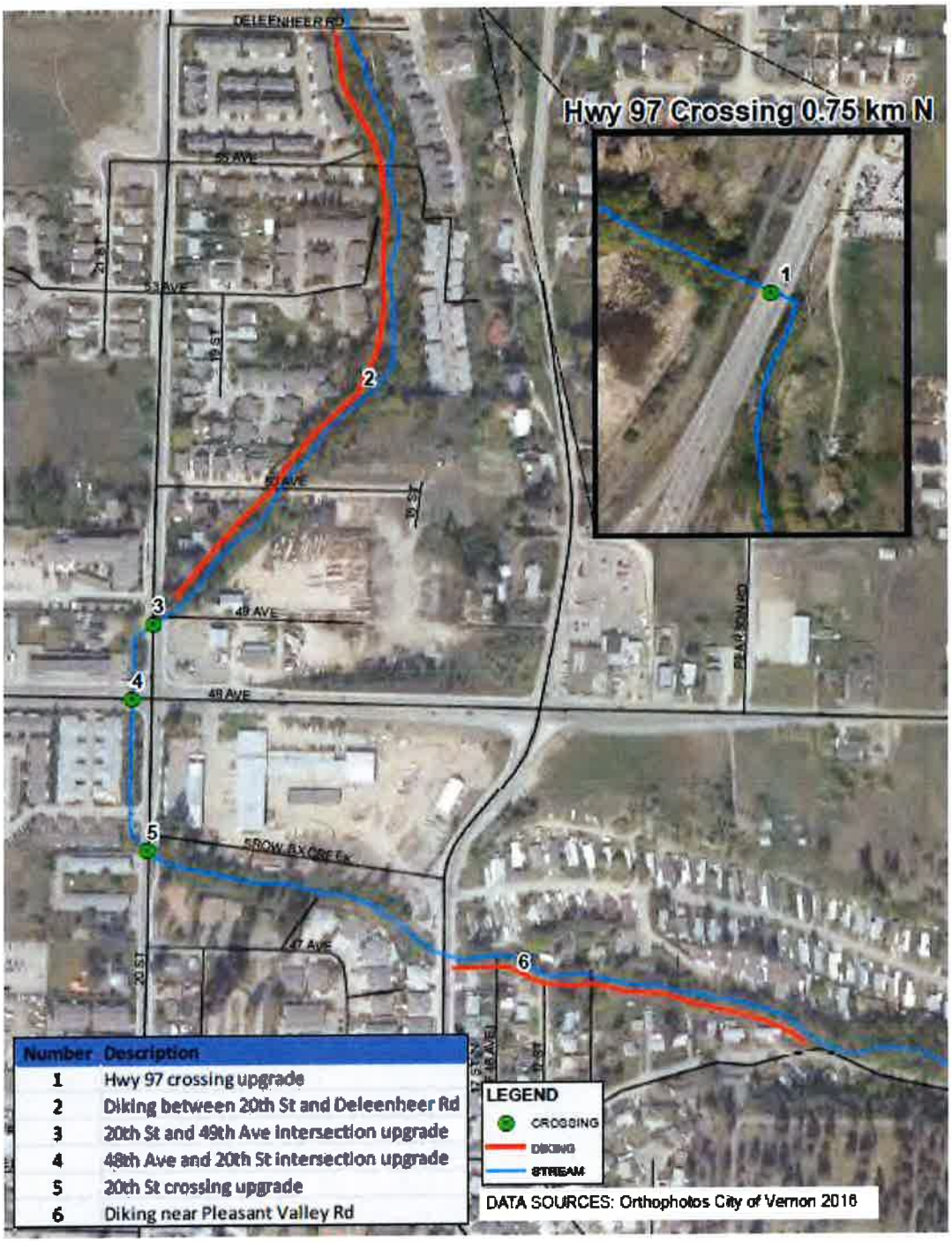


Figure 8.1 Suggested structural mitigation options for Upper B.X. Creek.

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 20th Street crossings and the 48th 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.

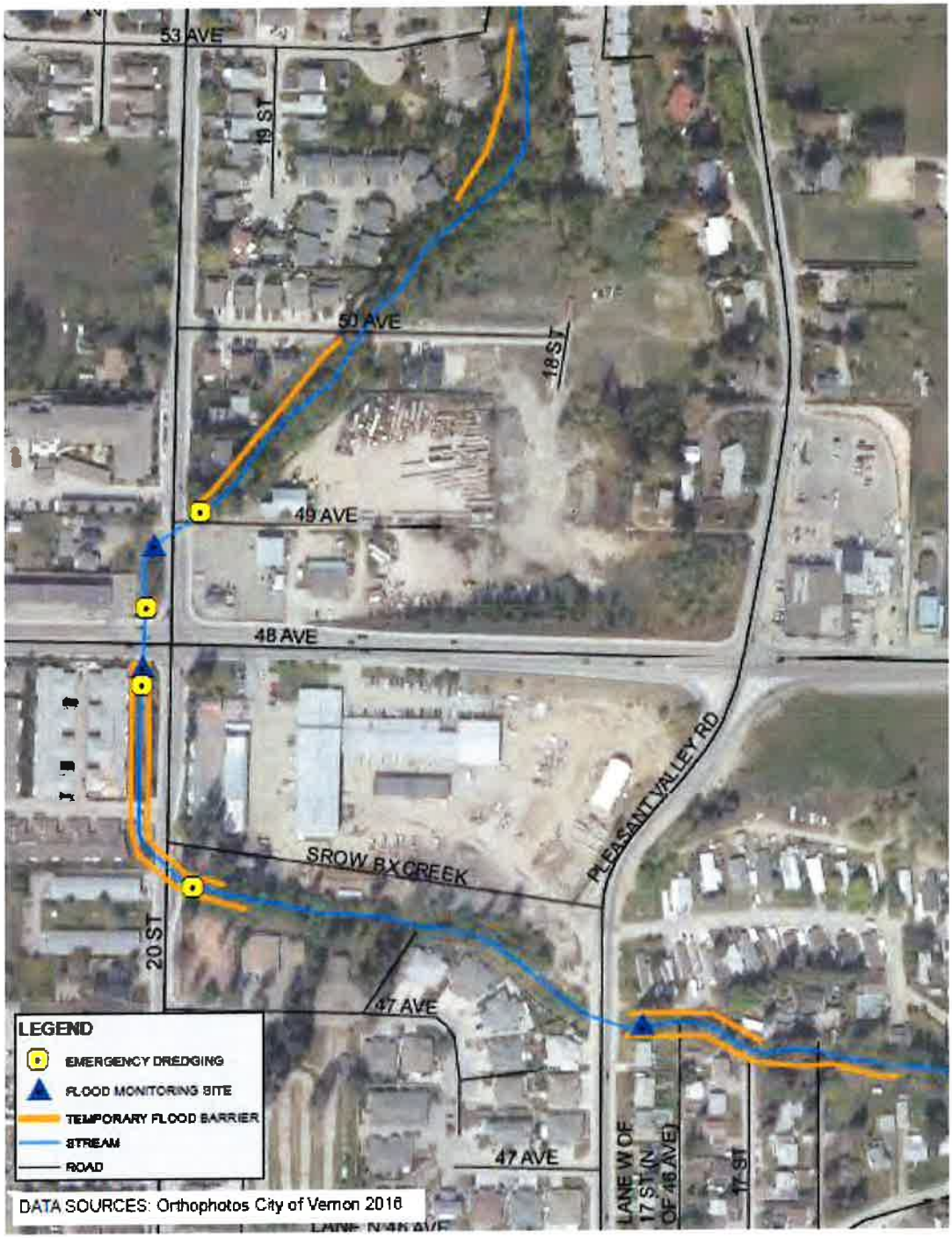


Figure 8.2 Suggested emergency response planning measures for Upper B.X. Creek.

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 20th Street crossing, first 48th Avenue crossing and second 20th 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

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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:	**Reviewed by:**
Unsigned document by ...	*Unsigned document by ...*
Arian Cueto Bergner, P. Eng. Project Engineer	Meg Broswick, P. Eng. Project Manager

ENCLOSURE

Figure 1 – City of Vernon Floodplain Mapping Study Area

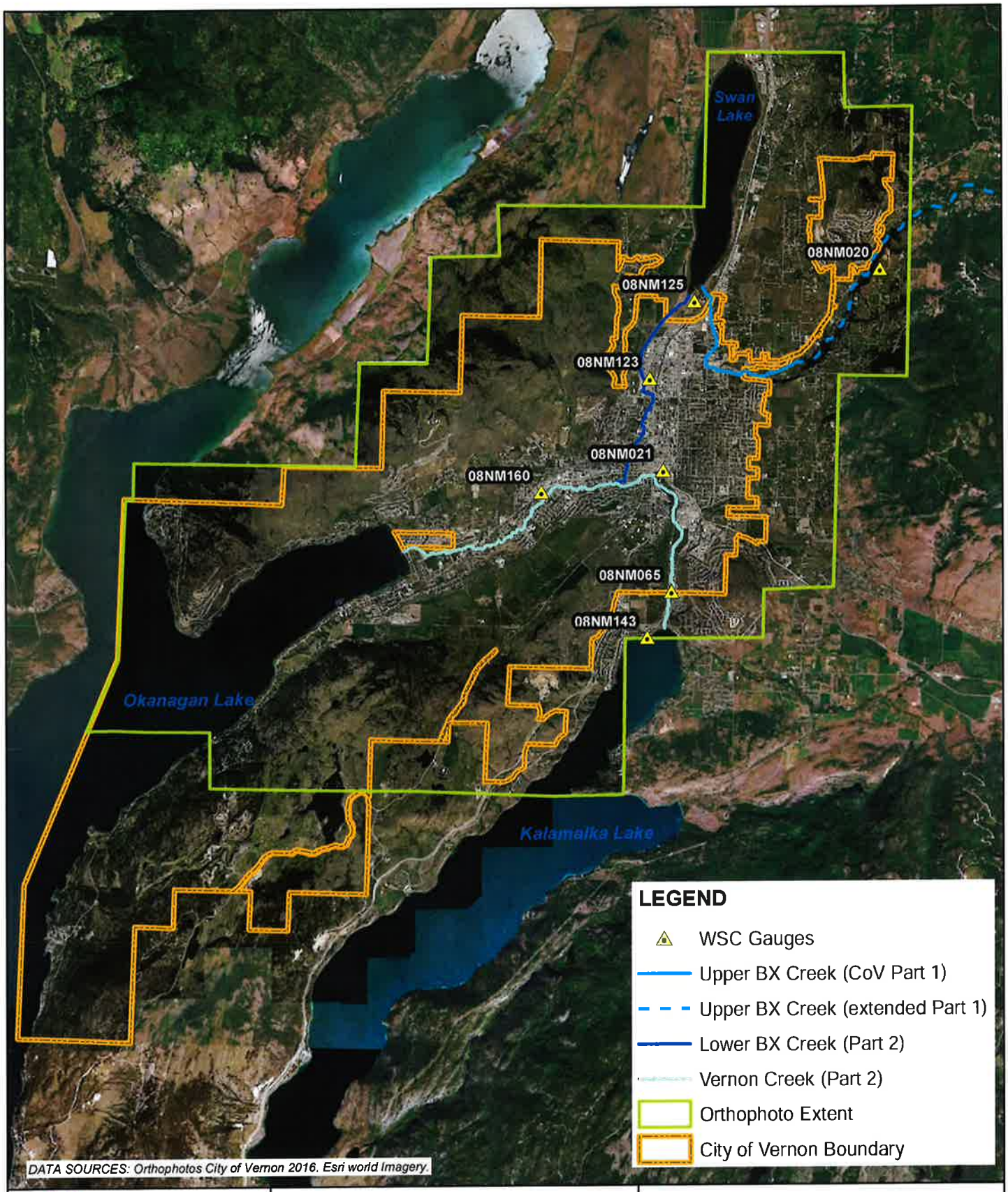
Figure 2 – Vernon Flood Mapping Survey Cross Sections, Upper B.X. Creek, Part 1

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

SCALE - 1:105,000

0 1 2 3 4 KM

N

nhc northwest hydraulic consultants

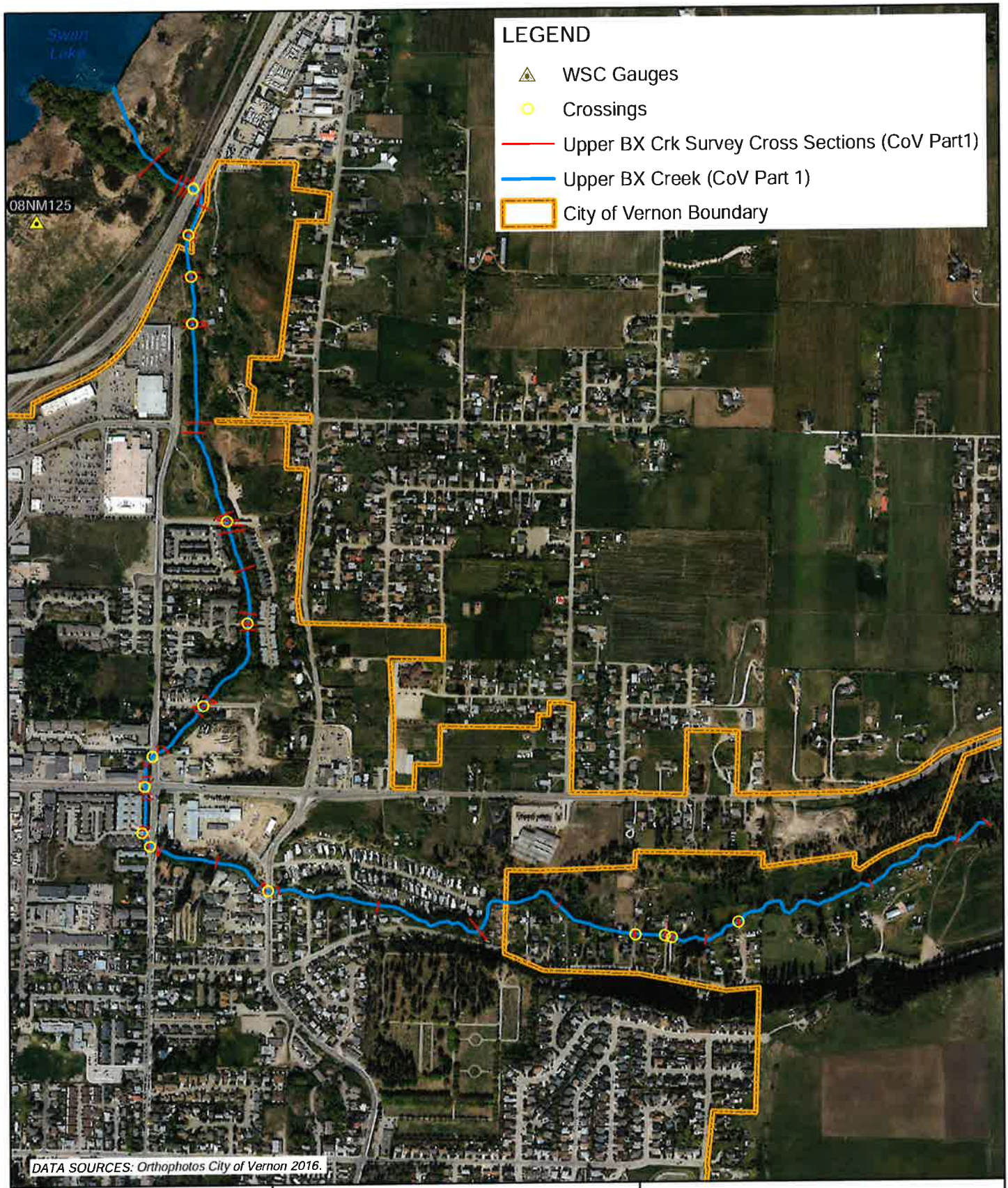
Coordinate System: NAD 1983 UTM ZONE 11N
Units: METRES

Job: 3005032 | Date: 17-SEP-2019

CITY OF VERNON FLOODPLAIN MAPPING STUDY AREA REFERENCE MAP

FIGURE 1

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



CITY OF Vernon

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

nhc northwest hydraulic consultants

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

Job: 3005032

Date: 17-SEP-2019

FIGURE 2

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%) 0.113 m blocked outlet (7%)	Not inspected
Bridge	930	58th Ave. Extension crossing	1.8	14.2		
Culvert	601	CSP culvert under construction 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 Highway 97 crossing	2	3.4	0.969 m blocked inlet (48%) 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.

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APPENDIX C Design Flow Estimation Technical Memo

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

nhc
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™, 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).

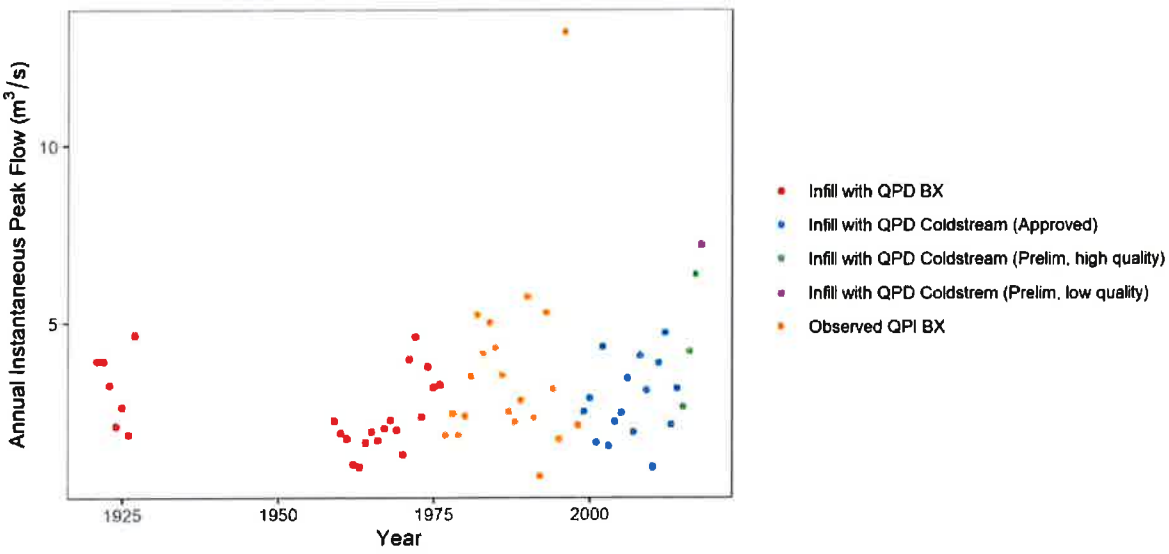

Figure 1 Extended annual instantaneous peak flow (QPI) record for WSC B.X.

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.

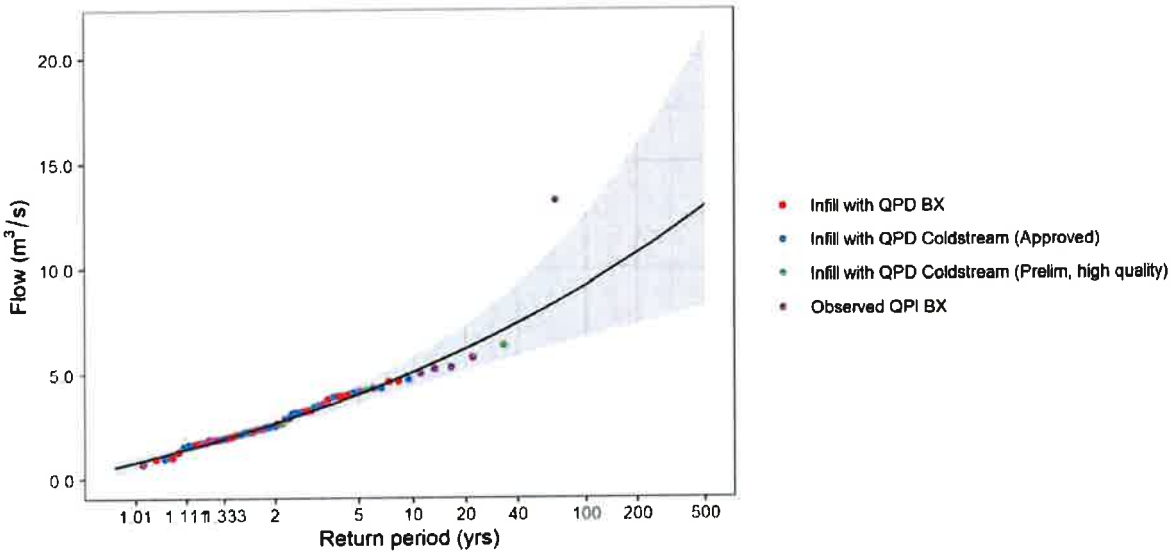

Figure 2 **Frequency analysis results for extended QPI record at WSC B.X., using the GEV distribution. Grey band indicates 90% confidence intervals.**

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.

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ENCLOSURE:

Appendix A: Additional Figures and Tables

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

DISCLAIMER

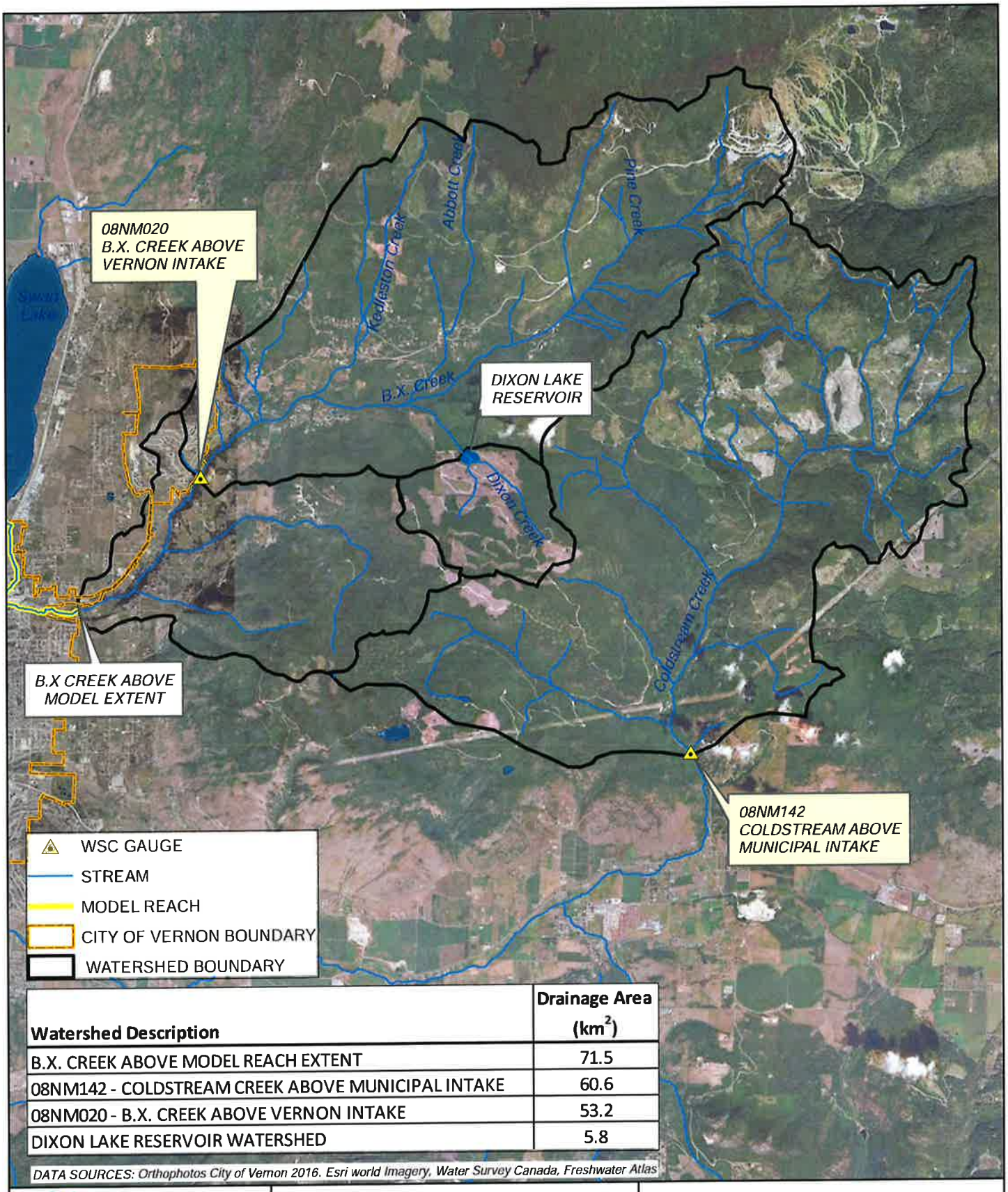
This document has been prepared by Northwest Hydraulic Consultants Ltd. for the benefit of the City of Vernon for specific application to floodplain mapping of B.X. Creek. The information and data contained herein represent Northwest Hydraulic Consultants Ltd. best professional judgment in light of the 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

SCALE - 1:92,000

0 1 2 4 KM

N

nhc northwest hydraulic consultants

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

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.**

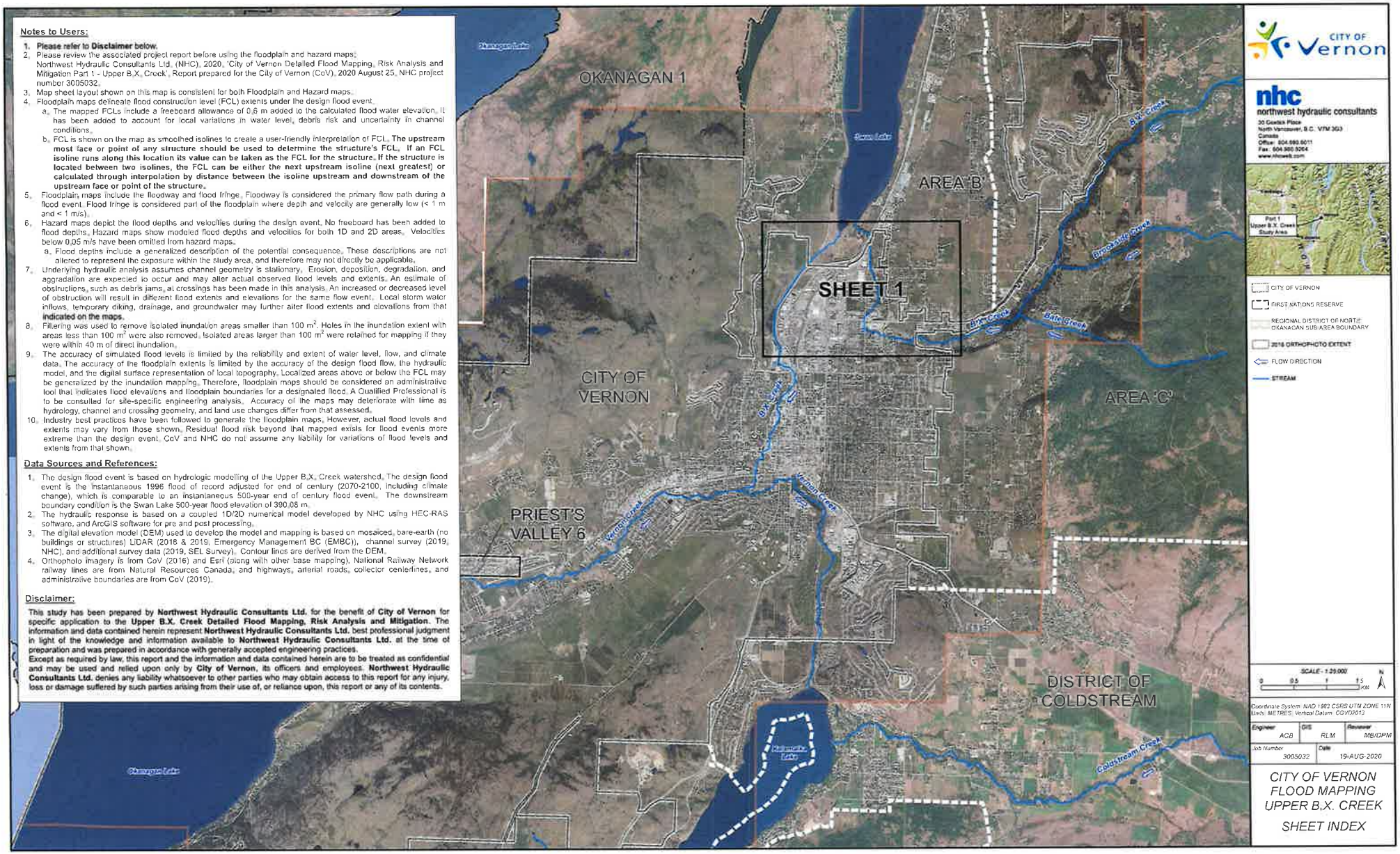
Year	QPD_BX (m^3/s)	QPI_BX (m^3/s)	Data type
1921	**3.3**	3.9	Infill with QPD BX
1922	**3.3**	3.9	Infill with QPD BX
1923	**2.8**	3.2	Infill with QPD BX
1924	**1.9**	2.1	Infill with QPD BX
1925	**2.3**	2.6	Infill with QPD BX
1926	**1.8**	1.8	Infill with QPD BX
1927	**3.8**	4.6	Infill with QPD BX
1959	**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. 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 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.

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

SCALE - 1:25,000
0 0.5 1 1.5 KM

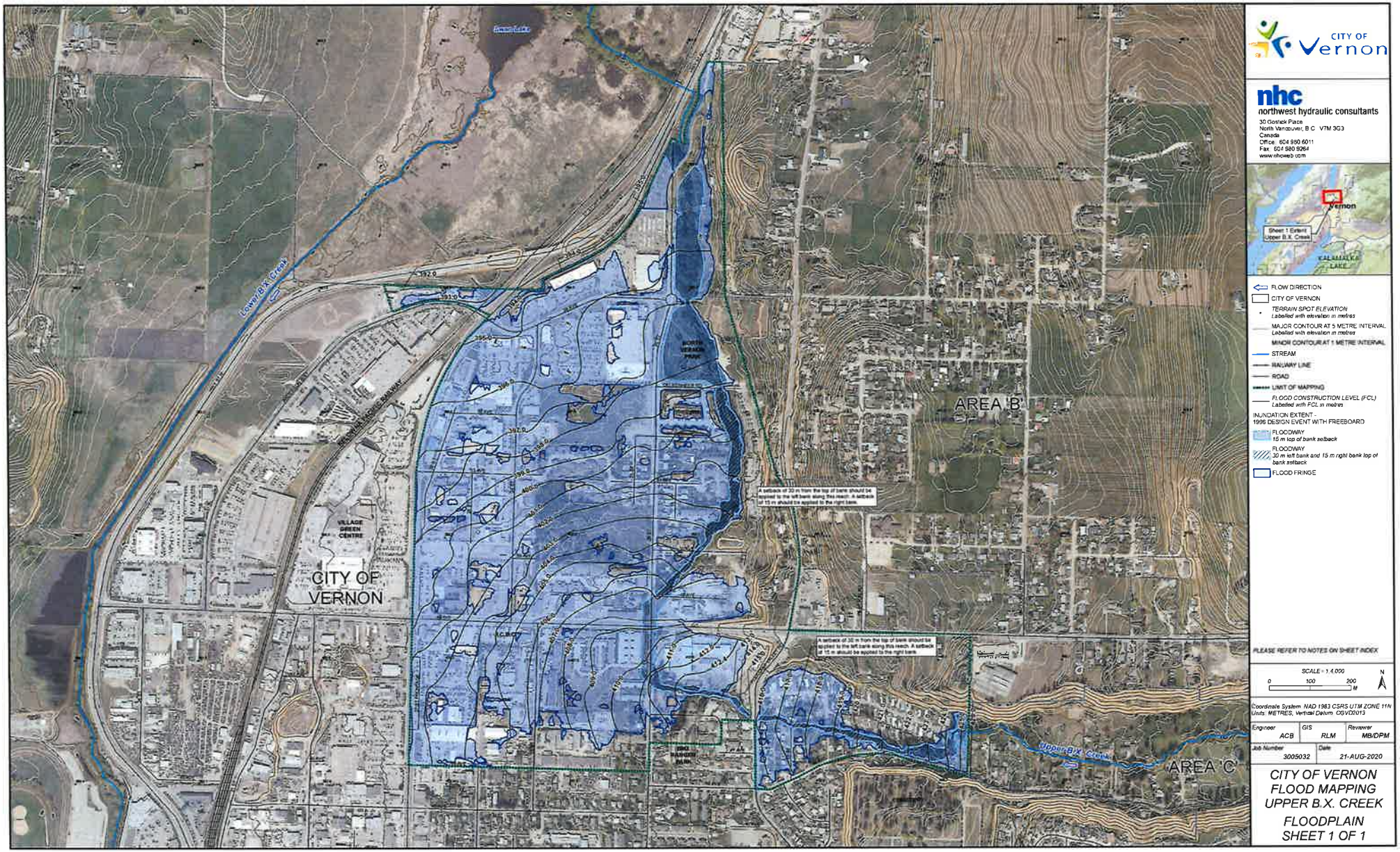
Coordinate System: NAD 1983 CSRS UTM ZONE 11N
Units: METRES; Vertical Datum: CGVD2013

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
AREA 'B'
AREA 'C'
Lower B.X. Creek
Upper B.X. Creek
Swan Lake
VILLAGE GREEN CENTRE
NORTH VERNON PARK
BIRD SANCTUARY PARK
CANADIAN PACIFIC RAILWAY
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.
CITY OF VERNON
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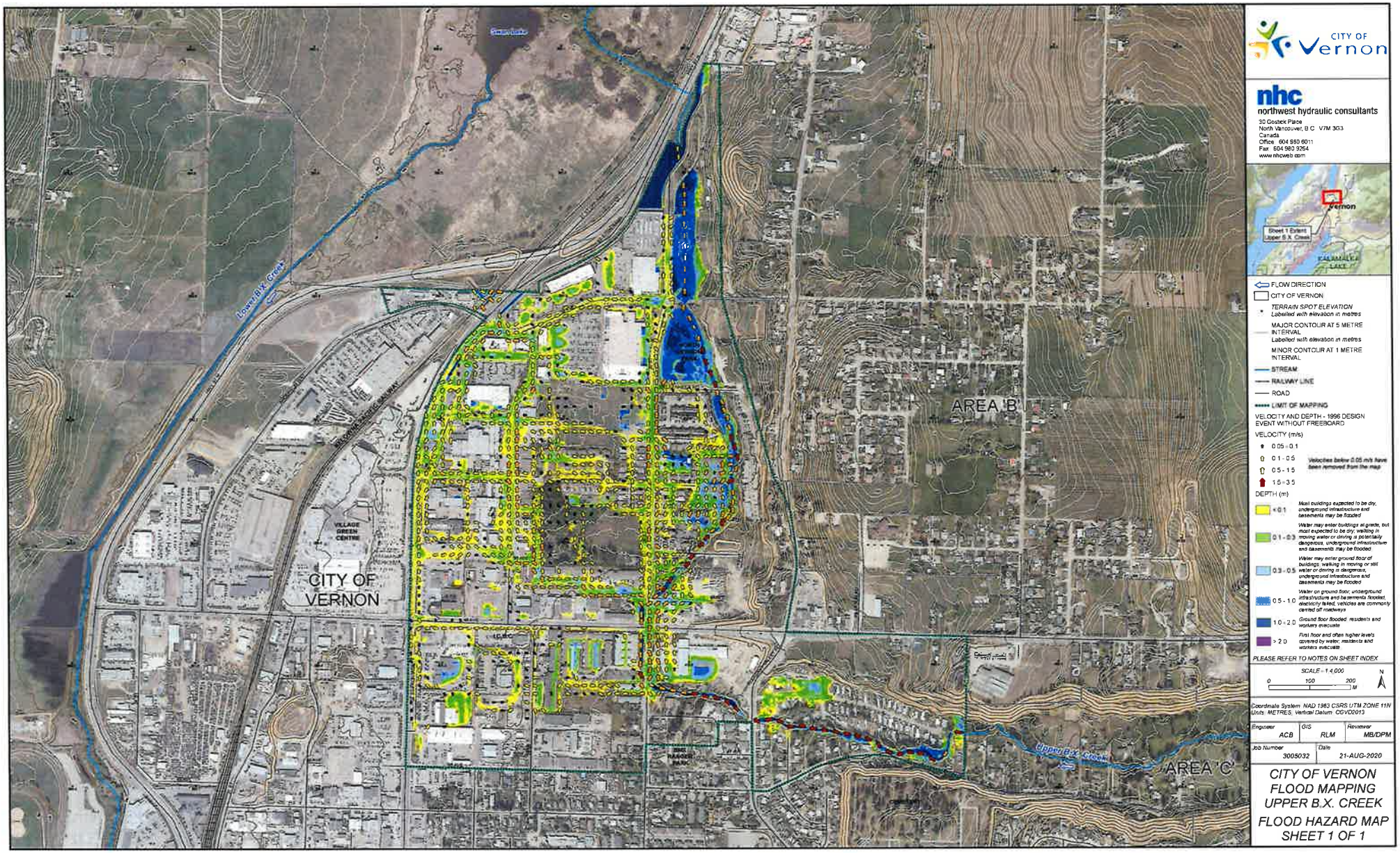
Vernon
Sheet 1 Extent Upper B.X. Creek
KALAMALKA LAKE
FLOW DIRECTION
CITY OF VERNON
TERRAIN SPOT ELEVATION
Labelled with elevation in metres
MAJOR CONTOUR AT 5 METRE INTERVAL
Labelled with elevation in metres
MINOR CONTOUR AT 1 METRE INTERVAL
STREAM
RAILWAY LINE
ROAD
LIMIT OF MAPPING
FLOOD CONSTRUCTION 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
N
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


CITY OF VERNON
AREA 'B'
AREA 'C'
Upper B.X. Creek
Lower B.X. Creek
VILLAGE GREEN CENTRE
CITY OF VERNON
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Office 604 980 6011
Fax 604 980 9264
www.nhcweb.com
Vernon
Sheet 1 Extent
Upper B.X. Creek
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 ACB
GIS RLM
Reviewer MB/DPM
Job Number 3005032
Date 21-AUG-2020
CITY OF VERNON
FLOOD MAPPING
UPPER B.X. CREEK
FLOOD HAZARD MAP
SHEET 1 OF 1

nhc

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

Photo source: NHC, 2019

City of Vernon: Detailed Flood Mapping, Risk Analysis, and Mitigation

Part 1 – Upper B.X. Creek Mitigation Evaluation

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1 INTRODUCTION

1.1 Background and Purpose

This report documents the structural mitigation evaluation component of the City of Vernon (CoV) Flood Mapping, Risk Analysis and Mitigation Project, Part 1 (NHC, 2020). The purpose of the project is to support the reduction of flood risk within the City of Vernon. The objectives of the work are:

1) Develop floodplain maps of B.X. Creek and Vernon Creek, with designated floodplain extents and flood construction levels;
2) Develop flood hazard maps indicating flood depth and velocity along B.X. Creek and Vernon Creek within the city boundary;
3) Provide an assessment of the flood risk based on the maps and underlying data;
4) Identify methods to mitigate flood risk; and
5) Evaluate the mitigation options.

The first two objectives, development of floodplain and flood hazard maps, provide information on the probability and extent of flooding. This provides a basis for flood risk assessment and together these assessments are used to identify and evaluate mitigation options. In addition, the maps can be used to inform land use planning, land management, emergency management, and public education with respect to flood hazards.

These non-structural approaches generally have a relatively low cost to implement and high level of effectiveness in reducing flood risk. Furthermore, having a current land use plan and active management of flood prone lands, such as through zoning, official community plans, or other flood bylaws, can be a condition for receipt of funding for structural flood mitigation measures. Due to the relatively high benefit and low cost, non-structural measures are considered the highest priority flood mitigation. Further assessment to prioritize is not warranted and is not presented within this document.

As a foundation for the development of land use regulations within the community and the basis for further flood reduction measures, the floodplain mapping was the focus of this project. This concentration of efforts, to ensure the highest quality product, includes the hydrology, survey, modelling, and analysis used to develop the maps.

Mitigation measures for Upper B.X. Creek flood hazards were identified during Part 1 of this study, as presented in Section 8 of the Part 1 report (NHC, 2020). Further evaluation of these measures is presented in the current document. This evaluation has been completed without community consultation. A comprehensive mitigation plan would include community input to identify and incorporate local community values beyond simply reducing the exposure or approximate cost of flood damages. The risk assessment and prioritization presented in this document should therefore be considered to inform instead of direct decisions on flood risk mitigation.

2 MITIGATION ASSESSMENT OF STRUCTURAL MEASURES

Identification and description of the recommended structural mitigation measures are presented in the main Part 1 report (NHC, 2020). These measures are:

- Sediment and debris management plan
- Diking near Pleasant Valley Road (item 6 in the following figure)
- 20th Street crossing upgrades (items 3, 4, and 5 in the following figure)
- Diking between 20th Street and Deleenheer Road (item 2 in the following figure)
- Highway 97 crossing upgrade (item 1 in the following figure)

The locations for the structural mitigation measures are shown in Figure 2.1. This document further evaluates these measures to inform decisions on their prioritization.

2.1.1 Diking Considerations

A dike is defined in the *Dike Maintenance Act* as:

"an embankment, wall, fill, piling, pump, gate, floodbox, pipe, sluice, culvert, canal, ditch, drain or any other thing that is constructed, assembled, or installed to prevent the flooding of land.[1]*"*

The construction of new dikes requires the local government to become a diking authority, who will be responsible for ownership, operation, and maintenance of the dike. The diking authority must acquire and maintain full legal access to the dike through land ownership or establishment of rights of way.

Standard dikes are considered embankments with a 4.0 m crest width, and suitable freeboard beyond the design flood elevation (generally 0.6 m beyond the 200-year peak mean daily flow, or flood of record). When considering standard dikes, setback dikes are preferred over river side dikes; however, in most areas along Upper B.X. Creek there is limited space for setback dikes. Setback dikes can avoid or reduce the need for costly armouring, provides increased hydraulic conveyance, is at less risk to channel migration and erosion, generally easier to raise in the future, allows for riparian habitat along the bank, and avoids or reduces conflict between dike maintenance and environmental values. However, space constraints may limit opportunity for setting back any dikes (MWLAP, 2003).

Given the complexity of diking along Upper B.X. Creek, feasibility studies should be completed as a first step to aid the decision-making process. The CoV may elect to use non-structural measures as an alternative to structural mitigation. Refer to the Part 1 and Part 2 (NHC, 2020, 2021) reports for further details on non-structural mitigation options.

Emergency response planning should be used in the short term to limit overbank flooding. This could include ensuring residents are aware and prepared for flooding, sandbags or other temporary barriers are made available for individual homes prior to a flood, and temporary diking is available and prepared for along the proposed dike alignment.

[1]British Columbia Dike Maintenance Act [RSBC 1996] Chapter 95
https://www.bclaws.gov.bc.ca/civix/document/id/consol20/consol20/00_96095_01#section1

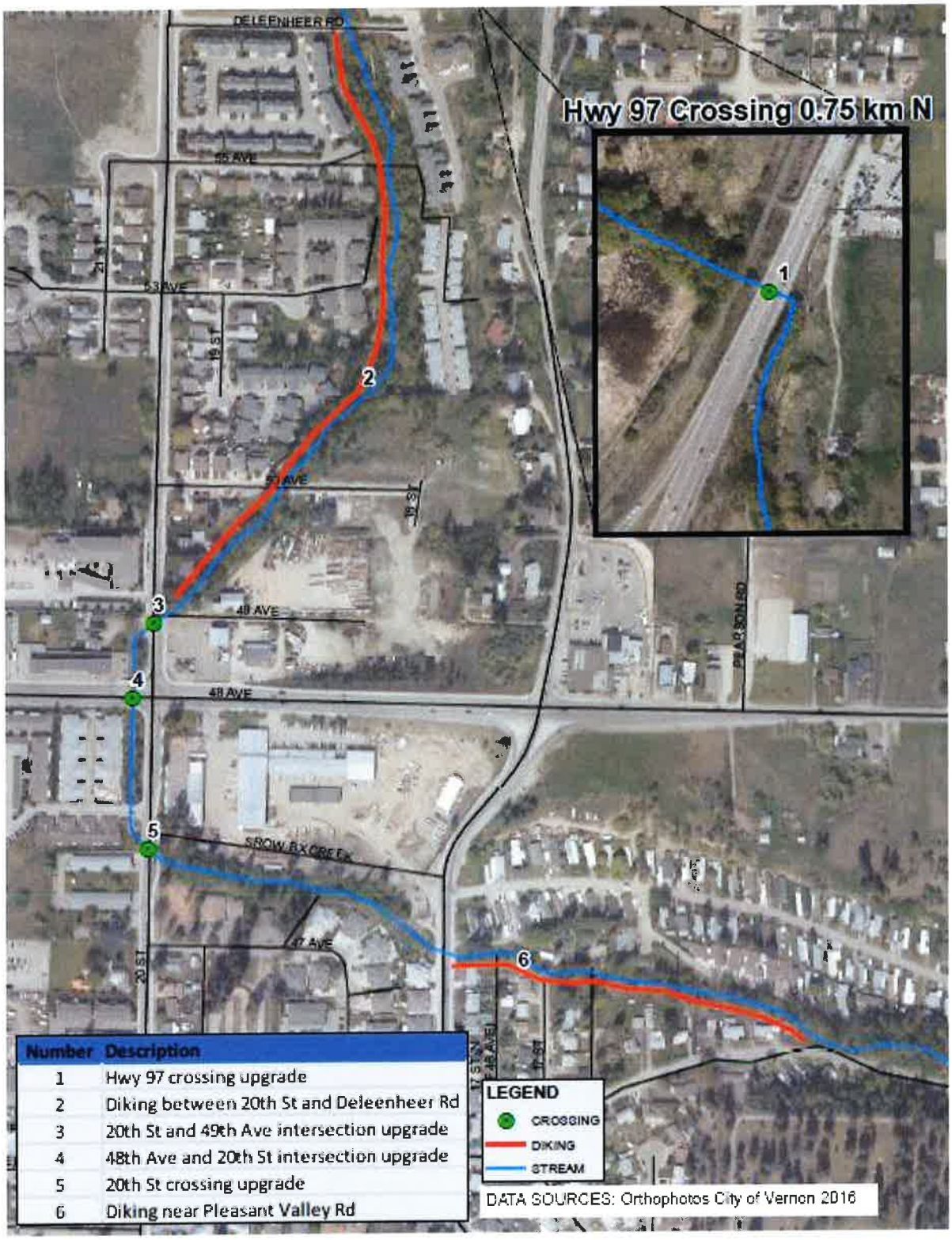

Figure 2.1. Suggested structural mitigation options for Upper B.X. Creek.

2.2 Mitigation Modelling

The numerical model developed and used for the floodplain mapping was adjusted to incorporate the proposed structural mitigation measures. Simulation of both existing and "mitigated" geometries have been compared to both assess the flood hazard reduction of the mitigation options and to confirm that the mitigations are unlikely to transfer the flood risk to adjacent or downstream properties. The transfer of risk refers to increasing flood depth or velocity, such as from dike encroachment or other influence on capacity or flow. Only three of the identified structural mitigation options were evaluated with the model. These are:

- 20th Street crossing upgrades
- Diking between 20th Street and Deleenheer Road
- Highway 97 crossing upgrade

Diking near Pleasant Valley Road was not explicitly included in the mitigation modelling, despite being a possible structural measure. Modelled flood extents upstream of Pleasant Valley Road are limited to a few properties adjacent to the channel; however, the addition of freeboard to this area (see Floodplain Maps) indicate that there is flood risk that may extend beyond Pleasant Valley Road. However, as this risk is related to freeboard and not direct model results, this option was not modelled. Simulation of the crossing upgrades near 20th Street and 48th Ave were assessed based on complete removal of the existing constriction; that is assuming the crossings are replaced with clear-span bridges or suitably sized conduits. This was done to assess the maximum benefit of upgrading the crossing. Hydraulics of any replacement crossing structure should be investigated in further detail at the conceptual design phase.

The following sub-section present the methods and results of the assessment of these three mitigation measures.

2.2.1 20th Street Crossing Upgrades

There are three CoV crossings along Upper B.X. Creek that sufficiently restrict flow during the design flood event resulting in upstream overbank flooding. Increasing the waterway opening will allow for passage of the design flood event without overbank flooding. Photos taken prior to and following high flow events indicate sediment deposition is a problem through this reach. Sediment removal efforts have historically been carried out (1996, 2009, 2017 and 2018) upstream and downstream of the 48th Ave crossing, indicating that the crossing restricts sediment transport (Figure 2.2). Replacing these crossings with clear-span bridges will also improve sediment transport through this reach. Note that crossing upgrades should be considered along with sediment and debris management.

Figure 2.2. Sediment deposited at the outlet of 48th Ave Crossing prior to dredging (CoV, 2018)

Four of the existing culvert crossings were modelled as clear-span bridges, including the upstream crossing of 20th Street, the private drive to Skyway Village, 48th Avenue and the downstream crossing of 20th Street. The Upper B.X. Creek channel through this reach has been influenced by the undersized crossings and no longer represents a natural channel size. Therefore, suitable channel bottom widths were estimated using a regime analysis.

NHC prepared a set of guidelines for the hydraulic design of flood control channels in erodible materials (NHC, 1984). This method consists of graphical and numerical procedures for estimating channel cross-sections based on discharge, channel slope, and sediment composition. The guidelines are based on geomorphic channel regime relationships. Regime relationships have empirically been developed for a range of alluvial rivers correlating channel geometry, slope, sediment supply, and discharge. The discharge is considered a dominant channel forming discharge, which is typically taken as the 2-year maximum daily flow (2-year QPD). The relationships are frequently used to approximate equilibrium form for a specific channel. For this project, regime relationships were used to indicate a potentially suitable channel width for the crossing upgrades.

A suitable channel bottom width of 5 m was selected based on the following inputs:

- Dominant channel forming discharge (2-year QPD) = 3.0 m^3/s
- Channel Slope = 0.017 m/m
- Streambed D50 sediment size = 68 mm
- Resistance to bank erosion = high (assuming riprap bank protection or concrete walls)

A 5 m bottom width was adopted for all 4 clear-span bridges, resulting in varying bridge spans (Table 2.1). An assumed bridge deck depth of 0.6 m was used for each crossing (based on existing road elevations) and the resulting clearance beyond the design flood event is included in Table 2.1. The

modelling included approximately 250 m of channel widening to connect the 4 crossings. Given the limited space in this area, vertical walls were used for crossing abutments and channel banks. Lastly the streambed profile was modified to provide a consistent slope through the 4 crossings.

Table 2.1. Modelled bridge spans and resulting clearance during the design flood event.

Crossing	Existing Crossing	Modelled Bridge Span (m)	Modelled Clearance (m)
20th St Crossing	1.66m (r) x 2.55 m (s) Arch Culvert	8	1.6
Skyway Village Entrance (Private)	2.5 m Concrete Box Culvert	6.6	0.3
48th Ave Crossing	1.6m (r) x 2.4m (s) Box Culvert transitioning to 1.7m (r) x 2.5m (s) Pipe Arch	7	0.8
20th St and 49th Ave Intersection	2.4m (r) x 3m (s) Box Culvert	14	0.2

Further investigation into suitable clearance should be investigated at the conceptual design phase, which may require the road profiles to be raised. The reduced flood extent is shown in Figure 2.3.

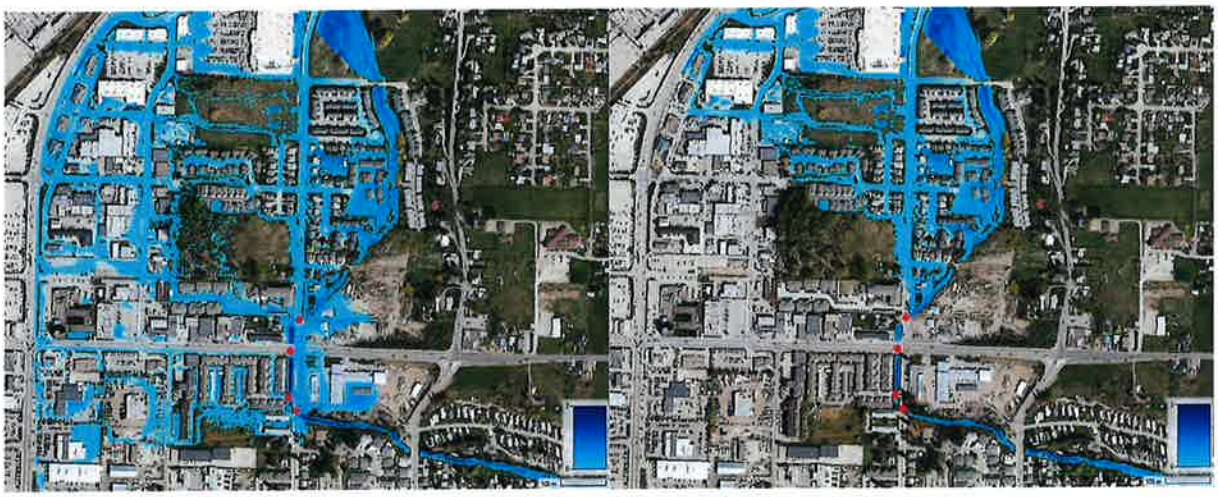

Figure 2.3 Flood extents at 20th Street crossings under current (left) and mitigated (right) conditions based on model results for the design flood event. Blue gradient indicates depth of water in meters.

Upgrading these crossings increases the flow in the downstream channel, which increases the flooded area downstream of Deleenheer Road. Therefore, this mitigation option should be considered alongside diking between 20th Street and Deleenheer Road. The other consideration is improved sediment transport through the upgraded crossings, which will be transported into the downstream channel.

2.2.2 Diking between 20th Street and Deleenheer Road

Modelling shows potential for flooding along the left bank of Upper B.X. Creek between 20th Street and Deleenheer Road, which has been subject to flooding in 1996, 2008, 2017 and 2018 (Figure 2.4). One

mitigation option for this location is to dike the left bank of Upper B.X. Creek. The model has been updated with a riverside dike located along the left bank; however, the suggested location and alignment of this dike is outside the scope of this project and should be investigated further at the feasibility and design phases.

Figure 2.4. Flooding along the left bank of Upper B.X. Creek directly downstream of 20th Street (CoV, 2017).

The following reaches of the left bank have been identified as low and require some form of diking to keep flow from exiting the channel:

- Beginning at 20th Street extending approximately 80 m downstream
- 165 m between 50th Ave and 53rd Ave, beginning approximately 35 m downstream of 50th Ave
- Beginning at 53rd Ave extending approximately 80 m downstream

These areas are shown in Figure 2.5.

Figure 2.5. Reaches of Upper B.X. Creek below 20th Street where left bank is prone to flooding.

Aggradation of the channel (i.e., rising bed level) may continue through this reach. The long-term aggradation trends in this reach will have an impact on the future flood profile and require a long-term sediment management plan or otherwise be addressed in the feasibility and design phases.

Modelling indicates that the left bank will need to be raised on average 1.0 m (including freeboard) in low laying areas. Downstream of Deleenheer Road the park is flooded, which is of low concern, but there is flooding at the intersection of 58th Avenue and 20th Street, due to the increase in flow to the channel from the upstream crossing upgrades. This intersection should be raised to reduce the flooded area. The reduced flood extent can be seen in Figure 2.6.

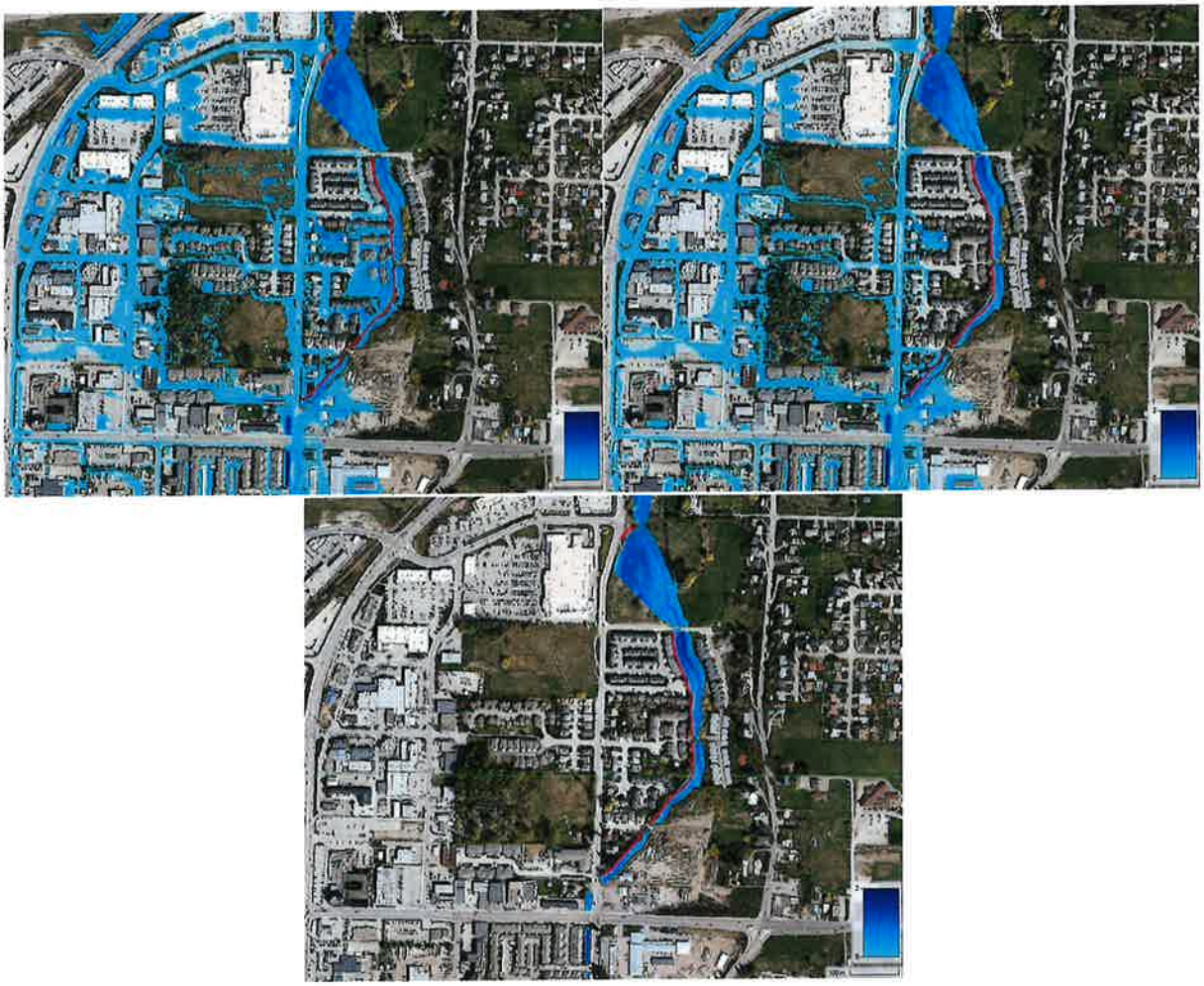

Figure 2.6 Flood extents between 20th Street and Deleenheer Road under current conditions (top left), with proposed dike (top right), and with proposed dike and 20th Street crossing upgrades (bottom) based on model results for the design flood event. Blue gradient indicates depth of water in meters.

Given the challenges of constructing a dike through this reach (such as land acquisition, engineering, permitting, funding, and construction), emergency response measures should be planned for in the short term. A feasibility study should investigate the following challenges in this area:

- Long-term aggradation trends and impacts on the design flood profile
- Alternative non-structural mitigation options
- Lack of space near homes and developments
- Alternative options for flood protection other than standard dikes, such as, flood protection walls, raising low laying areas, increasing channel capacity, etc.
- Liaison with permitting agencies

2.2.3 Highway 97 Crossing Upgrade

The crossing of Highway 97 is under the authority of the Ministry of Transportation and Infrastructure (MoTI). Model results for the 1996 design event indicate that Highway 97 would overtop, inundating the highway, a major emergency route. A recommended mitigation option is to upgrade the existing 2 m (rise) x 3.4 m (span) pipe arch culvert crossing with a larger structure, such as a clear-span bridge. Following MoTI guidelines this structure should convey the 200-year flood event with suitable clearance. Although the 200-year flow is less than the design flood event, the clearance should be sufficient to avoid overtopping during the 1996 design event. Conveyance of the design flood event should be considered during the detailed design phase of this crossing replacement. Crossing upgrades should be designed with consideration of the sediment and debris management plan to ensure adequate capacity for sediment and debris (including sediment deposition).

To assess the potential reduction in flood hazard and risk, this crossing was simulated as a clear-span bridge with a deck thickness of 0.6 m (below the current road elevation). The regime method described in Section 2.2.1 has been applied. However, a 4.8 m bottom width was selected for this crossing, as it matches the bottom width of the newly constructed 20th Street crossing located approximately 200 m upstream, resulting in a 9 m bridge span. This upgrade provides 0.7 m of clearance beyond the design flood elevation, although there is still backwatering in the flood profile due to the downstream rail crossing. The existing rail crossing is a wooden truss bridge with low clearance. To investigate the impacts of the rail crossing on the flood profile, the crossing was removed from the model, which reduced the backwatering and provided an additional 0.2 m of clearance. It is unlikely that the rail crossing will be upgraded and therefore any crossing upgrades at Highway 97 should include an assessment of the backwatering from the downstream rail crossing. The changes in flood extent from upgrades at Highway 97 can be seen in Figure 2.7.

Figure 2.7 Flood extents at Hwy 97 under current conditions (left), with proposed upgrade (right) based on model results for the design flood event. Blue gradient indicates depth of water in meters.

3 MITIGATION OPTIONS ASSESSMENT

3.1 Approach

The structural flood mitigation measures have been evaluated using a qualitative risk and feasibility assessment. **The risk component of the assessment assigns a score of the severity of risk avoided by the proposed mitigation. The feasibility component of the assessment assigns a score to represent the ease of implementation of the proposed mitigation.** These two scores are then combined into a risk: feasibility ratio. A high risk avoided score and a low feasibility score indicates the best scenario under this rating system.

3.1.1 Scoring of Risk Avoidance

To identify the level of risk avoided through each mitigation, a risk score was assigned based on the likelihood of the flood event overwhelming existing defences and the consequence of the flood event. Flood risk as defined by EGBC is a measure of the likelihood and severity of an adverse effect to health, property, or the environment. Risk is often estimated by the product of likelihood and consequence. (EGBC, 2018). For this project, risk is determined through the matrix shown in Table 3.1.

The likelihood of the adverse effect is evaluated based on the probability that a flood event will overwhelm existing defences and impact an area. The consequence is described for the area that would be defended by the mitigation. Consequence, as defined by EGBC (2018) is "the outcomes or potential outcomes arising from the occurrence of a flood, expressed qualitatively or quantitatively in terms of loss, disadvantage or gain, damage, injury, or loss of life". Consequence is estimated by an assessment of the people, assets directly exposed to the flood hazard, and the potential extent of damage associated with the flood hazard which would be eliminated by the mitigation measure. Assessment of consequence aligns with the approach used in the flood risk assessment documented in Section 7 of the main Part 1 project report (NHC, 2020).

The estimated, approximate protected area for each structural mitigation measure has been identified, based on flood mapping results. The impact to people, economy, environment, and cultural receptors was qualitatively categorized within the protected area. This matrix does not capture the importance to the community of the consequences estimated. Community consultation could further refine this matrix, through adjustment of the estimated consequence axis to better represent community values.

Based on the risk assessment, each feature is assigned a risk score between 1 to 5, based on the matrix shown in Table 3.1. A score of 5 indicates highest risk avoided or greatest benefit of the mitigation measure.

Table 3.1 Scoring matrix for risk avoidance.

Likelihood of Reducing Hazard	Rating:	Risk Score		
Very likely to be highly effective	High – 3	**3**	**4**	**5**
Likely to be highly effective	Medium – 2	**2**	**3**	**4**
Likely to be moderately effective	Low – 1	**1**	**2**	**3**
Estimated Consequence without Proposed Mitigation		Minimal exposure of people, economic sociocultural, & ecological receptors/areas	Some exposure of people, economic sociocultural, & ecological receptors/areas	High exposure of people, economic sociocultural, & ecological receptors/areas
	Rating:	Low – 1	Medium – 2	High – 3

3.1.2 Feasibility Score

The feasibility score quantifies the feasibility of each mitigation option. A low feasibility score represents a project which is easy to implement. The feasibility score has been estimated by applying the matrix (Table 3.2) to the two feasibility factors:

- Ease of execution; and
- Cost of implementation.

Ease of execution includes considerations regarding design complexity, environmental constraints, land acquisition or easements, and impacts on property-owners or other stakeholders. The cost of implementation factor considers the estimated costs of the proposed works. Category descriptions are provided in the following table. Factors applied and the values assigned to the factors can be refined through stakeholder or community discussion and progressing the design and costing.

Table 3.2 Scoring matrix for feasibility factor.

Cost of Implementation	Rating:	Feasibility Score		
>$1,500,000	High – 3	**3**	**4**	**5**
$750,000 to $1,500,000	Medium – 2	**2**	**3**	**4**
<$750,000	Low – 1	**1**	**2**	**3**
Ease of Execution		Straightforward design and implementation. Minimal environmental impact. Does not require changes in land ownership. Minimal impact to stakeholders.	Somewhat complex design and implementation. May include moderate environmental impact. May require minor changes in land ownership. May have moderate impact on other stakeholders.	Complex design. May include substantial environmental impact. May require changes in land ownership. May substantially impact other stakeholders.
	Rating:	Low – 1	Medium – 2	High – 3

3.1.3 Approach for Cost Estimation

Cost estimation for structural mitigation measures has been carried out at a 'planning' level of estimating which is defined by BC Ministry of Transportation and Infrastructure (MoTI) (2013b) as being "based on sufficient knowledge of site conditions adequate to identify high level risk". The expected accuracy range for this level of estimating is +/- 40%. Unit prices for construction items were obtained from recent NHC projects in the region.

Soft costs are typically 15% to 35% of construction costs. This is supported by provincial documentation by MoTI which suggests 25% (2013a). For this project we have adopted soft costs at the middle of this range, assuming some service costs, such as environmental monitoring, surveying, and material testing, is incorporated with the contractor's scope. The distribution of this is as follows:

- Project management and planning: 3%
- Design: 15%
- Construction supervision and inspection: 7%

Costs were inflated to reflect the uncertainty of the estimate by a contingency rate of 40% of construction cost. This contingency rate is commensurate with the accuracy range of this project as per MoTI (2013b). The presented cost estimates only include design and construction costs. On-going monitoring and maintenance have not been included but should be budgeted for.

3.1.4 Limitations

This assessment is based on the hydraulic model results of the existing conditions and assumed sediment infilling and crossing blockages along Upper B.X. Creek; the reader is encouraged to review the main report for details. Changes in bed conditions from that simulated will have an impact on the flood levels and extents. Based on the preliminary investigation of the identified mitigation measures, there is expected to be low transfer of flooding risk to other properties. However, this should be confirmed at design phase for any structural work within a floodplain.

Cost estimates are based on results from the existing hydraulic model and course geometric generalizations. This level of uncertainty is reflected by the 40% contingency added to the total project costs. Survey and design of the mitigation measures are required to refine the estimate of quantities and costs. Costs and unit rates used in the estimates are based on other similar projects in the region and may differ from unit rates used in the detailed design and construction phase.

3.2 Results

3.2.1 Sediment and Debris Management

Sediment and debris management requires a plan followed by implementation.

A sediment and debris management plan as outlined in the main report would include installation and maintenance of a series of sediment traps and/or basins along Upper B.X. Creek. The sediment and debris management plan should be developed with a qualified geomorphologist based on a clear understanding of the sediment and debris sources, range in annual volume of sediment load, changes in stream power and sediment class along the channel, identification of depositional zones, identification of highest risk elements or locations with respect to sediment and debris, and the expected changes in the geomorphic regime over time (focused on the project scale of time).

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.
- Inspections on the condition of sediment basins/traps and problematic crossings. 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 or traps.
- Reporting requirements to better document sediment removal efforts to better quantify sediment volumes and removal costs.

Implementation can include source control (such as stabilizing upstream sources through maintaining riparian forest buffers, revegetation, road drainage improvements, etc..). Sediment mobilized within the channel can then be reduced further through installation of sediment basins and traps. Sediment traps are considered smaller than basins, requiring less space, but also providing less storage volume.

Risk Avoidance Assessment

Likelihood

Sediment and debris can substantially reduce the capacity of culverts and crossings along Upper B.X. Creek. Structure blockages during a flood can quickly result in overbank flooding. The execution of a sediment and debris management plan can be effective in mitigating this risk. The effectiveness hinges on the design of a suitable plan as well as the consistent maintenance with both routine and event-triggered removal of sediment and debris. If an effective plan was developed and implemented, the estimated likelihood is 'medium' or '2', described as *'likely to be highly effective'*.

Consequence

There is no defined area where implementation of a sediment and debris management plan would reduce flooding. The consequence estimation is based on non-quantitative findings from model runs whereby conveyance blockages through crossings were modelled. In the areas that would be positively affected by implantation of this plan, the consequence avoided would be best classified as 'medium' or '2', *described as avoidance of 'some exposure of people, economic sociocultural, & ecological assets/areas'*.

Risk Avoidance Score

Based on the matrix shown in Table 3.1, the overall risk avoidance score is a 3.

Table 3.3. Risk avoidance score for a sediment and debris management plan.

Proposed Measure	Risk Avoided Score			
	Factor	Factor Score	Factor Description	Overall Score
Sediment and debris management plan	Likelihood	2	Likely to be highly effective	3
	Consequence	2	Some exposure of people, economic sociocultural, & ecological assets/areas	

Feasibility Assessment

Ease of Execution

The ease of execution of the sediment and debris management score is ranked as 'medium' or '2', described as *'Somewhat complex design and implementation. May include moderate environmental impact. May require minor changes in land ownership. May have moderate impact on other stakeholders.'*. The sediment and debris management plan may include impacts to natural habitat or fisheries through sediment removal, although efforts can be made to minimize impacts. This item also has feasibility difficulties associated with long-term, ongoing maintenance. A sediment management plan is only effective if it is implemented consistently, and its' effectiveness is reduced if maintenance ceases. The ease of execution is ranked as a medium due to the long-term, ongoing commitment.

Cost Estimate

The cost of a sediment and debris management plan can be separated into three parts:

- Preparation of the plan;
- Construction of additional sediment traps and basins; and
- Maintenance of existing and proposed sediment traps and basins.

Estimates for each of these items is shown in Table 3.4. The estimate for the cost of additional sediment traps and basins will be dependent on the number of structures installed and their location. The CoV had traps installed, or modified in 2009, as documented in the focus email dated November 03, 2009 as part of the Upper B.X. Creek Watershed Improvement Project. The cost summarized in this email include both engineering and construction costs and has been used as a basis for estimating costs for sediment traps and basins as well as maintenance costs. The 2009 costs have been translated into 2020 costs using the Bank of Canada Inflation Calculator (Bank of Canada, 2020). Costs for the basin are based on the 2009 design of the sediment basin located in B.X. Ranch Park. NHC is aware the CoV is currently undergoing the design of a sediment basin on Upper B.X. Creek. The costs that develop from that work are likely more reflective of the costs for a sediment basin.

Table 3.4. Sediment and debris management costs.

Item	Quantity	Unit Rate	Cost
Initial Project Costs			
Sediment and Debris Management Plan	1	L.S.	$75,000
Construction of sediment traps[1]	2	$78,000/trap	$154,000
Construction of sediment basin[2]	1	215 $/m^3	$365,500
Supplementary Construction	1	$100,000	$100,000
Soft Costs	25%	-	$173,625
Contingency	40%	-	$277,800
Total			**$1,150,000**
Annual Costs			
Maintenance[3]			
Traps	4	$2,500/trap/yr	$10,000
Basin	1	$35,000/yr	$35,000
Soft Costs (permitting, QA/QC, Environmental monitoring, etc.)[4]	10%	-	$4,500
Contingency	40%	-	$18,000
Total Annual Costs			**$70,000**

Notes:

1. Assuming 2 additional sediment traps installed on Upper B.X. Creek.
2. Assuming a total volume of 1,700 m^3, taken from 2009 Focus design.
3. Assuming 5 structures, 4 traps and 1 basin on an annual basis.
4. Soft costs reduced to 10% for annual maintenance.

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, demobilization and other costs beyond the items included in the estimate. The total cost has been rounded to the nearest $10,000.

Feasibility Score

Based on the matrix shown in Table 3.2, the overall feasibility score is a 3.

Table 3.5. Feasibility score for a sediment and debris management plan.

Proposed Measure	Feasibility Score			
	Factor	Factor Score	Factor Description	Overall Score
Sediment and debris management plan	Ease of execution	2	Somewhat complex design and implementation. May include moderate environmental impact. May require minor changes in land ownership. May have moderate impact on other stakeholders.	3
	Cost of implementation	2	$750,000 to $1,500,000	

Overall Ratio Score

The following table presents the risk to feasibility ratio for implementing a sediment and debris management plan along Upper B.X. Creek. A high risk avoided score and a low feasibility score indicates the best scenario. This sediment and debris management plan received both a medium-risk avoidance score and a medium cost to implement score, resulting in a 3:3 ratio of risk to feasibility.

Table 3.6. Risk : feasibility ratio for a sediment and debris management plan.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Sediment and debris management plan	Likelihood	2	3	Ease of execution	2	3	3:3
	Consequence	2		Cost of implementation	2		

3.2.2 Diking near Pleasant Valley Road

Model results indicate a potential for flooding beyond Pleasant Valley Road, which could be made worse by a debris blockage at the crossing. The implementation of a sediment and debris management plan could reduce this risk; however, mitigation options have been considered for this location as an alternative. 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. The cost estimate has been based on a riverside dike.

Risk Avoidance Assessment

Likelihood

The implementation of a dike along Pleasant Valley Road, would *'very likely provide effective flood mitigation'*, however, only low probability floods are anticipated to have the potential to overtop the left bank and Pleasant Valley Road, especially if a sediment and debris management plan is implemented. As such, even though the dike would be very effective, as it is only needed in low probability events, it is ranked as a 'Medium' or '2', described as *'likely to be highly effective'*.

Consequence

Since the consequence could be increased by a debris blockage, which has not been modelled, the delineation was not based on specific flood extents and does not represent a modelled scenario. The area likely protected with a dike represents several homes in a relatively small portion of the floodplain where flood depths are expected to be relatively deep. As such, the consequence score without this mitigation is 'low' or '1', described as *'minimal exposure of people, economic sociocultural, & ecological assets/areas'*.

Risk Avoidance Score

Based on the matrix shown in Table 3.1, the overall risk avoidance score is a 2.

Table 3.7. Risk avoidance score for Diking near Pleasant Valley Road.

Proposed Measure	Risk Avoided Score			
	Factor	Factor Score	Factor Description	Overall Score
Diking near Pleasant Valley Road	Likelihood	2	Likely to be highly effective	2
	Consequence	1	Minimal exposure of people, economic sociocultural, & ecological receptors/areas	

Feasibility Assessment

Ease of Execution

The ease of execution of a dike along Pleasant Valley Road is low, as the dike would require engineering, a lengthy permit process, permanent maintenance through a diking authority (CoV), as well as land acquisition. To avoid impact to habitat, the dike would have to be designed with habitat considerations and constructed during periods when least likely to negatively impact fish and fish habitat. The dike is likely to have a negative impact on the environmental due to reduction of riparian vegetation. The footprint of the dike would be larger than the existing shoreline buffer, which would impact existing structures and require land acquisition. The alternative option of raising Pleasant Valley Road would also require engineering and planning to accommodate utilities, intersections, and land acquisition. This alternative option would also not protect any of the homes upstream of Pleasant Valley Road.

Therefore, the ease of execution is ranked as '3' or 'low' and described as '*Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly*'.

Cost Estimate

The quantities and cost for this work has been estimated based on the riverside dike option using the rough geometry over the existing terrain. Volumes and costs should be refined at the feasibility and design phases. The cost estimate assumes that the dike would be set along the left bank of the channel and raised 1.0 m above the existing ground. Riprap protection is expected to be required along the left bank of the creek to protect the dike from erosion or scour.

A substantial cost for this dike is the acquisition of right-of-way (ROW) for the structure plus an offset of 7.5 m on the land side of the dike. The cost of obtaining the ROW has been estimated based on an average land value cost of $222,125 along the proposed works and assuming 25% of the average property cost would be purchased by the CoV.

Table 3.8. Diking near Pleasant Valley Road cost estimate.

Item	Quantity	Unit Rate	Cost
Length of Protection (m)	325		
Average Height (m)	1		
Clearing and Grubbing (ha)	0.71	$5,000/ha	$3,555
Dike Fill (m^3)	2280	$85/$m^3$	$193,800
Riprap Armouring (m^3)	1800	$185/$m^3$	$333,000
Property Acquisition	L.S.	$444,250	$444,250
Supplementary Construction	1	$100,000	$100,000
Soft Costs (Design, permitting, QA/QC, Environmental monitoring, etc.)	25%	-	$268,651
Contingency	40%	-	$429,842
Total			$1,770,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, demobilization, and other costs beyond the items included in the estimate. The total cost has been rounded to the nearest $10,000.

Feasibility Score

Based on the matrix shown in Table 3.2, the overall feasibility score is a 5.

Table 3.9. Feasibility score for diking near Pleasant Valley Road.

Proposed Measure	Feasibility Score			
	Factor	Factor Score	Factor Description	Overall Score
Diking near Pleasant Valley Road	Ease of execution	3	Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly	5
	Cost of implementation	3	>$1,500,000	

Overall Ratio Score

The following table presents the risk to feasibility ratio for diking near Pleasant Valley Road along Upper B.X. Creek. A high risk avoided score and a low feasibility score indicates the best scenario. This project received a low-risk avoidance score and a high cost to implement score, resulting in a 2:5 ratio of benefit to cost.

Table 3.10. Risk : feasibility ratio for diking near Pleasant Valley Road.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Diking near Pleasant Valley Road	Likelihood	2	2	Ease of execution	3	5	2:5
	Consequence	1		Cost of implementation	3		

3.2.3 20th Street Crossing Upgrades

Risk Avoidance Assessment

Likelihood

Enlarging crossings would have a positive effect on flow conveyance through this reach of Upper B.X. Creek. The likelihood of effectiveness at mitigating flooding in Vernon is a '3' or 'high' described as *'very likely to be highly effective'*. This likelihood score does not consider potential downstream impacts. Increasing the waterway opening on these crossings is expected to transport more sediment into the downstream channel, therefore this upgrade should also investigate the impact on the downstream channel.

Consequence

Implementing crossing upgrades would reduce flooding in several areas, as shown in Figure 2.3. The assets protected through this measure are characterized as '3' or 'high and described as *'High exposure of people, economic sociocultural, & ecological receptors/areas'*. The consequence avoided through this measure is high as protection includes important infrastructure and residential areas.

Risk Avoidance Score

Based on the matrix shown in Table 3.1, the overall risk avoidance score is a 5.

Table 3.11. Risk avoidance score for 20th Street crossing upgrades.

Proposed Measure	Risk Avoided Score			
	Factor	Factor Score	Factor Description	Overall Score
Crossing upgrades	Likelihood	3	Very likely to be highly effective	5
	Consequence	3	High exposure of people, economic sociocultural, & ecological receptors/areas	

Feasibility Assessment

Ease of Execution

The ease of execution of crossing upgrades along Upper B.X. Creek is low, as the crossing upgrades will require engineering with challenges associated to working in and around watercourses as well as limiting impacts to adjacent roads, utilities, and buildings. The ease of execution is ranked as '3' or 'low' and described as '*Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly*'.

Cost Estimate

For this assessment it has been assumed that all three CoV crossings and the private crossing would be upgraded to clear-span bridges. The need for bridges vs culverts has not been included in the current scope of this project and the type of replacement structures should be considered at the conceptual design phase. The use of culverts may be suitable and result in reduced cost. However, the crossing structures should be designed with capacity and clearance suitable to pass the design flow plus the expected sediment and debris.

It is expected that the replacement of these crossings would require the roads to be raised and retaining walls (i.e. headwall and abutments) to be constructed to keep the project footprint from impacting adjacent buildings and roads. As the cost of these structures will be closely tied to construction of retaining walls the cost estimate has been created using a cost per linear length of wall through the three CoV crossings, assuming a 0.5 m raise in the road height.

There is also a private crossing between the upstream crossing of 20th Street and the 48th Avenue crossing. The private crossing didn't cause overland flooding during the design event; however, as it is closely tied to the other three crossings, it may also require upgrading and should be considered when designing upgrades for the other three. For this assessment, this private crossing has been included in the cost estimate.

It has been assumed that crossing upgrades would be completed as one project, sharing in costs such as mobilization, demobilization, and traffic management. Costs are developed from other projects that had

similar design constraints. However, these project costs are based on MoTI projects. Table 3.12 summarises the estimated cost of upgrading all four crossings.

Table 3.12. Cost estimate for 20th Street crossing upgrades.

Item	Quantity	Unit Rate	Cost
Mobilization and demobilization	1	$50,000	$50,000
Traffic Management	1	$100,000	$100,000
Demolition of existing crossings	3	$100,000	$300,000
Total wall length (m)	500	$11,000	$5,500,000
Total distance of raised road profile (m)	300	$3,500	$1,050,000
Supplementary Construction	1	$250,000	$250,000
Soft Costs	25%	-	$1,812,500
Contingency	40%	-	$2,900,000
Total			$11,960,000

This estimated total project cost is equivalent roughly to $3M per crossing.

Feasibility Score

Based on the matrix shown in Table 3.2, the overall feasibility score is a 5.

Table 3.13. Feasibility score for 20th Street crossing upgrades.

Proposed Measure	Feasibility Score			
	Factor	Factor Score	Factor Description	Overall Score
Crossing upgrades	Ease of execution	3	Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly	5
	Cost of implementation	3	>$1,500,000	

Overall Ratio Score

The following table presents the risk to feasibility ratio for the 20th Street crossing upgrades. A high risk avoided score and a low feasibility score indicates the best scenario. This project received a high risk avoidance score and a high cost to implement score, resulting in a 5:5 ratio of benefit to cost.

Table 3.14. Risk : feasibility ratio for a 20th Street crossing upgrades.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Crossing Upgrades	Likelihood	3	5	Ease of execution	3	5	5:5
	Consequence	3		Cost of implementation	3		

3.2.4 Diking between 20th Street and Deleenheer Road

Risk Avoidance Assessment

Likelihood

The implementation of diking between 20th Street and Deleenheer Road, would very likely provide effective flood mitigation. Furthermore, this area is one of the most flood prone along Upper B.X. Creek and is anticipated to flood at a variety of return periods including both low and high. Flood depths in the area are relatively high and would not likely be completely mitigated through sediment and debris management. Alternatively, upgrading the upstream crossings would increase the flow and sediment to this reach. Diking between 20th Street and Deleenheer Road is ranked as a 'high' or '3', described as *'very likely to be highly effective'*.

Consequence

The area anticipated to be protected by a dike from 20th Street to Deleenheer Road is shown in Figure 2.6. As can be seen in the figure, the area likely protected with a dike includes many residential homes. As such, the consequence score without this mitigation is 'high' or '3', described as *'high exposure of people, economic sociocultural, & ecological assets/areas'*.

Risk Avoidance Score

Based on the matrix shown in Table 3.1, the overall risk avoidance score is a 5.

Table 3.15. Risk avoidance score for diking between 20th Street and Deleenheer Road.

Proposed Measure	Risk Avoided Score			
	Factor	Factor Score	Factor Description	Overall Score
Diking between 20th Street and Deleenheer Road	Likelihood	3	Very likely to be highly effective	5
	Consequence	3	High exposure of people, economic sociocultural, & ecological assets/areas	

Feasibility Assessment

Ease of Execution

The ease of execution of a dike from 20th Street to Deleenheer Road is low, as the dike would require engineering, a lengthy permit process, permanent maintenance through the diking authority (CoV), as well as land acquisition. The required dike area as well as setback distances would require a relatively large land acquisition process in the area, which can be difficult to achieve. To avoid impact to habitat, the dike would have to be designed with habitat considerations and constructed when flows are low and when impacts to fish and fish habitat minimized. Loss of riparian habitat is expected to have a negative impact on environmental value. Therefore, the ease of execution is ranked as '3' or 'low' and described as *'Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly'*.

Cost Estimate

The quantities and cost for this work has been estimated based on the riverside dike option using the rough geometry over the existing terrain. Volumes and cost should be refined at the feasibility and design phases. The cost estimate assumes that the dike would be set along the left bank of the channel and raised on average 1.0 m above the existing ground. Riprap protection is assumed along the left bank of the creek to protect the dike from erosion or scour.

A review of the property ownership in this area shows that the CoV owns a section of the left bank that is on average 15 m wide. Therefore, the cost of acquiring the ROW would be reduced. The 15 m ROW may not be wide enough to include the entire structure and the 7.5 m offset from the toe of the dike and therefore property acquisition costs have still been included in the cost estimate. The cost of obtaining the ROW has been estimated based on an average land value cost of $268,338 along the proposed works and assuming 15% of the average property cost would be purchased by the CoV.

Table 3.16. Diking between 20th Street and Deleenheer Road cost estimate.

Item	Quantity	Unit Rate	Cost
Length (m)	570		
Average Height (m)	1.0		
Clearing and Grubbing (ha)	1.25	5000	$6,234
Dike Fill (m3)	3990	85	$339,150
Riprap Armouring (m3)	3100	$185	$573,500
Property Acquisition	L.S.	$540,000	$540,000
Supplementary Construction	L.S.	$100,000	$100,000
Soft Costs	25%	-	$389,721
Contingency	40%	-	$623,554
Total			$2,570,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, demobilization, and other costs beyond the items included in the estimate. The total cost has been rounded to the nearest $10,000.

Feasibility Score

Based on the matrix shown in Table 3.2, the overall feasibility score is a 5.

Table 3.17. Feasibility score for diking between 20th Street and Deleenheer Road.

Proposed Measure	Feasibility Score			
	Factor	Factor Score	Factor Description	Overall Score
Diking between 20th Street and Deleenheer Road	Ease of execution	3	Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly	5
	Cost of implementation	3	>$1,500,000	

Overall Ratio Score

The following table presents the risk to feasibility ratio for implementing a dike between 20th Street and Deleenheer Road. A high risk avoided score and a low feasibility score indicates the best scenario. This project received both a high-risk avoidance score and a high cost to implement score, resulting in a 5:5 ratio of benefit to cost.

Table 3.18. Risk : feasibility ratio for diking between 20th Street and Deleenheer Road.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Diking between 20th Street and Deleenheer Road	Likelihood	3	5	Ease of execution	3	5	5:5
	Consequence	3		Cost of implementation	3		

3.2.5 Highway 97 Crossing Upgrade

Risk Avoidance Assessment

Likelihood

Upgrading the Highway 97 crossing would reduce the possibility of flooding over the highway. While debris is a factor in the likelihood of the crossing overtopping, a larger crossing would be designed to include clearance beyond the design flood event and therefore is less likely to be impacted by debris.

Therefore, a Highway 97 crossing upgrade is rated as '3' or 'high' and described as *'likely to be highly effective'*.

Consequence

Highway 97 is a primary transportation route in the area, especially for access from Vernon and Kelowna to communities north of Vernon (i.e. Salmon Arm, Kamloops, Armstrong, etc.). The consequence avoided is ranked as a '2' or 'medium' and described as *'some exposure of people, economic, sociocultural, & ecological assets/areas'*.

Risk Avoidance Score

Based on the matrix shown in Table 3.1, the overall risk avoidance score is a 4.

Table 3.19. Risk avoidance score for Highway 97 crossing upgrade.

Proposed Measure	Risk Avoided Score			
	Factor	Factor Score	Factor Description	Overall Score
Highway 97 crossing upgrade	Likelihood	3	Likely to be highly effective	4
	Consequence	2	Some exposure of people, economic sociocultural, & ecological assets/areas	

Feasibility Assessment

Ease of Execution

Due to the size and traffic volume of this road, the upgrade of this crossing would require substantial engineering, construction, traffic management, and planning. The crossing and construction phasing would be a relatively complex undertaking. Also, as the highway is a key transportation corridor, disruption to traffic for construction would impact public and business stakeholders. Therefore, the ease of execution for a Highway 97 crossing upgrade is a '3' or 'low', described as *'complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly.'*

Cost Estimate

The design and construction costs for a Highway 97 crossing are expected to be '3' or 'high' and exceed $1,500,000. Note that as this crossing is owned by MoTI, and therefore this upgrade cost is not anticipated to be the responsibility of the CoV, and therefore a preliminary cost estimate has not been prepared.

Feasibility Score

Based on the matrix shown in Table 3.2, the overall feasibility score is a 5.

Table 3.20. Feasibility score for Highway 97 crossing upgrade.

Proposed Measure	Feasibility Score			
	Factor	Factor Score	Factor Description	Overall Score
Highway 97 crossing upgrade	Ease of execution	3	Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly	5
	Cost of implementation	3	>$1,500,000	

Overall Ratio Score

The following table presents the risk to feasibility ratio for upgrading the Highway 97 crossing. A high risk avoided score and a low feasibility score indicates the best scenario. This project received both a relatively high-risk avoidance score and a high cost to implement score, resulting in a 4:5 ratio of benefit to cost.

Table 3.21. Risk: feasibility ratio for Highway 97 crossing upgrade.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Highway 97 crossing upgrade	Likelihood	3	4	Ease of execution	3	5	4:5
	Consequence	2		Cost of implementation	3		

4 CONCLUSION

The Upper B.X. Creek floodplain maps and flood risk assessment were used to identify and assess potential flood mitigation measures within the CoV along Upper B.X. Creek. Options for structural and non-structural mitigation measures are described in detail in the main report (NHC, 2020). This report documents scoring of the structural options based on feasibility, cost, and risk avoidance. It is recommended that non-structural mitigation measures be considered and implemented in conjunction with these structural measures due to the large benefit versus reasonable costs.

Structural flood mitigation measures are costly to construct and maintain and are frequently delayed by the difficulty in obtaining property rights. Therefore, structural mitigation measures are rarely practical except for areas where the hazard and consequence are high, and property is already available by the community. Table 4.1 lists all the structural mitigation measures evaluated in this report, represents the estimated cost, and the risk to feasibility scoring. A high risk score and low feasibility score indicates that the project is likely to have a substantial reduction in flood risk and is likely to have a low cost; a project that should likely proceed sooner. A low risk score and high feasibility score indicates that the project has limited potential to reduce flood risk and is complicated or costly to implement; that is, a project likely with a low priority for flood risk reduction.

Table 4.1. Summary of structural mitigation measures.

Structural Mitigation Measure	Risk : Feasibility Score	Cost
Sediment and debris management plan	3:3	$1,150,000
Diking near Pleasant Valley Road	2:5	$1,510,000
20th Street Crossing upgrades	5:5	$12,460,000
Diking between 20th Street and Deleenheer Road	5:5	$2,570,000
Highway 97 crossing upgrade	4:5	>$1,500,000

The greatest risk avoidance or benefit is expected to occur from upgrading the crossings near 20th Street and diking between 20th Street and Deleenheer Road. Modelling indicates that these mitigations are best carried out together. Flood risk in the surrounding areas will remain unless both mitigations options are implemented. However, these measures, along with most of the others are anticipated to be complicated and expensive to design and construct.

The Highway 97 crossing upgrade is anticipated to be the next most effective mitigation measure but is also anticipated to be difficult and expensive to implement. The sediment and debris management plan has a medium risk avoided score; however, this score is matched by its relatively feasible implementation. The diking near Pleasant Valley Road is anticipated to be somewhat helpful in mitigating floods, and likely very difficult and expensive to construct.

Refer to the NHC Part 2 report, City of Vernon: Detailed Flood Mapping, Risk Analysis, and Mitigation, Part 2 – B.X. Creek below Swan Lake and Vernon Creek below Kalamalka Lake (NHC, 2021) for the ranking of these mitigation options along side the Part 2 mitigation options.

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FINAL REPORT: City of Vernon: Detailed Flood Mapping, Risk Analysis, and Mitigation

Part 2 – B.X. Creek below Swan Lake and Vernon Creek below Kalamalka Lake

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DISCLAIMER

This document has been prepared by Northwest Hydraulic Consultants Ltd. for the benefit of the City of Vernon for specific application to the B.X. Creek below Swan Lake and Vernon Creek below Kalamalka Lake detailed flood mapping, risk analysis, and mitigation project. The information and data contained herein represent Northwest Hydraulic Consultants Ltd. best professional judgment considering the knowledge and information available to Northwest Hydraulic Consultants Ltd. at the time of preparation and was prepared in accordance with generally accepted engineering and geoscience practices.

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EXECUTIVE SUMMARY

Flooding in the City of Vernon (Vernon) in 2017, 2018, and 2020 has resulted in an increased focus on the hazards of flooding to the community, and an interest in understanding how these hazards may change in the future. As a result, Vernon hired Northwest Hydraulic Consultants Ltd. to update the floodplain inundation and hazard mapping in two parts. Part 1, completed in 2020, covered flooding on B.X. Creek above Swan Lake. Part 2, this report, covers flooding on B.X. Creek from Swan Lake to its confluence with Vernon Creek, and Vernon Creek from Kalamalka Lake to Okanagan Lake.

This report and the associated floodplain maps provide a basis for evaluating and mitigating flood hazards within the study area and for assessing and guiding future development with respect to flood extents. It is recommended that this report and attachments be read in entirety prior to applying any of the findings.

The purpose of this project was to prepare detailed floodplain and hazard maps for the study reaches 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.

The flood maps and risk assessment provide the basis for the identification and implementation of mitigation measures to reduce flood risk.

Design flows for lower B.X. and lower Vernon Creek were determined through a combination of hydrologic modelling and analysis of gauge data within Vernon. Modelling of releases from Kalamalka Lake in a future climate resulted in an estimated 200-year return period release of 12.6 m^3/s from Kalamalka Lake into Vernon Creek. As in Part 1, the 1996 flood of record (5.8 m^3/s) from upper B.X. Creek was estimated to be larger than the 200-year flow on lower B.X. Creek and was used as the design event after an increase for climate change impacts (to 6.5 m^3/s). This flow was used as the design outflow from Swan Lake into B.X. Creek. Additionally, a combination of hydrologic modelling and gauge data analysis estimated a climate change adjusted 200-year local inflow within the city limits to B.X. and Vernon Creek of 7.1 m^3/s. This local inflow was distributed between B.X. and Vernon Creek based on contributing watershed areas.

The flood extents, levels and depths associated with the design flows were simulated with a hydraulic model. The model was developed in HEC-RAS software (the US Army Corps of Engineers Hydraulic Engineering Centre's River Analysis System) based on LiDAR and bathymetric survey data collected as part of this project. The model results were compared with past observations from the 2020 flood to verify the model prior to simulation of the design flood. A 0.6 m freeboard was added to the modeled water surface profile to account for local water level variations and uncertainty in the analysis. This design water surface was mapped by extending flood levels across the floodplain as represented by the LiDAR data, to approximate the extents of inundation. Isolines were added to the map at a uniform interval to provide recommended minimum flood construction levels (FCL).

The survey and all maps were prepared in the recently adopted CGVD2013 vertical datum. This should ensure ease of use, as the datum allows consistent survey with modern GPS survey techniques. Data in CGVD2013 is roughly 0.3 m greater in elevation than data in the previously used datum, CGVD28 (1928) HT2.0.

Stream setbacks are recommended at 15 m, according to EGBC guidelines. However, there are sections in the results with overbank flow that is further from the bank than 15m, and obstruction at culverts or bridges can further increase these areas. Setbacks are therefore recommended as 30 m in these locations to ensure flow remains unconstricted (indicated on the maps, Appendix C).

The flood risk assessment in this report presents a qualitative 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 Engineers and Geoscientists of British Columbia (EGBC, 2018). The 20-year flood 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 200 and 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.

An important finding from the flood risk assessment is that the fermenter building in the Vernon Water Reclamation Centre (wastewater treatment plant) is exposed to both the design flood and 20-year flood events. Cascading infrastructure failure due to flooding such as lack of electricity at the centre should be considered. The risk assessment also found that groundwater saturation or non-connected ponding could affect the stability of runway surfaces at Vernon's airports. Site specific studies of these facilities are outside the scope of this work, but may warrant consideration for emergency planning.

Additionally, though outside the boundary of the City of Vernon, the flood risk assessment found that the residents of Priest's Valley First Nation are anticipated to be affected by both the 20-year and design flood events.

There is a variety of both structural and non-structural flood risk reduction options, which have been selected and discussed based on the results of the analysis in this area. Non-structural mitigation options include:

- 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.
- Recovery pre-planning through the development of recovery plans and resources in advance of a flood or other hazard event.

Structural mitigation is considered as any specific engineering works that reduce flooding impacts. Several undersized crossing structures (overtopping / backwatering) have been identified in the study area and are summarized. Site specific structural mitigation measures to reduce flood risk within the community have been developed and modelled for the Part 2 study area:

- 43rd Street crossing upgrades
- Okanagan Landing Road crossing upgrades
- Lakeshore Road crossing upgrades

These mitigation options have also been ranked in combination with the recommendations in the Part 1 report to provide a comprehensive list of most significant mitigation options for the City of Vernon.

GLOSSARY

Definitions of technical terms used specifically in this report.

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.
Digital elevation model (DEM):	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 event selected for establishing design criteria and defined by some form of magnitude (generally including flow or water level) and often an associated probability of occurrence.
Flood construction level (FCL):	The sum of freeboard and the design flood level.
Flood fringe:	An area at risk from flood events that is not expected to experience high velocity, large depth, or substantially contribute to flow conveyance during flood.
Flood map:	A map that illustrates the design flood event as the inundation extent, flood level, flood depth, flood velocity, and/or flood timing.
Floodplain:	The land adjacent to a river or lake that may be submerged by floodwaters, in this case during the design event.
Flood Hazard Assessment	A report written by a Qualified Professional to characterize the flood processes, identify the existing and future elements at risk, and determine the flood intensity characteristics that may damaged the proposed development. It will determine whether the proposed development is subject to flood, debris flood, debris flow or other hazards. It does not address other potential natural hazards such as landslides, soil erosion, subsidence, or avalanches except as related to flooding.
Flood risk:	The product of the probability of floods occurring that have the potential to result in hazardous consequences and expected consequences of the floods.

Floodway:	An area at risk from a flood event that is expected to substantially contribute to flow conveyance and or experience high velocity or large depth of inundation during a flood. The floodway generally encompasses all active channels plus overbank areas and relic 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 water surface calculated for the design flood event to account for local variations in water level and uncertainty in the underlying data and analysis.
Hazard map:	A map that highlights areas that are affected by or are vulnerable to a particular hazard.
Light detection and ranging (LiDAR):	A remote sensing technology used to create DEMs that employs a laser to measure distances from known elevations to the surface of the earth.
Natural boundary:	The visible high watermark of a lake, stream, river, or other body of water where the presence and action of the water is so common, usual, and long continued as to mark upon the soil a character distinct from that of the banks.
Peak daily flow (QPD):	The maximum of all daily-averaged streamflow that occurs in a given period (usually a year).
Peak instantaneous flow (QPI):	The maximum instantaneous streamflow that occurs in a given period (usually a year).
Qualified Professional:	A person with experience and training in the pertinent discipline, and who is a qualified expert with expertise appropriate for the relevant critical area
Return period (RP):	Also called average recurrence interval (ARI). The average time until an event (in this case a peak flow) re-occurs. Usually expressed in years.
Sediment infilling:	The process through which sediment transported by a stream is deposited in such a way that it reduces the cross-sectional flow area of a channel or crossing, often resulting in reduced flow capacity.
Setback:	Refers to the distance from the top of bank of a water body or existing dike in which development should be prohibited or restricted to limit local flood risk, limit transfer of risk to upstream properties, and provide sufficient space for future flood protection (e.g. dikes).
Structural mitigation:	Reduces flood risk through the establishment of new or modification of existing physical features that alter the hydrology or hydraulics of a flood.

	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 flood boxes.
Top of bank:	The upper edge of a watercourse.
1D flow modelling:	Modelling flow in one dimension, with simulations assuming all flow is parallel to the primary flow path.
2D flow modelling:	Modelling flow in two dimensions, with simulations assuming all flow is planar to the water surface. Vertical flow components are not simulated.

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1 INTRODUCTION

The City of Vernon (Vernon) is located on the northern end of Kalamalka Lake in British Columbia's North Okanagan. A number of streams run through the city, including Vernon Creek, which flows from Kalamalka Lake into Okanagan Lake, and B.X. Creek, which has its headwaters northwest of Vernon and runs through Swan Lake before joining Vernon Creek. These water bodies and creeks can impose flood hazard on the community. In order to define the flood hazard to the community, the City of Vernon retained NHC to develop floodplain maps for B.X. Creek and Vernon Creek within Vernon's city limits.

The project was split into two phases. Part 1 (NHC, 2020b) focused on upper B.X. Creek, upstream of Swan Lake. In this report (Part 2), the work focuses specifically on flood mapping and risk analysis on lower B.X. Creek, between Swan Lake and Vernon Creek, and Vernon Creek, from the outlet of Kalamalka Lake to Okanagan Lake. Information from Part 1, as well as NHC's recent work mapping the Okanagan Mainstem Lakes (NHC, 2020d) have supported the work described in this report. This report is intended as a complement to the Part 1 report; we avoid repetition of information from the Part 1 report when possible. Thus, review of both reports is recommended for full understanding of Vernon's updated floodplain mapping work.

1.1 Project Objectives

Building upon Part 1, the purpose of this project is to prepare detailed floodplain and hazard maps for lower B.X. Creek and Vernon Creek within the Vernon city boundary, assess the associated flood risk, and document and communicate the findings. The information developed is intended to be used for flood risk management (prevention and mitigation), land use planning, emergency preparedness, 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 hazard analysis is aimed to be of sufficiently high 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

Part 2 of the Vernon floodplain mapping focuses on flood inundation along approximately 4.5 km of lower B.X. Creek, from the outlet of Swan Lake to the confluence with Vernon Creek, and along the approximately 11 km reach of Vernon Creek, from the outlet of Kalamalka Lake to Okanagan Lake. The model reaches are shown in Figure 1.1.

Boundary conditions are dictated by lake levels in Swan, Kalamalka, and Okanagan Lake. Modelling extends beyond the Vernon city boundary to sufficiently limit sensitivity to the model boundary conditions. Results are presented only within the City of Vernon boundary.

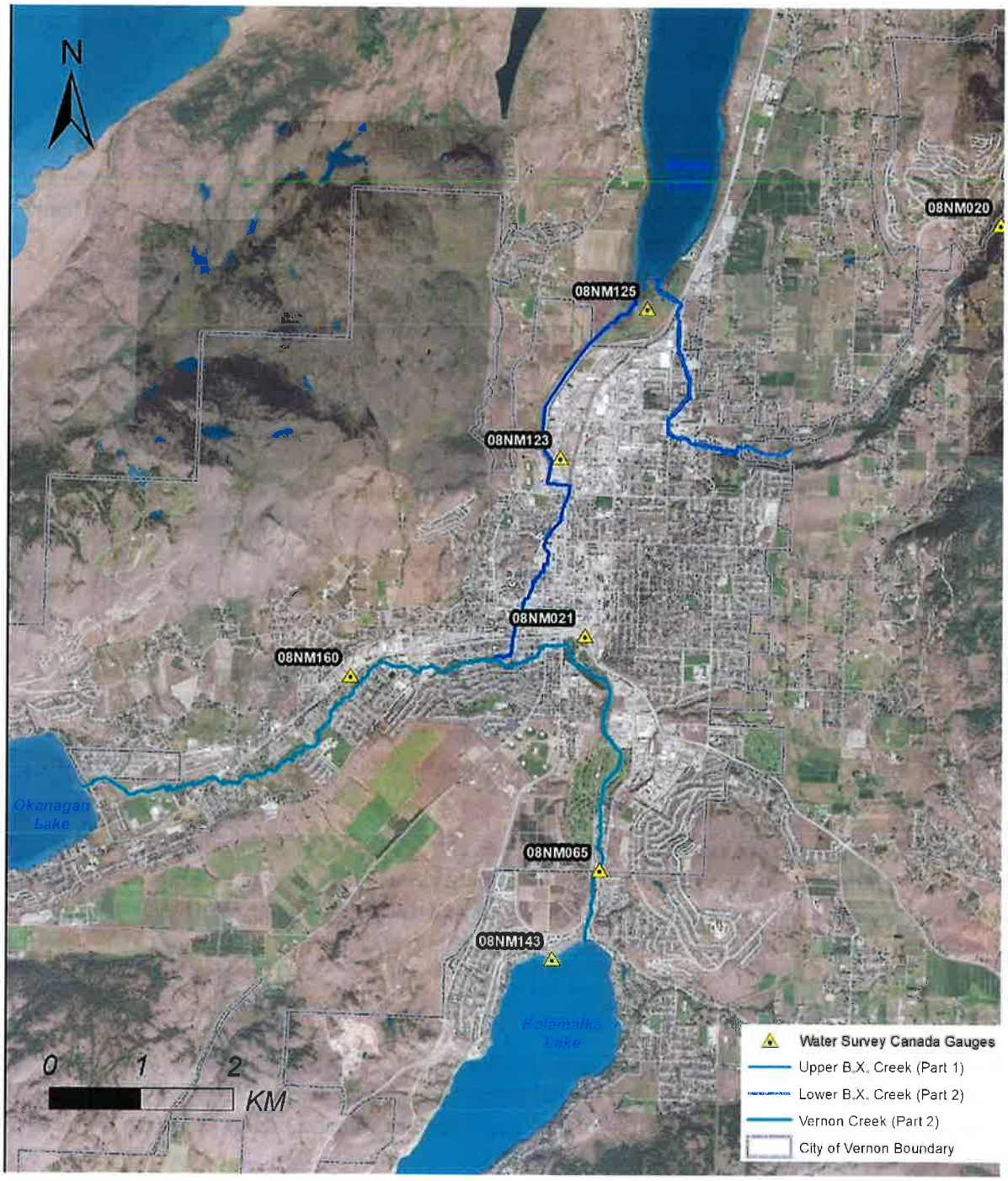


Figure 1.1 Project location for Parts 1 and 2.

1.3 Scope of Work

This report presents the main tasks completed for the City of Vernon's overarching "Detailed Flood Mapping, Risk Analysis and Mitigation Project" for Part 2: lower B.X. Creek and Vernon Creek. The tasks specific to Part 2 described in this report include:

- Data acquisition and background data review (Section 3)
- Geometrical 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 risk reduction planning (Section 8)

Public engagement is being carried out via a web-based flood story map (in development as of August 2021).

1.3.1 Flood Mapping, Risk Analysis, and Mitigation

Flood risk reduction can be understood in the three steps depicted in Figure 1.2. While the steps are depicted in a linear fashion, they are a cycle which must be revisited and updated as actions are taken, new information becomes available, and a community evolves.

Flood risk reduction starts with understanding the hazard. The first step involves mapping the inundation extents, which is achieved by analysing and determining the design flood event. The maps are prepared to be readily understood by 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 receptors are exposed to the modelled flood hazard. The risk assessment for this project is based on the flood hazard mapping and available receptor data. 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 mitigation measures. Potential mitigation measures are identified as a part of this project; however, further analysis and community input is needed to develop a comprehensive flood risk reduction plan. In other words, this report represents one phase in the ongoing cycle of flood risk reduction.

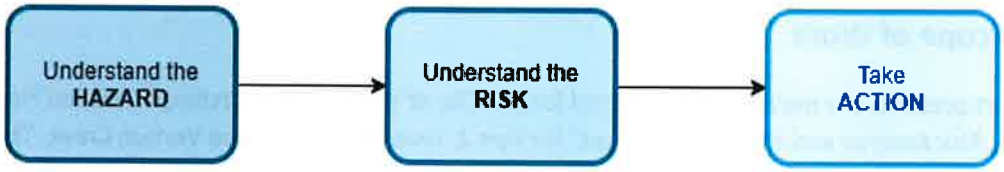


Figure 1.2 Flood risk reduction process (NRCan).

1.4 Applicable Guidelines and Regulations

The following guidelines and regulatory documents are applicable to 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 (MFLNRORD, 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 (NRCan and Public Safety Canada, 2019)

Flood risk assessment is a non-standardized process, particularly in BC, where there are a wide range of potentially interacting flood hazards and inconsistencies in data and interpretation of receptors and associated vulnerability. Guidance for this project was attained from:

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

1.5 Limitations

Floodplain hazard mapping, assessment of flood risks, and hydrologic and hydraulic modelling to support such work are core services for NHC. This study has been completed with ongoing review from Vernon and NHC's internal review team to assure the quality of services and deliverables. However, the study and its deliverables are still 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:

- The models developed and used in this study are based on current land-use conditions and historic data. Changes to land-use or new information or data may require analysis and the produced maps to be updated.
- There may be errors in the data and software used in this study that have not been identified.
- Streamflow values estimated for design are based on extrapolation of frequency analyses and model simulations to less frequent events. The impact of regulation operations on the outlets of Kalamalka Lake and Swan Lake are simulated versions of actual human operation during major flooding. Thus, the resulting design values have an inherent uncertainty.
- Model simulations for future conditions use plausible climate conditions that could occur in the future, given current projections on increases in greenhouse gas concentrations in our planet's atmosphere. The climate conditions that will actually exist in the future are not known.
- 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 may alter that surface used in the simulation and mapping, potentially altering the hydraulics from those simulated. Site-specific flood hazard assessments may be required to assess a specific proposed development.
- Occurrence of flood events larger than the flood-of-record for any areas included in the study should trigger re-evaluation of the design flood hydrology.
- 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.
- Prior to engaging the public on the development of the flood maps, the City of Vernon pursued development of both structural and non-structural mitigation measures. The City shared the flooding mapping information while still in draft format with OKIB, OBWB and directly impacted key community facilities identified in Section 7 of this report. The Risk Assessment presented in this report is expected to evolve as a better understanding of the receptors and their vulnerability are better understood.
- Ground truthing (e.g. on-the-ground confirmation of data from GIS and satellite layers) was not applied in the development of this study to identify or assess vulnerability of flood risk receptors. Risk assessment results may vary as the understanding of receptors and their vulnerability are refined.
- The impact to people is calculated based on direct exposure (i.e. dwellings located within the mapped floodplain). Vulnerability and consequences extend beyond the exposed residents, as others would be impacted by a flood through transportation or service disruptions. However, these additional receptors were not incorporated in this flood risk analysis.
- Building damage estimates are based on damage curves developed for the United States as comparable Canadian curves were not available at the time of analysis. Construction standards differ in Canada so these damage estimates may not be entirely representative.

This document should be read and understood in its entirety before applying the maps, models, or other findings 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 Study Area Description

Both the watershed characteristics and the flood generating processes for lower B.X. Creek and Vernon Creek (Part 2 of the study) are notably different than those of upper B.X. Creek (Part 1). While upper B.X. Creek is driven by a relatively steep, natural, mountainous stream, lower B.X. Creek and Vernon Creek are dominated by regulated outflows from two lakes, and the local watershed area is primarily lower elevation terrain which does not see substantial winter snowfall.

Inflows to lower B.X. Creek are dominated by release from Swan Lake, which is regulated by a small dam at its southern end. Upper B.X. Creek flows into Swan Lake, with the lake's storage attenuating peak flows before flow continues downstream through the Swan Lake dam. Flow past the dam is regulated through the manual addition and removal of stoplogs by the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). A full description of the dam and its operational strategy is available from Ecora (2019).

Similarly, flows on Vernon Creek within the study area are dictated by releases from Kalamalka Lake via the Kalamalka Lake dam at the northern end of Kalamalka Lake, near the corner of Westkal Road and Kalamalka Road. BC FLNRORD operates the gates of the Kalamalka Lake dam to balance multiple operational goals including:

- Avoiding flooding on Kalamalka and Wood Lake
- Maintaining high enough lake levels for recreational use and water supply
- Maintaining minimum environmental flows on Vernon Creek
- Minimizing exposure to damaging high flows on Vernon Creek or flooding within the City of Vernon.

In years when large inflows to Kalamalka Lake are expected, based on measurements of high elevation snow, Kalamalka Lake is drawn down in late winter in anticipation of a large spring freshet. A full description of the Kalamalka Lake operational strategy is available from AE (2017).

For the Kalamalka Lake dam, flows are generally dictated by operational decisions. However, during extreme high flow (or high lake level) situations, water has the potential to flow around the structure. During the 2017 freshet season, sandbagging was required around the Kalamalka Lake dam to maintain regulatory control and limit flooding downstream. Because floodplain mapping requires simulation of extreme high flow situations, our modelling focuses on these situations where regulation may no longer be effective; we developed an "open gates" scenario for the Kalamalka Lake dam, following the methods from NHC (2020d) used for the Okanagan River. This scenario uses a combination of empirical rating

curve and hydraulic modelling to determine flows into Vernon Creek during extreme conditions. It is described further in NHC (2020a).

Along with the high flows that can occur due to high lake levels upstream of the study reaches, flooding on lower B.X. and Vernon Creek has the potential for two further exacerbating factors. The first is local inflows generated within the City of Vernon along the study reaches. Whereas the releases from Swan Lake and Kalamalka Lake are likely to be driven by spikes in inflow when lake levels are already high, local inflows can be caused by shorter, high intensity, rainstorms

Second, the downstream boundary condition of Okanagan Lake influences flooding at the lower end of the study area. High lake levels prevent water from draining quickly from lower Vernon Creek. This scenario is quite likely; high lake levels on Kalamalka and Swan Lake occur at the same time as high lake levels on Okanagan Lake. Our design flood events assume a scenario in which all these events occur at the same time.

2.2 Flood History

Various cases of local flood inundation have occurred within Vernon in the past 30 years. Notable events are summarized below. For a history of flooding in the entire Okanagan system, see the Okanagan Flood Story[1].

- Extreme lake levels on Okanagan and Kalamalka lakes in 1990 resulted in sandbagging in the City of Vernon (see Okanagan Flood Story).
- Extreme flows on upper B.X. Creek May 1996, led to high lake levels on Swan Lake (Summit, 1996).
- The highest flow release from Kalamalka Lake on record occurred in June 1997, due to extreme snow depth in the Okanagan watershed and high inflows to Kalamalka Lake (See Appendix A).
- Flow went over and around the Swan Lake Dam in 2012 (Vernon, pers. comm. 2020).
- Extreme lake levels were experienced on Okanagan and Kalamalka lake in 2017 due to high spring rainfall and rapid snowmelt in the spring of 2017 (AE, 2017; NHC, 2020d)
- Flooding near 48th Avenue in Vernon occurred May 2018 due to heavy rainfall (Vernon, pers. comm. 2020).
- Flooding near Polson Park in Vernon occurred 2020 due to heavy rainfall and apparently saturated ground (Vernon, pers. comm. 2020).
- Flow over and around the Swan Lake dam occurred during the 2020 freshet (Vernon, pers. comm. 2020).

[1] https://okanagan-basin-flood-portal-rdco.hub.arcgis.com/

2.3 Available Data

In addition to the data sources described in NHC (2020b), the following references and data sources were used:

- Vernon provided 2019 orthophotos for the lower B.X. and Vernon creek study area.
- Vernon provided utility infrastructure spatial data layers including BC Hydro, FortisBC gas, Shaw telecom, and Telus telecom infrastructure.
- Spatial data layers were obtained from the BC Data Catalogue for species and ecosystems at risk, critical habitat for federally-listed species at risk, and sensitive ecosystems (Government of British Columbia, 2021).

3 DATA ACQUISITION AND DEM DEVELOPMENT

3.1 Coordinate Systems 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. In a recent study completed May 2021, which aimed to assess the current level of awareness of flood risks among the communities in BC, 42 of the 109 local governments that responded reported having created or updated floodplain maps. Of the 42 communities, 85% of those who knew which vertical datum was used reported using CGVD2013 (BCREA & UBCO, 2021).

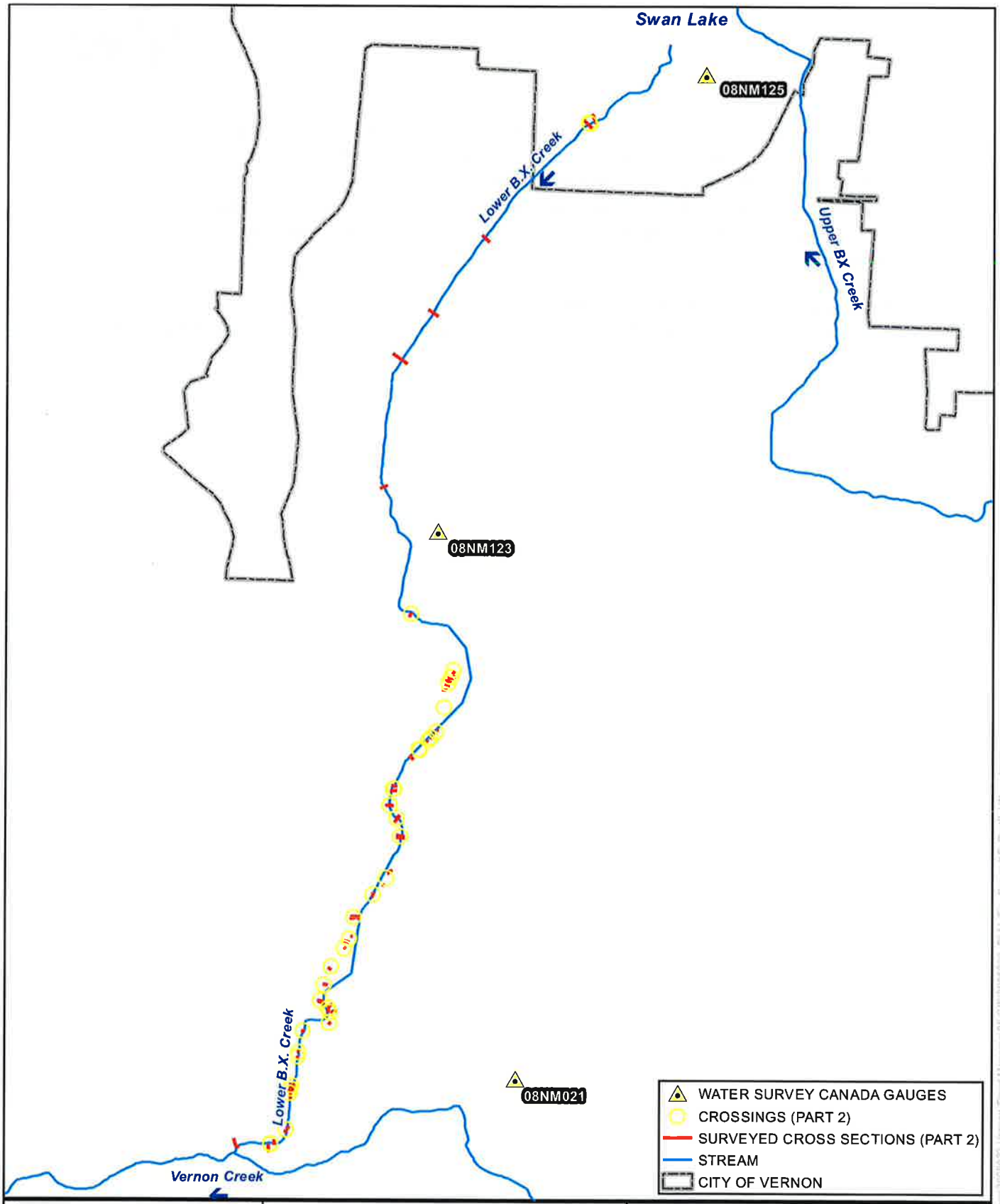
3.2 Survey

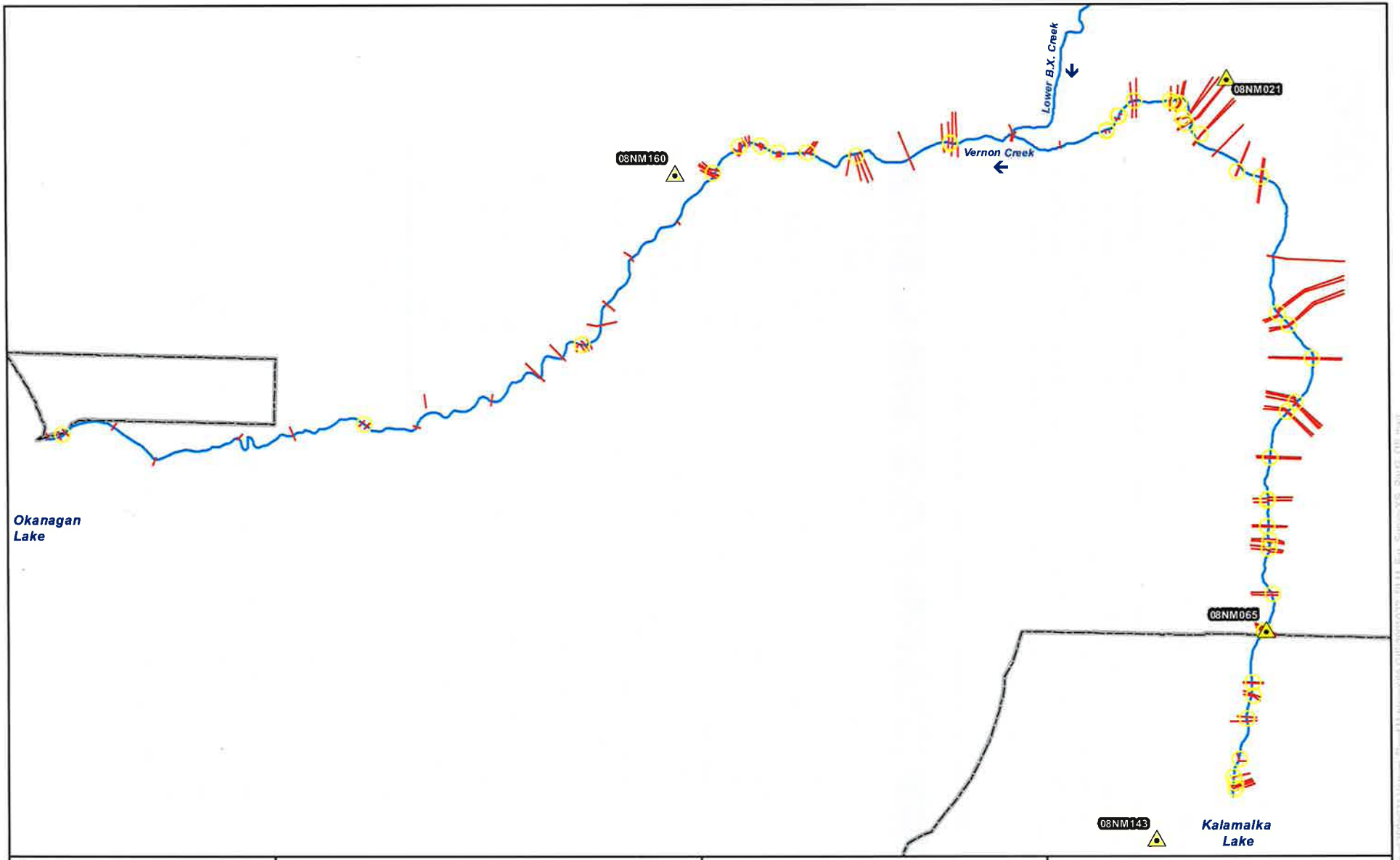
Over the span of 3.5 weeks (Sept 28th to October 25th, 2019), survey data concentrating on channel bathymetry was collected for both Part 1: upper B.X. Creek to Swan Lake and Part 2: Swan Lake along lower B.X. Creek to the confluence of Vernon Creek, and Kalamalka Lake along Vernon Creek to the inlet of Okanagan Lake. Survey equipment, data collection and data quality control details can be found in NHC (2020b). For the purposes of mapping and reporting, Vernon Creek has been split into upper Vernon Creek and lower Vernon Creek, divided by the lower B.X. confluence.

A total of 65 cross sections were surveyed along the 5.1 km reach of lower B.X. Creek, 62 cross sections along the 4.7 km reach of upper Vernon Creek, and 54 along the 6.3 km reach of lower Vernon Creek.

Cross sections were collected primarily upstream and downstream of each crossing structure (bridge, culvert, or pipe crossing) and at specific locations between crossings that were found pertinent to the model development. Project data collected includes bridge and culvert details for 110 structures within the project extent, 86 of which are along lower B.X. Creek and Vernon Creek. Detailed photographs of each crossing were taken during the survey and provided to Vernon with the collected survey data during Part 1.

Figure 3.1 and Figure 3.2 show the surveyed cross sections and crossing locations along each reach. A crossing inventory outlining observed and surveyed crossing information can be found in Appendix B.


Swan Lake
08NM125
Lower B.X. Creek
Upper BX Creek
08NM123
08NM021
Lower B.X. Creek
Vernon Creek
WATER SURVEY CANADA GAUGES
CROSSINGS (PART 2)
SURVEYED CROSS SECTIONS (PART 2)
STREAM
CITY OF VERNON
SCALE - 1:18,000
0 0.15 0.3 0.6
KM
N
Coordinate System: NAD 1983 UTM ZONE 11N
Units: METRES
Job: 3005032
18-AUG-2021
CITY OF VERNON
FLOODPLAIN MAPPING
LOWER B.X. CREEK
SURVEYED CROSS SECTIONS
PART II
FIGURE 3.1



WATER SURVEY CANADA GAUGES
CROSSINGS (PART 2)
SURVEYED CROSS SECTIONS (PART 2)
STREAM
CITY OF VERNON

SCALE - 1:24,000

0 0.2 0.4 0.8 KM

N

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

Job: 3005032 | 18-AUG-2021

CITY OF VERNON FLOODPLAIN MAPPING

VERNON CREEK SUVEYED CROSS SECTION LOCATIONS - PART II

FIGURE 3.2

3.3 Digital Elevation Model (DEM) Development

DEM development methodologies described in Part 1 covered the complete project area for both Part 1 and Part 2. Details describing LiDAR collection, point density, and accuracy can be found in NHC (2020b).

Bridges are typically removed from the LiDAR-derived bare earth DEM, so that the DEM approximately represents the channel under the bridge, whereas culverts are typically not removed from the DEM. Although this was the case with most of the DEM data supplied for the City of Vernon, some of the smaller structures were either missed or mistakenly identified by the LiDAR provider. One culvert was removed after LiDAR collection. A total of 11 structures were edited by NHC in the bare earth DEM. The locations are listed in the Table 3.1 below:

Table 3.1 DEM editing of bridge and culverts for the hydraulic model.

Location	NHC Crossing ID	Purpose of Edit
Downstream (8 m) of Swan Lake Weir	XING - 51	Triple barrel culvert removed by MoTI, 2020
32 St. and 42 Ave. – Blue Stream Motel	XING - 54	Bridge not removed – small pedestrian bridge
Kalamalka Rd. and College Way – Dutch's Campground	XING - 102	Bridge not removed – small wooden car bridge
Kalamalka Lake Rd. – Uncle Dave's Pizzeria and Alpine Center	XING - 104	Triple barrel culvert removed, mistaken as bridge – NHC patched in
Browne Rd. – Kalloway Greens	XING - 109.1	Bridge not removed – concrete vehicle bridge
Browne Rd. – Private Drive 409A and 409B	XING - 110	Bridge not removed – concrete vehicle bridge
Polson Drive – Vernon Golf and Country Club	XING - 122	Bridge not removed – concrete vehicle bridge
Polson Park near 32 St.	XING - 132	Bridge not removed – small steel walking bridge
34 St. south of 25 Ave.	XING - 136	Bridge not removed – large multilane vehicle bridge
24 Ave. – Private drive at back of Elephant Storage	XING - 144	Bridge not removed – large vehicle bridge

Where cross sections were needed in the hydraulic model, elevation data extracted from the DEM data was combined with the bathymetric cross section survey data. An additional 223 cross sections were added to the model based on the LiDAR and adjacent survey data. These additional sections were added to represent features in the channel not sufficiently captured in the survey data, such as channel widening or embankment elevation changes. The DEM was used to represent the overbank areas in the

hydraulic model. Quality control and accuracy checks were completed for the LiDAR and survey data collected, and can be found in NHC (2020b).

Colour orthophotos collected by EMBC in 2018-2019 were provided by Vernon. Orthophotos 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 model results. They were also used to create the base image for floodplain mapping.

4 HYDROLOGY

This section summarizes the design flows developed for lower B.X. Creek and Vernon Creek. Development of the design flows are described in greater detail in NHC (2020a), attached as Appendix A to this report.

Flow in both lower B.X. Creek and Vernon Creek come from upstream, regulated lakes, thus standard flood frequency analysis on these creeks is inappropriate. NHC expanded upon the hydrologic and reservoir operations model developed for the Okanagan mainstem floodplain mapping project (NHC, 2020d) to model lake outflows to present and projected future (end of century) design conditions. As with Part 1, the 1996 peak flow on upper B.X. Creek (the flood of record, estimated as roughly a 500-year event) was used as the design event input to Swan Lake and lower B.X. Creek. According to model output from NHC's Okanagan mainstem model, this corresponds to a flow equivalent of a future 500-year event at the outlet of Swan Lake as well. For Vernon Creek, the 200-year return period outflow from Kalamalka Lake from the Okanagan mainstem hydrologic model was used as the design event, assuming dam gates were fully open.

Additionally, local inflows (assumed to occur during the design events) along each reach of the hydraulic model (Section 5) were estimated using a combination of hydrologic model output and observational data. Relevant design flows, used in the hydraulic modelling for the three input locations, are summarized in Table 4.1. The 20-year event is considered the 'likely' flood event used in the flood risk assessment and thus included in the Table 4.1. Note that future flows for the 20-year return period represent mid-century conditions (2041-2070) whereas design flows (200-year or flood of record) represent end of century (2071-2100) conditions. Mid-century conditions are considered to have a slightly lower uncertainty than end of century conditions.

Table 4.1 Design flow summary. Flows shown in m^3/s. * indicates primary design event flows.

Return Period (yr)	Vernon Creek from Kalamalka Lake		Lower B.X. Creek from Swan Lake		Local inflows to B.X. and Vernon Creek	
	Present	Future	Present	Future	Present	Future
20	6.1	8.5	3.6	4.1	5.1	5.5
200	8.4	12.6*	N/A	N/A	6.1	7.1*
1996 Event	N/A	N/A	5.8	6.5*	N/A	N/A

An elevation of 343.86 m (CGVD2013), the same design level for Okanagan Lake used in NHC (2020d) was used for the downstream boundary condition on Okanagan Lake during the design event. 342.89 m was used for the 20-year event.

5 HYDRAULIC MODELING

The hydraulic analysis of Part 2 is comprised of constructing and calibrating a numerical hydraulic model to calculate hydraulic conditions along lower B.X. Creek and Vernon Creek during the design flood event. This section discusses model development and calibration results. The resulting hydraulics (flood extent, depth and velocity) from simulation of the design flows are discussed in 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 lower B.X. Creek and Vernon Creek. A 1D/2D coupled model was used to simulate flood flows in the channel. Where flow is predominantly in one direction, either in the channel or floodplain, 1D modelling was used. The 1D model reaches are based on cross sectional data of the channel. Where flow in multiple directions, such as across an overbank route not parallel to the main channel, 2D modelling was used. The 2D model simulates hydrodynamic flow routing over a surface represented by a mesh of interconnected elements. This modelling approach combines the advantages of 1D and 2D modelling, such as the inclusion of established bridge and culvert crossing representation in the 1D model and detailed representation of converging and diverging flow over the floodplain in the 2D model. This modelling method does present certain disadvantages, as a coupled 1D/2D model can often be more complex to develop and can exhibit numerical stability problems at the 1D/2D interfaces.

The hydraulic model covers a reach length of approximately 4.5 km on lower B.X. Creek from Swan Lake to the confluence with Vernon Creek, and 11 km on Vernon Creek from Kalamalka Lake to Okanagan Lake. The 1D model is based on digitization of the 2016 orthophoto, 181 cross sections derived from NHC in-channel surveys (2019), overbank LiDAR data, and a total of 67 crossings (38 bridges and 29 culverts) surveyed by NHC (2019). Where culverts size was unclear due to 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 (including the infilling noted during survey). Specifically, the crossing at 34th St north of 43rd Avenue – composed a box culvert followed by two differently sized circular culverts – and the crossing at 32nd St south of 25th Avenue – composed of an arch culvert followed by an ellipse culvert recessed under a bridge with an arch outlet – were both modelled to represent the smallest culverts. Details on all crossings are presented in Appendix B.

Long bending culverts and culvert size changes are not within HEC-RAS's capability to simulate. HEC-RAS cannot simulate head loss from pipe constrictions, expansions, or bends. Lower B.X Creek contains a large number of crossings that are either very long, bend, change size, or have some kind of obstruction within the culvert/bridge which makes them difficult to accurately simulate in the HEC-RAS model. A

PCSWMM model was therefore developed for lower B.X. Creek to verify the HEC-RAS simulation of these structures. PCSWMM is a

and watershed systems model developed by Computational Hydraulics International (CHI) which is designed to simulate pipe flow. Water surface profiles calculated using the two models were compared for a range of flows. This comparison was used to refine the simulation parameters for the HEC-RAS model.

The 2D floodplain model is comprised of 3 sections: 1) the confluence of lower B.X. Creek and Vernon Creek; 2) near the Vernon Water Reclamation Centre; and 3) at the outlet of Vernon Creek into Okanagan Lake (Figure 5.1). The 2D model is composed of a 5 m by 5 m mesh for the first two locations (the confluence and near the water reclamation facility), and a variably spaced mesh down to 5 m by 5 m near the Vernon Creek outlet. The topography is derived from the DEM described in Section 3.3. The 2D component does not include any municipal stormwater systems. Therefore, water can only flow along the terrain. This assumes that the design event would include high intensity rainfall within the city 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 Okanagan Lake water levels defined in Section 0 were applied as fixed upstream and downstream boundary conditions, respectively. Local B.X. and Vernon Creek inflows were distributed based on the watershed area of the three main stream reaches within Vernon. For the design event (7.1 m^3/s) this resulted in:

- 1.1 m^3/s along lower B.X. Creek from Swan Lake to Vernon Creek (9.8 km^2 watershed area). This was applied at the upstream boundary at Swan Lake.
- 3.0 m^3/s for upper Vernon Creek from Kalamalka Lake to the confluence with B.X. Creek (25.2 km^2 watershed area). This was applied at the upstream boundary at Kalamalka Lake.
- 3.0 m^3/s for lower Vernon Creek from the confluence with B.X. Creek to Okanagan Lake (25.1 km^2 watershed area). As a conservative assumption, this was applied at the confluence of Vernon Creek and B.X. Creek.

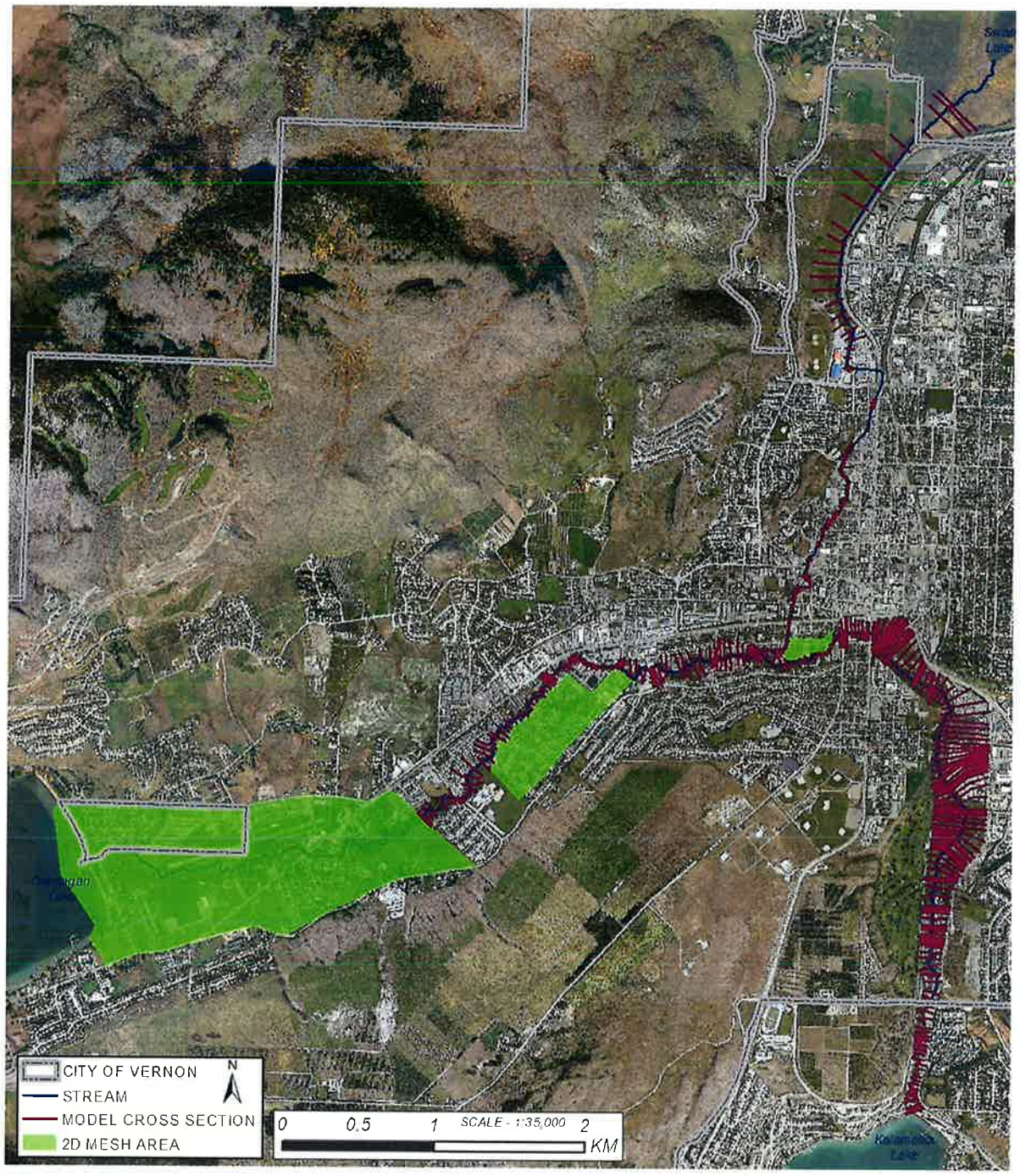


Figure 5.1 Hydraulic model layout map

5.2 Model Calibration

Evaluation of model parameters during calibration showed that, other than geometry (including blockage of culverts) and flow, channel roughness has the most influence overall on the simulated water surface elevation for Vernon and lower B.X. Creek. Entrance and exit losses for culverts also impacted the simulated water surface elevation locally. In contrast, overbank roughness has little effect due to most of the flow being conveyed within the channels except for near the outlet of Vernon Creek. The Manning's n value used to define channel roughness, following calibration, varied between 0.06 and 0.04; 0.06 was used in the more heavily vegetated portions of the reach and 0.04 in the less constricted sections. 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

Despite recent flooding in 2020, 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 2020 flood provided by the City of Vernon. A sample of the photo record is illustrated in Figure 5.2. Water surface elevations and flood extents were deduced from such information and compared to model results for calibration purposes. The main calibration parameter was channel roughness as described above.

Figure 5.2 Photographic evidence of 2020 flood used for calibration purposes (provided by City of Vernon).

The spring 2020 discharge for Vernon Creek was collected from the WSC gauge - *Vernon Creek at Outlet of Kalamalka Lake* and the downstream lake level was collected from WSC gauge - *Okanagan Lake at Kelowna*. An accurate estimate of the 2020 discharge was not available for lower B.X. Creek.

Figure 5.3 shows the modelled profiles for the three observed flood events in spring 2020 compared to observed water elevations. Overall, there is good agreement between the calibration and the modelled water surface for the reach where calibration data is available. Upstream of the 32nd Street crossing on Vernon Creek, the modelled water surface elevation is about 40 cm higher than observed. This discrepancy could be caused by the changing size of the culvert. The inlet is an arch culvert but was modelled as an ellipse culvert because it is the smallest of the three culvert types in this specific crossing, and consequently the limiting factor. There was no photo data available for lower B.X. Creek and lower Vernon Creek and numerical calibration was not possible.

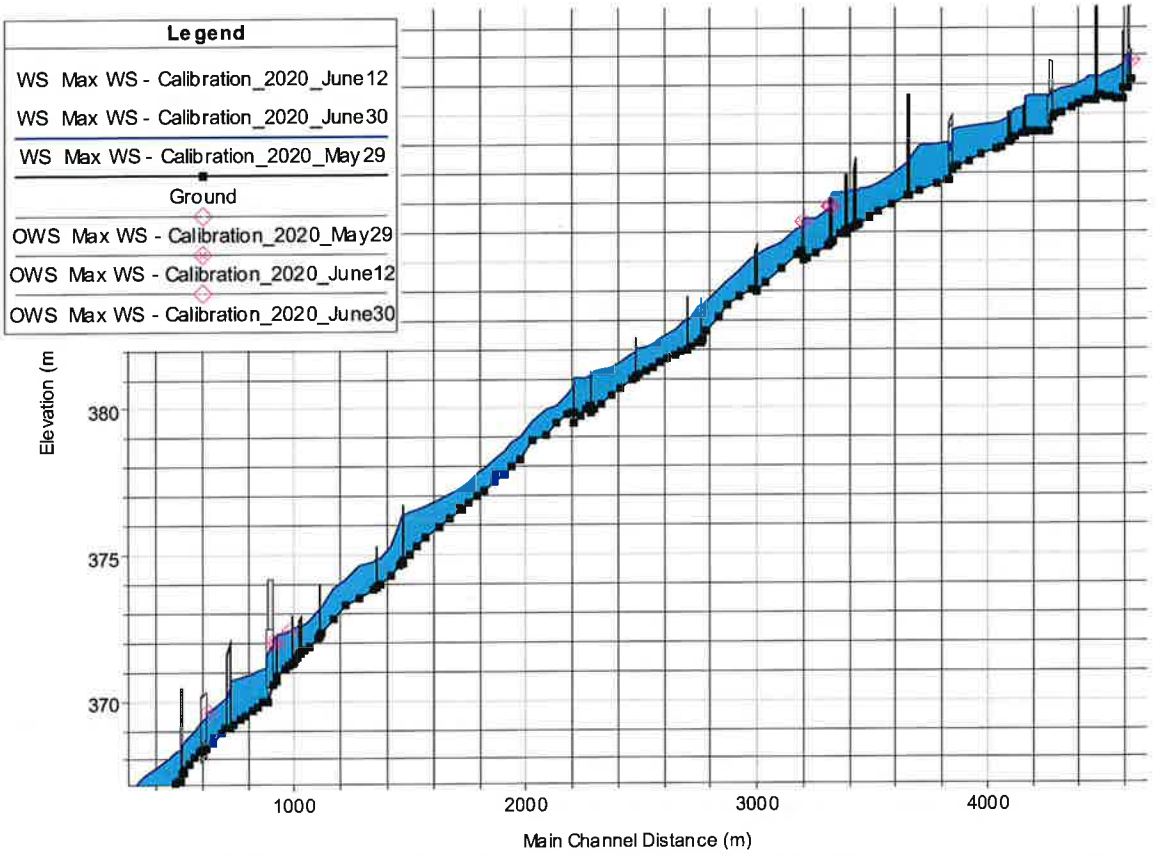


Figure 5.3 Calibration results for the 2020 spring flood, upper Vernon Creek (3 separate dates).

Given the sparsity of observed high water data and no available flow data for lower B.X. Creek or lower Vernon Creek during the 2020 flood event, no further calibration was carried out. This lack of calibration data limits confidence in the model results. Further model calibration should be conducted when water level and flow data from future high flow events is collected.

Model representation of the observed water surface is affected by the assumption that the channel geometry, particularly the bed, is fixed. During a flood event, the channel may degrade, widen, or become obstructed with sediment deposition or debris blockage.

5.3 Modelling Approach

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

- Overbank flow on the right bank of Vernon Creek just upstream of 24th Avenue
- Overbank flow on the left bank of Vernon Creek at 43rd Street
- Overbank flow upstream and downstream of the Okanagan Landing Road
- Overbank flow upstream of Lakeshore Road

As a coupled 1D/2D model, the overbank flow in the above four areas were modelled using a 2D floodplain mesh. This allowed the simulation of overbank flow through town and around buildings. The 1D component of the model was linked to the 2D mesh either through a series of lateral weirs representing the high terrain along the banks which allowed water in and out of the channel or through a 1D to 2D connection in the channel. Flow overtopping at crossings (bridge decks) stays within the 1D component of the model. This limitation is considered acceptable as overtopping flow would likely flow over the road and into the channel downstream of the crossing.

A hydrograph with a prolonged peak was used in the simulation to mimic steady flow conditions. Simulations were run sufficiently long (24 hours) to ensure stable water surface elevations across the flood extents, indicative that equilibrium was reached.

5.4 Modelling Results

For the design flood event, flooding occurs in the following locations.

From Vernon Creek:

- Vernon Golf and Country Club and in Polson Park.
- 25th Avenue between 32nd Street (Hwy 97) and 34th Street
- Intersection at 24th Avenue and 34th Street; flow continues along 24th Avenue towards B.X Creek and along 34th Street back into Vernon Creek
- 24th Avenue further downstream, near 39th Street.
- 43rd Street and the subdivision south of the Vernon Water Reclamation facility
- Creekside Drive in two separate locations
- Okanagan Landing Road and several nearby streets and subdivisions
- Lakeshore Road and nearby neighborhoods to both sides of the creek

From lower B.X. Creek:

- Agricultural land near Swan Lake and Kal Tire Place
- Schell Motel (South of 30 Avenue)
- 36th Street near the confluence

Water mostly stays in the channel through the rest of Vernon Creek and lower B.X Creek. While the flow may be mostly confined to the channel, many of the culvert and bridge crossings along lower B.X. Creek are either at capacity or being overtopped. Obstruction at any of the crossings, from sediment deposition or debris, could result if greater flooding. Further discussion on the structure capacity can be found in Section 8.2 and Appendix E.

5.4.1 Sensitivity Testing

Due to the large number of crossings within Vernon, the model is sensitive to several parameters. Variations in flow (for example a 25% increase) can increase the water level roughly 0.1 m – 0.15 m throughout the channel. However, the local flooding at a structure can increase upwards of 0.5 m. This can cause a structure that was close to, or at capacity, to overtop a road or flood nearby properties. The crossings are also sensitive to blockages. If a blockage were to occur in a channel or at the crossing during the flood, it would change the water level in the channel, possibly sending it overbank and over the roads. The model is also sensitive to the entrance and exit losses of the culverts locally, which affect the head and tailwater elevations. The model is not very sensitivity to roughness coefficient in the overbanks.

5.5 Limitations

The following is a sample of assumptions and limitations of this study. Despite these limitations, the flood maps produced are expected to sufficiently represent design flood levels and extents to be used for flood mitigation planning.

- The channel bed and banks are fixed.
- The current study does not investigate probability or impact of structural failure of the dams at Swan Lake and Kalamalka Lake.
- Flood extent boundaries have not been verified in the field.
- The design flood events have been selected based on typically accepted level of probability of exceedance. Events less likely to occur (longer average return period) can occur and result in increased flooding.

Uncertainties in the model geometry are:

- Uncertainties in survey data (0.05-0.10 m for topographic data and ~0.05 m for gauge station data) and fluctuations between the cross sections that were surveyed (can be much larger than the stated survey error).
- Uncertainty in the LiDAR data: 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, 2019).
- Although specified to contain bare-earth data, the LiDAR used for developing the DEM may contain some artificially high points, especially in areas where the vegetation is dense, creating unrealistic "dry spots" for some floodplain model runs. Additionally, the DEM may contain low points or under predict the crest height on structures that are porous by natures (large rock constructs such as breakwaters or riprap structures).
- Culverts, ditches, and other drainage features located on the floodplain instead of the creek channels were not incorporated in the model.

6 FLOOD AND HAZARD MAPPING

The hydraulic model results for the design flood events were mapped. Two types of maps were produced:

1. Floodplain maps: maps of flood inundation limits and flood construction levels, including freeboard.
2. Flood hazard maps: maps of flood depth and velocity, excluding freeboard.

Maps are displayed on a set of six 22" x 34" map sheets at a 1:4,000 scale. The coordinate system used is UTM Zone 11 metres NAD 83 (CSRS) and CGVD2013 vertical datum. The floodplain maps are accompanied by a 1:25,000 scale index map which includes detailed map notes. Index, floodplain, and hazard maps are included in Appendix C. Geographic information system (GIS) layers produced for flood mapping are summarized in Table 6.1.

Table 6.1 Floodplain mapping GIS layers.

Description	Includes Climate Change	Includes Freeboard	Includes FCL	Polygon, Line, or Point	Depth Raster	Velocity Point
FLOODPLAIN INUNDATION AND HAZARD (1D & 2D MERGED MODEL RESULTS)						
Mapping limit	n/a	n/a	n/a	Y-on map	n/a	n/a
Flood construction levels (FCL) isolines	Y	Y	Y-on map	N	N	N
Design flood event extent (with freeboard)	Y	Y	Y-on map	Y-on map	N	N
Design flood event extent (without freeboard)	Y	N	N	Y	Y	Y
20-year flood event extent (without freeboard)	Y	N	N	Y	Y	N
MODEL REFERENCE LAYERS						
Surveyed river cross sections	Y	Y-depending on event	n/a	n/a	n/a	n/a
Model 1D/2D area boundaries	n/a	n/a	n/a	Y	n/a	n/a
Bridges and culverts	n/a	n/a	n/a	Y-on map	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 the 1996 event on lower B.X. Creek and 200-year event on Vernon Creek (Section 5.4).

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 confidence in the data and

assessment. APEGBC (2017) suggests that a minimum freeboard of 0.3 m should be applied to the annual peak instantaneous (QPI) flows and 0.6 m to the annual max daily (QPD) flows. For lower B.X. Creek and Vernon Creek, a 0.6 m freeboard has been applied to the design flood event (QPI flow). This freeboard is considered appropriate given the sparse data available for model calibration and potential for local increases in water level associated with partial obstruction of any of the many culverts and bridges within this study.

The FCLs are based on model results plus freeboard. For the 1D model area, the freeboard is added to the cross sections and projected out along the cross section. For areas modelled in 2D, flood extents and FCLs were defined based on the water surface elevation calculated by the model with the addition of freeboard. All FCLs have been clipped to the flood extents and the City of Vernon administrative boundary.

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 FCL at 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 two 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 39 m upstream from the 402 m FCL isoline.
- The FCL for the labelled building can be calculated as follows:
  - Approach 1: $403.0\ \mathrm{m}$
  - Approach 2: $402.0 + (403.0 - 402.0)\left(\frac{39}{45}\right) = 402.6\ \mathrm{m}$

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

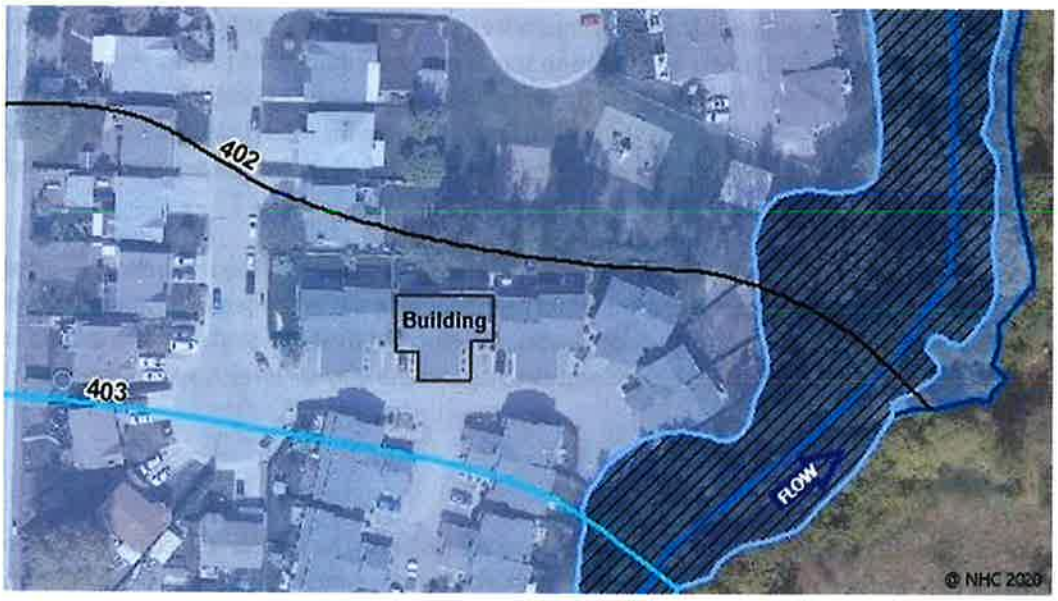


Figure 6.1 Example of FCL line calculation.

6.1.2 Mapping Boundaries and Filtering

The standard approach of projecting the FCL perpendicular across the floodplain is not possible for all locations mapped. At some locations the FCL projects across a dropping slope instead of a rising slope, suggesting an ever-increasing flood depth. Where such a condition exists and the flood level without freeboard is above the banks, 2D modelling was used to determine an expected flow path and depth. The results of the 2D model were then used to define the overbank FCL. Where only the freeboard extended overbank, a boundary was defined. Beyond this boundary, any overbank flow is expected to be low enough to be blocked (such as with sandbags or a flood barrier) or thinned out enough (sheets of water in the gutters of the roads) to be intercepted by existing stormwater infrastructure under the design event. As further precaution, an FCL for these unmapped areas can be defined as 0.3 m above the surrounding dominate grade to account for the potential water that might flow to these areas.

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. Isolated inundation areas smaller than 100 m^2 were removed, except for those 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 limit the risk of future development becoming impacted by channel migration and bank erosion. Additionally, setbacks may be increased in areas where structural mitigation is recommended to ensure such areas are not taken for development. 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. For Vernon Creek and B.X. Creek, the natural boundary is either at or within the top of banks for the creeks. The setback has been established from the top of bank for the floodplain maps to further address future slumping or failure of the banks due to scour and erosion. However, there are sections with overbank flow that is further from the bank than 15 m, and obstruction at culverts or bridges can further increase these areas. Setbacks are therefore recommended to be increased to 30 m in such locations. The prescribed increase in setback is to ensure the flow is not constricted (potentially increasing upstream flood hazard), future development is not at excessive threat to high velocity flow or erosion, and to provide space for future construction of structural mitigations (such as dikes).

6.2 Flood Hazard

The flood hazard map depicts the design flood event. Simulated water depths are shown for each inundated cell in the 2D mesh and calculated velocities were filtered down to a 20 m grid to clearly represent overland flow and in-channel velocities at the 1:4,000 mapping scale. Within the river channel in 1D locations, flood depths are based on 1D model results and velocities are based on 1D model velocities at cross section locations. 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, 2020e), which were adapted from the European Exchange Circle on Flood Mapping (EXCIMAP, 2007) and the national standard in Japan (MLIT, 2005). Full bathymetric survey data was not collected for the entirety of the reaches, only at cross section locations. As such, the deepest depths (purple) are not representative of accurate in-channel depths and have been labeled as "> 2.0; River". The description of potential consequences stated in Table 6.2 are based on those presented from the original references. These consequences are expected to be relevant but are generic and not verified against the specific buildings, electrical system, and roads present in the study area.

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; River	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 has been completed for the Part 2 study area, evaluating the impacts of the 20-year and design flood scenarios. The following sub-sections discuss the risk assessment approach, data sources, findings, conclusions, and limitations.

7.1 Approach

For this project, a flood risk assessment is the process by which the consequence and likelihood of flooding is assessed. Best practices for a risk assessment includes a spatial analysis using available flood hazard information and mapping of receptors (people, economy, culture, and environment) that are affected by flooding. Figure 7.1 provides an outline of the components of a risk assessment; detailed definitions of the presented terms are in Section 7.2.

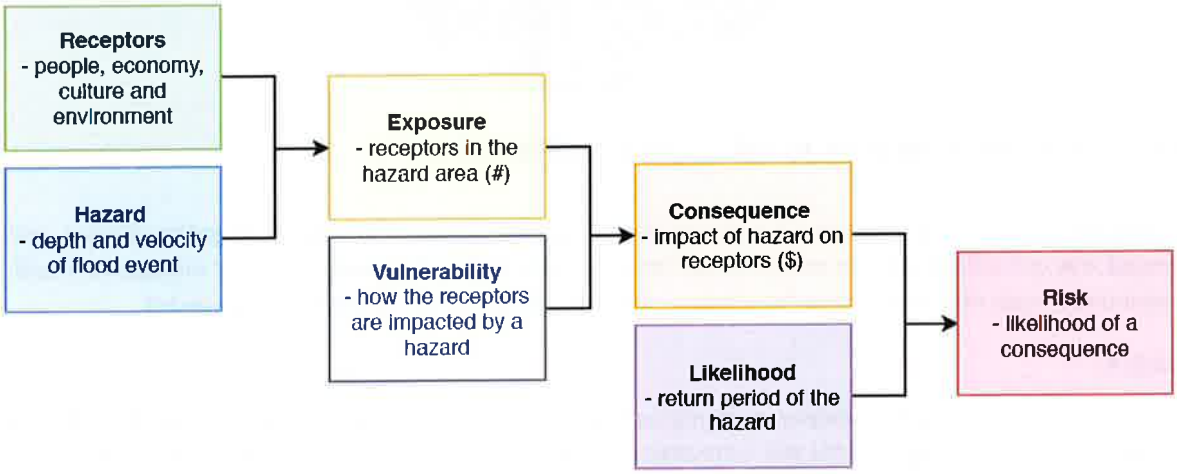


Figure 7.1 Risk assessment terminology and concept diagram.

7.2 Terminology Definitions

Receptors

Within flood risk assessments, "receptors" is a term commonly used[2] 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. For this project, both locally and

[2] Valued asset is an alternative phrase used for receptor

provincially available datasets were used, however, the project was completed without direct ground truthing (e.g. field investigations) of receptors. It is expected that future work should include this step.

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

Additionally, as the City of Vernon is pursuing both structural and non-structural mitigation options, this project was completed prior to extensive community input on flood receptors. Public engagement and community input may be planned for a later time to validate and refine this risk assessment.

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 may refer to flood water characteristics including depth, velocity, debris, duration, and onset speed 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.

Exposure

Exposure is "the [location] of people, infrastructure, housing, production capacities and other tangible human receptors 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.

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 estimate the percent damage for a given flood depth 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.

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.

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.

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

The following sections discuss the specific receptors considered within the categories of people, economy, environment, and culture. For both the 20-yr and design flood events, the modelled flood

extent and depth (without freeboard) have been overlaid with spatial datasets using GIS analysis to determine which receptors will be exposed to flood hazard. Vulnerability of the exposed receptors to the flood hazard has also been assessed, where possible. This has been completed for Vernon and, where applicable, the community of Priest's Valley 6, which is located southwest of Vernon at the downstream extent of Vernon Creek.

7.3.1 People

To determine flood impacts to people, an assessment was conducted to estimate the number of Vernon residents likely to be displaced from their homes. It has been assumed that such displacement from a residential building will occur if the building is exposed to flooding. The building is considered exposed if:

- The building is within the flooded area; or
- Roadway flooding prevents access to the building.

Population information was sourced from Canadian Census data (most recently available from 2016). As census data are reported by aggregated areas, the smallest of which is a census block, there is substantial error associated with using census results to study the populations of small areas. As such, the census data was used solely to calculate the average population per Vernon dwelling, which is 2.2 people.

A building analysis was then conducted to estimate the number of exposed dwellings. Vernon provided NHC with spatial data layers containing:

- Building footprints;
- Vernon Official Community Plan (OCP) land use plan; and
- Vernon zoning districts.

OCP land use designations were used to identify which of the flood exposed buildings are classified as residential. Multi-unit residential buildings were identified from the Vernon zoning districts and the number of dwellings per multi-unit building was estimated based on satellite imagery and Google Street View.

The assumed residential density of 2.2 people per dwelling located within Vernon was applied to the total estimated number of dwellings in exposed residential buildings to approximate the exposed population. The estimated number of dwellings (residential units in residential buildings) and people exposed to flooding are summarized in Table 7.1.

Table 7.1 Estimated Vernon population displaced by flooding based on number of exposed dwellings.

Factor	20-year Flood Event	Design Flood Event
Exposed Dwellings	580	1320
Displaced Population (number[1])	1,276	2,904
Displaced Population (percent[2])	3%	6%

Notes:
1. Assumes 2.2 people per Vernon dwelling based on 2016 census data.
2. Based on total Vernon population of 48,073 from 2016 census data.

7.3.1.1 Priest's Valley

Priest's Valley 6 is an Indigenous reserve of the Syilx Okanagan People, located on the shores of Okanagan Lake directly southwest of Vernon, along the downstream extent of Vernon Creek. The extent of flooding through this area is notable for both the 20-year and design flood events.

Though Priest's Valley is located outside of the Vernon city limits, the urbanization of B.X. Creek and Vernon Creek within Vernon could influence flood effects on the downstream community. Furthermore, in the event of a hazardous flood, Priest's Valley residents are likely to be displaced into Vernon and use resources available to them there.

The same methodology introduced in Section 7.3.1 was employed to estimate the number of Priest's Valley residents exposed to the 20-year and design floods. Based on 2016 Canadian Census data, the average population per Priest's Valley dwelling is 2.1 people. The estimated number of dwellings and people exposed to flooding are summarized in Table 7.2.

Table 7.2 Estimated Priest's Valley population displaced by flooding based on number of exposed dwellings.

Factor	20-year Flood Event	Design Flood Event
Exposed Dwellings	60	138
Displaced Population (number[1])	126	290
Displaced Population (percent[2])	20%	46%

Notes:
1. Assumes 2.1 people per Priest's Valley dwelling based on 2016 census data.
2. Based on total Priest's Valley population of 628 from 2016 census data.

7.3.2 Economy

Key economic receptors include agricultural land, infrastructure, and buildings. The receptors exposed to the 20-year and design floods were identified within the following spatial datasets, which were provided to NHC by Vernon unless otherwise cited:

- Vernon OCP land use plan;
- Vernon zoning districts;
- Stormwater mains (City of Vernon, 2021);
- BC Hydro infrastructure including underground hydro distribution (primary and secondary lines), overhead hydro distribution (primary and secondary lines), hydro poles, hydro junction boxes, underground transformers, manholes, and transmission structures;
- Fortis BC gas infrastructure including distribution valves, distribution pipes, distribution stations, transmission pipes, transmission valves, and transmission pipe facilities;
- Shaw and Telus telecom infrastructure including telecom facilities, telecom poles, underground lines, cable wires, and manholes;
- Transportation infrastructure including roads (City of Vernon, 2021) and railways (Natural Resources Canada, 2013); and
- Building footprints.

7.3.2.1 Agricultural Land

There are several rural properties near the upstream extent of lower B.X. Creek that are classified as ALR (Agricultural Land Reserve) by the Vernon OCP. The Vernon zoning districts classify these properties as country residential rather than agricultural, and from a desktop study using Google Maps and Google Street View it has been assumed that these properties are not currently used for agricultural purposes. However, given their ALR classification, there is potential that they will be used for agriculture in the future, in which case there would be some economic risk for exposure to flooding. During the 20-year event 1.4 ha of ALR land will be inundated from flooding on B.X. Creek, and during the design flood event, 12.4 ha of ALR land will be inundated.

Based on the assumption that these ALR properties are not currently used for agriculture, there is no present flood risk to agricultural land within the study area. This may change if the land is developed for agriculture in the future, or if ground truthing can confirm that any of the properties are presently used for agricultural practices. Additionally, flooding is not necessarily a detriment to agricultural land, if infrastructure is undamaged. Flooding can help replenish nutrients to soils and thus increase future productivity.

7.3.2.2 Utility Infrastructure

Utility infrastructure found within the modelled flood extents of the 20-year and design events are summarized in Table 7.3. More specific details of the exposed infrastructure components are provided in Appendix D.

As infrastructure ranges from below grade to 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 exposure and potential disruption to utility infrastructure, rather than damage. To determine potential damage to infrastructure, utility

companies should be involved in identifying the impacts of inundation. Impacts can include water damage, 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 7.3 Exposed utility infrastructure.

Infrastructure Category	Infrastructure Type	Quantity[1]	20-year Flood Event	Design Flood Event
Stormwater	Mains	Count	75	115
		Length (m)	3,442	5,441
BC Hydro	Primary underground distribution lines	Count	6	20
		Length (m)	356	957
	Secondary underground distribution lines	Count	19	33
		Length (m)	448	734
	Primary overhead distribution lines	Count	56	129
		Length (m)	3,214	6,034
	Secondary overhead distribution lines	Count	140	328
		Length (m)	3,766	7,923
	Poles	Count	54	118
	Junction boxes	Count	0	1
	Underground transformers	Count	0	2
	Manholes	Count	0	0
	Transmission structures	Count	0	1
FortisBC Gas	Distribution valves	Count	0	1
	Distribution pipes	Count	47	91
		Length (m)	5,830	10,115
	Distribution stations	Count	0	0
	Transmission valves	Count	0	0
	Transmission pipes	Count	8	9
		Length (m)	325	420
	Transmission pipeline facility	Count	0	0
Shaw Telecom	Telecom facility	Count	12	30
	Poles	Count	78	152
	Manholes	Count	0	0
	Underground lines	Count	32	78
		Length (m)	1,928	3,775
Telus Telecom	Telecom facility	Count	0	0
	Poles	Count	32	79
	Manholes	Count	0	3
	Cable wire	Count	53	102
		Length (m)	5,836	7,981

Notes:
1. For linear features such as mains, lines, pipes, and wires, "Count" refers to the number of segments within the flood affected area and "Length" refers to the total length of the exposed segments.

7.3.2.3 Transportation Infrastructure

Road infrastructure in Vernon and Priest's Valley has been assessed for exposure to flooding based on the provided road widths, or an assumed width of 5 m if no width data was available. A detailed inventory of road segments exposed to flooding is provided in Appendix D; Table 7.4 provides a summary based on road type. Note that private roads such as those within apartment building strata or mobile home parks were not included in this analysis as no spatial data was available for them.

Table 7.4 Flooded road infrastructure.

Road Type	Quantity[1]	20-year Flood Event	Design Flood Event
Vernon			
Arterial	Count	5	8
	Length (m)	1,623	2,486
Collector	Count	3	10
	Length (m)	1,151	2,480
Local	Count	20	36
	Length (m)	4,423	7,421
Lane	Count	0	2
	Length (m)	0	282
Street right of way	Count	8	20
	Length (m)	2,921	10,680
Priest's Valley 6			
Local	Count	4	17
	Length (m)	565	2,189

Notes:
1. "Count" refers to the number of road segments within the flood affected area and "Length" refers to the total length of the exposed segments.

One minor section of railway track, located west of Polson Drive upstream of Polson Park, is overtopped during both flood events. During the 20-year flood, 5 m of the track is overtopped with a maximum depth of 9 cm. During the 200-year flood, 7 m of the track is overtopped with a maximum depth of 21 cm.

The Vernon Regional Airport property is subject to some flooding during both events, including flood extents around the western end of the runway. However, there is no flooding modelled on the runway itself or any other airport facilities for either event, and as such direct flooding is not anticipated to affect flights or airport activity. However, it is possible that groundwater saturation or non-connected ponding could affect the stability of runway surfaces or connecting roads to to/from the airport. Study

of such impacts is outside the scope of this work, but may warrant consideration for emergency planning.

7.3.2.4 Building Infrastructure

To evaluate flood impact to buildings, the building dataset was overlaid with the modelled flood depth results. The DEM used to develop the flood depth raster datasets included raised building footprints, so to account for this, the building footprints were buffered by 2 m to overlap them with surrounding floodwaters. The maximum flood depth for each building within this buffer was identified.

The ER2 Rapid Risk Evaluation Tool (Version 2.05) developed by the University of New Brunswick was used to estimate flood damage to the exposed buildings and their contents (University of New Brunswick, 2016). The depth-damage curves built into the ER2 Rapid Risk Evaluation tool were used to estimate the consequence of the maximum flood depth experienced by each building, based on building type. Without a comprehensive building database, several assumptions were made about all structures, including that they are of average quality and built in 1995. 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. Further assumptions, which varied by building type, are identified in Table 7.5.

There were numerous sheds and parking structures found within the flood extents. Damage to these smaller structures was not estimated using the ER2 tool.

The results of the flood damage assessment are summarized in Table 7.6 for Vernon and Table 7.7 for Priest's Valley. Full damage results are provided in Appendix D.

An important finding from the building infrastructure analysis is that one of the buildings in the Vernon Water Reclamation Centre (wastewater treatment plant) is exposed to both flood events. Further, road access to the primary and secondary treatment areas of the plant is blocked by flooding on 43rd Street during the design event, which may or may not impact the continued operation of the plant. Damage to the exposed building or a prolonged lack of personnel access to part of the facility could result in a contaminant breach due to damage or a backed-up sanitary sewer system from loss of use. This could have environmental consequences and human health concerns, in addition to the potential costs required for local and/or regional clean-up, as well as facility repairs.

Table 7.5 Building type assumptions for ER2 Rapid Risk Evaluation tool.

Building Type	Parameter	Value Assumed	Reasoning
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.
Duplex Triplex/Quad Multi-Dwellings, 5-9 Multi-Dwellings, 20-49 Multi-Dwellings, 50+	Stories	2 stories	2 or multi-story buildings based on likely configurations; flooding does not exceed first floor depth so exact number of stories does not affect calculation.
	Basement	No	Basement not compatible with ER2 tool for these building types.
Manufactured Housing	Stories	1 story	Assumed value based on likely configuration.
	Basement	No	Assumed value based on likely configuration.
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	Basement not compatible with ER2 tool for this building type.
Temporary Lodging	Stories	2 stories	2 or multi-story buildings based on likely configurations; flooding does not exceed first floor depth so exact number of stories does not affect calculation.
	Basement	No	Basement not compatible with ER2 tool for this building type.
Retail Trade	Stories	1 story	1 story assumed based on typical configuration observed from air photos.
	Basement	No	Assumed value based on likely configuration.
Light Industry	Stories	1 story	1 story assumed based on typical configuration observed from air photos.
	Basement	No	Assumed value based on likely configuration.
Institutional	Stories	2-stories	2 stories selected based on specific buildings.
	Basement	No	Assumed value based on likely configuration.
General Services (Gov)	Stories	1 or 2 stories	1 or 2 stories selected based on specific buildings.
	Basement	No	Assumed value based on likely configuration.
Medical Office	Stories	2-stories	2 stories selected based on specific building.
	Basement	No	Assumed value based on likely configuration.
Churches	Stories	2 Story	1 story selected based on specific building.
	Basement	No	Assumed value based on likely configuration.

Table 7.6 Vernon building damage estimate summary. Structure and content damage values represent the estimated percent of replacement cost.

Building Type	Parameter	20-year Flood Event	Design Flood Event
Single Family Dwelling	Count	43	88
	Average Estimated Structure Damage	22%	27%
	Average Estimated Content Damage	20%	25%
Duplex	Count	3	10
	Average Estimated Structure Damage	23%	25%
	Average Estimated Content Damage	28%	27%
Triplex/Quad	Count	6	65
	Average Estimated Structure Damage	29%	23%
	Average Estimated Content Damage	34%	27%
Multi-Dwellings, 5-9	Count	0	3
	Average Estimated Structure Damage	N/A	15%
	Average Estimated Content Damage	N/A	15%
Multi-Dwellings, 20-49	Count	0	1
	Average Estimated Structure Damage	N/A	37%
	Average Estimated Content Damage	N/A	45%
Multi-Dwellings, 50+	Count	1	1
	Average Estimated Structure Damage	34%	34%
	Average Estimated Content Damage	42%	48%
Manufactured Housing	Count	71	82
	Average Estimated Structure Damage	50%	61%
	Average Estimated Content Damage	40%	52%
Nursing Home	Count	3	3
	Average Estimated Structure Damage	2%	2%
	Average Estimated Content Damage	9%	14%
Temporary Lodging	Count	3	7
	Average Estimated Structure Damage	3%	9%
	Average Estimated Content Damage	12%	32%
Retail Trade	Count	3	9
	Average Estimated Structure Damage	2%	13%
	Average Estimated Content Damage	6%	47%
Light Industry	Count	3	5
	Average Estimated Structure Damage	8%	15%
	Average Estimated Content Damage	14%	33%
Institutional	Count	2	2
	Average Estimated Structure Damage	9%	21%
	Average Estimated Content Damage	58%	100%
General Services (Gov)	Count	3	4
	Average Estimated Structure Damage	13%	25%
	Average Estimated Content Damage	100%	100%
Medical Office	Count	0	1
	Average Estimated Structure Damage	N/A	13%
	Average Estimated Content Damage	N/A	79%
Churches	Count	1	1
	Average Estimated Structure Damage	6%	8%
	Average Estimated Content Damage	48%	63%
All Buildings	**Count**	**142**	**282**

Table 7.7 Priest's Valley 6 building damage estimate summary.

Building Type	Parameter	20-year Flood Event	Design Flood Event
Manufactured Housing	Count	60	118
	Average Estimated Structure Damage	45%	63%
	Average Estimated Content Damage	35%	54%

Datasets of key community facilities were also examined for exposure to flooding, including datasets provided to NHC from Vernon showing emergency services (fire stations, police stations), healthcare facilities, schools, daycares, and community centres. These datasets were confirmed and expanded upon through a desktop study with Google Maps and Google Street View, however the datasets were not augmented or confirmed in the field (ground-truthing). Key facilities identified through this process, and the reason for their potential sensitivity to flooding, are listed in Table 7.8.

Table 7.8 Key community facilities.

Facility Name	Flood Event	Reason for Sensitivity
Vernon Restholm Retirement Home (2808 35th St)	Design flood event	Residents may have limited mobility and face difficulties in a potential evacuation, requiring extra time and assistance.
Silver Springs Seniors Community (3309 39th Ave)	20-year and design flood events	
Creekside Landing Retirement Home (6190 Okanagan Landing Rd)	20-year and design flood events	
Creekside Village Retirement Home (3502 27th Ave)	20-year and design flood events	
Pharmacy in Safeway (3417 30th Ave)	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 medication.
Stirling Centre (3210 25th Ave)	Design flood event	Includes several healthcare facilities including the Stirling Centre, Centreville Clinic, RX Pharmacy, Lakeshore Medical Supplies, Interior Health Authority Lab, and several doctors' offices. If flooding eliminates access to or function of the Stirling Centre, people's access to healthcare and medication may be disrupted.
Turning Points Collaborative Society (social services organization; 3301 24th Ave)	Design flood event	These organizations support at-risk populations through providing access to safe housing, health care, and education and employment opportunities. Loss of function of these facilities may put the people dependent on them at increased risk.
John Howard Society (social services organization; 2307 43rd St)	20-year and design flood events	

7.3.3 Environment

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

Contamination sources can include fuel supplies, 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 those sources were not characterized.

At the northern extent of the study area, in the upstream section of lower B.X. Creek, the 20-year and design floods inundate ALR lands. These lands do not appear to be currently used for agriculture, but if they ever are, they will be potential sources of contaminants such as pesticides, fertilizer, manure, or fuel.

The Vernon Water Reclamation Centre is located approximately 1 km downstream of the confluence of lower B.X. Creek and Vernon Creek. The fermenter building is exposed to both the 20-year and design flood extents, and it is possible that damage to the building could negatively impact the viability of the wastewater treatment process or, in the case of a breach, could cause contamination of floodwaters. Further, road access to the primary and secondary wastewater treatment areas is blocked during the design event by flooding on 43 Street. It is unknown whether lack of personnel access to this section of the wastewater treatment plant could delay plant operations, but if that is the case such lack of access may result in backups of the sanitary sewer network, which could have both environmental and human health impacts. Cascading infrastructure failure due to flooding such as lack of electricity at the centre should be considered. A facility-specific risk assessment to flooding is recommended to identify resiliency improvements.

There is sanitary sewer collection in most of Vernon and some septic systems toward the west side of town near Okanagan lake and in neighborhoods located further from the city centre. The only area with septic systems at risk from Vernon Creek is within the Dallas neighbourhood south of Okanagan Landing Road, around Myriad Road and Dallas Road, which is exposed to flooding during both the 20-year and design flood events. Flooding of septic fields carries a risk for contamination. The contaminated water can spread in the flood waters and be carried downstream to impact a larger area.

NHC has confirmed with Vernon that the stormwater and sanitary sewer systems are not combined, and as a result if flooding overwhelms storm sewers it should not affect the sanitary sewer system or cause any resulting contamination[3]. However, flooding can cause sewage backups at individual residences or through breakage of a municipal sewer pipe. This can cause the contamination of floodwaters with sewage, leading to difficult cleanups as well as health and environmental impacts.

[3] Conversations with the Vernon Utilities Manager confirmed that though the storm and sanitary sewer systems are separate, there may be minor anomalies where private services (i.e., non Vernon infrastructure) have been tied into the system, however these are estimated to be a very small percentage of the overall networks and are corrected if found.

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 Greater Vernon Water utility, which draws water from Kalamalka Lake and Duteau Creek, both of which are outside of the flood affected area. Wells are not considered as a sensitive receptor; while there may be some wells within the study area, they are not likely used for drinking water since there is municipally supplied water.

The following datasets from the BC Data Catalogue (Government of British Columbia, 2021) were reviewed to identify sensitive ecosystems, critical habitat, and species at risk that could be exposed to flood impacts. The results are summarized in Table 7.9:

- Species and Ecosystems at Risk;
- Critical Habitat for Federally-Listed Species at Risk; and
- Sensitive Ecosystems Inventory.

Table 7.9 Exposed Species and Ecosystems at Risk, Critical Habitat, and Sensitive Ecosystems.

Species and Ecosystems at Risk	Flood-Affected Area (ha)	
	20-year Flood Event	Design Flood Event
Species and Ecosystems at Risk		
American Badger	58	101
Black Cottonwood / Common Snowberry - Roses	32	41
Common Cattail Marsh	0.1	0.3
Dark Lamb's-quarters	0.0	0.02
Dark Saltflat Tiger Beetle	4.1	7.3
Gopher Snake, Deserticola Subspecies	0.2	0.3
Great Basin Spadefoot	1.6	2.2
Hard-stemmed Bulrush Deep Marsh	4.6	7.4
Mexican Mosquito Fern	0.7	0.8
Painted Turtle - Intermountain - Rocky Mountain Population	0.3	0.4
Rocky Mountain Ridged Mussel	1.3	1.3
Vivid Dancer	0.5	0.8
Western Harvest Mouse	33	47
Western Screech-owl, Macfarlanei Subspecies	20	29
Critical Habitat for Federally-Listed Species at Risk		
Great Basin Gophersnake	72	117
Great Basin Spadefoot	59	84
Mexican Mosquito-fern	2.8	3.3
Western Rattlesnake	72	117
Sensitive Ecosystems[1]		
BW:ac - Broadleaf Woodland, aspen copse	0.1	0.1
FS - Seasonally Flooded Fields	1.1	1.6
GR:dg - Grasslands, disturbed	0.1	0.1
RI:be - Riparian, beach	0.001	0.002
RI:ff - Riparian, fringe	0.1	0.2
RI:fp - Riparian, fluvial plain	23	27
WN:ms - Wetland, marsh	3.6	6.1

Notes:
1. Refers to the Sensitive Ecosystem Inventory first component, which is the dominant sensitive ecosystem in the given area (Iverson, 2008).

7.3.4 Culture

Potential cultural impacts were identified through looking at Indigenous lands 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. A desktop study was completed using Google Maps and Google Street View to identify cultural receptors in the inundation zones for the 20-year and design flood events.

Vernon and the extent of the flood affected area located within the traditional lands of the Syilx Okanagan and Secwépemc peoples, and as such it is possible that cultural receptors of importance to these Indigenous communities may be located within anticipated flood extents. The large-scale Okanagan Nation Alliance t̓ik̓t (flood) Adaptation Project[4], which covers the entire Okanagan Basin, identifies several cultural amenities within the predicted flood area. Additional cultural receptors of importance could be identified through future consultation with local First Nations, including but not limited to the residents of Priest's Valley, who are anticipated to be affected by both the 20-year and design flood events.

The remaining cultural receptors identified within Vernon from the desktop study are summarized in Table 7.10. Additional receptors may exist, which could be identified by members of the Vernon community through consultation.

Table 7.10 Exposed cultural receptors.

Receptor Name	Flood Event
Vernon Golf & Country Club	20-year and design flood events
Polson Park and Polson Park Trail	20-year and design flood events
Living Word Lutheran Church	20-year and design flood events
Marshall Field Park and Marshall Fields Trail	20-year and design flood events
Lakers Park	20-year and design flood events
Lakers Clubhouse	20-year and design flood events
Lakeshore Park and Beach	Design flood event
Sandy Beach Campground	Design flood event

[4] https://www.syilx.org/projects/t%cc%93ik%cc%93t-flood-adaptation-project/

7.4 Classification and Findings

The findings 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 of the four receptor categories. Note that the results for Priest's Valley have been incorporated into this overall risk assessment for Vernon, based on the assumption that there is substantial community overlap.

The risk classifications for this project have been developed based on risk ratings provided in the National Disaster and Mitigation Program Risk Assessment Information Template (RAIT; Public Safety Canada, 2016) and an example flood risk matrix in the EGBC professional practice guidelines *Legislated Flood Assessments in a Changing Climate in BC* (EGBC, 2018). The risk matrix developed as a synthesis of these two resources is presented in Table 7.11, and classifications are discussed in the preceding sub-sections. Note that 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 7.11 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:	**1 -Negligible**	**2-Minor**	**3-Moderate**	**4-High**	**5-Severe**

Notes:
The Risk Level letters represent the following characterization of risk as defined by the example EBGC flood risk matrix (EGBC, 2018). 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 within a reasonable time frame (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 as part of the risk assessment. The 20-year flood has a relatively high likelihood; it is classified as "likely" in the EGBC example flood risk matrix and assigned a likelihood rating of 5/5 in the RAIT based on a return period of less than 30 years. The design flood event has a return period of 200-years or greater, classifying it as "unlikely" by the example EGBC flood risk matrix and giving it a relatively low likelihood of 2/5 in the RAIT based on a return period between 50-500 years. With reference to the suggested risk matrix in Table 7.11, the 20-year flood and design flood have been assigned likelihoods of "likely" and "unlikely", respectively.

7.4.1 People

The impact to people from these flood events is primarily displacement, damage experienced, and disruption of daily activities, such as transportation and commercial activities. For assigning a risk classification to people, it is appropriate to consider the entire flood-affected area, including the area assessed in Part 1 of this project (NHC, 2020b). Table 7.12 summarizes the estimated number of people displaced from their homes, including results from Part 1 and Part 2.

Table 7.12 Summary of displaced people from Part 1 and Part 2 study areas.

Displaced People	20-year Flood Event	Design Flood Event
Part 1[1]	95	232
Part 2	1,402	3,194
Total	1,497	3,426
Percentage of Total Population[2]	3%	7%

Notes:
1. Results are from *City of Vernon Detailed Flood Mapping, Risk Analysis and Mitigation: Part 1 - Upper B.X. Creek* (NHC, 2020b)
2. Based on total Vernon population of 48,073 and total Priest's Valley population of 628 from 2016 census data.

Due to the presence of lakes at the upstream extents of lower B.X. Creek and Vernon Creek, flooding of either stream is relatively predictable and is not expected to be a rapid onset event such as a debris flow or a dike breach; as such, flooding is unlikely to cause death or serious injury. With effective evacuation, it is likely possible to remove all residents from the path of the floodwater. There is potential for injury amongst emergency responders and locals who remain in the area. In addition to those directly affected, it is likely that thousands more people will be affected through loss of business, damage to properties, and interruption to routine.

As both 20-year and design floods are not likely to cause fatalities and any injuries will likely be within local response capacity, both floods are classified to be of "negligible" consequence in the respect of human safety as per the EGBC example flood risk matrix (EGBC, 2018).

The RAIT classifies people related impacts in terms of fatalities, injuries, percentage of displaced individuals, and duration of displacement (Public Safety Canada, 2016). For both flood events, fatalities and injuries receive a RAIT classification of 1/5. Percentage of displaced individuals receives a RAIT classification of 2/5 for the 20-year flood and 3/5 for the design flood. Duration of displacement for either flood is likely to be around one to two weeks, which classifies as a 2/5 to 3/5 on the RAIT (Public Safety Canada, 2016).

Overall, based on the above ratings, the consequence classifications for people for the current project are "2-Minor" for the 20-year flood and "3-Moderate" for the design flood.

In considering impacts to people, it is essential to understand that not all people are affected equally by the same circumstances. Social vulnerability can lead to differential impacts which typically cause more

significant impacts to those who are more vulnerable as identified by metrics such as first language, income, health, etc. Socially vulnerable individuals should be considered as more at-risk and this should be factored into flood risk reduction decisions and other emergency planning and preparedness programs.

7.4.2 Economy

The economic impact has been examined through affected utility and transportation infrastructure, buildings, and community facilities. The stormwater system is likely sensitive to flooding and there is potential for it to be overwhelmed, leading to prolonged occurrence of overland flooding. Other underground utilities may also be at risk from floodwater, especially the underground hydro transformer identified and other junction or distribution facilities which are below the waterline. The wastewater treatment plant is exposed to flooding during both events, could be costly to repair and may lead to contamination. Enhancing infrastructure resiliency helps reduce flood risk, especially by reducing recovery duration. The RAIT characterizes impact to utilities in terms of impacts to a percentage of the area's population; however, this study only examines the utilities that are considered exposed within the flood affected area. As noted in Section 7.3.2.2, the relationship between flood depth and consequence is not known and requires input from utility companies to accurately quantify.

The impact on transportation is likely to be one of the most substantial risks associated with these potential floods. Transportation throughout the flooded areas of Vernon will be difficult 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 both flood events would be substantial disruptions to access in the area and the wider community. The RAIT classifies impact to transportation partially in terms of affected population, but determining the affected population will require a detailed analysis that is not within the scope of this assessment. The most appropriate RAIT classification in terms of transportation is likely a 2/5, with local activity stopped for 13-24 hours and minor reduction in access to local area and/or delivery of crucial services or products (Public Safety Canada, 2016).

The 20-year flood is expected to damage 202 buildings, compared to the 400 buildings anticipated to be flooded in the design event. For some areas where 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. Of note are the key community facilities identified in Table 7.8. The four retirement homes which are exposed to flooding have increased flood risk as evacuation from these facilities will require extra time and resources. The two pharmacies and several healthcare facilities are exposed to flooding, so specific plans should be developed to ensure a flood-resilient supply of medication and access to health care treatment, especially to those who may have lower mobility.

Based on the discussed economic impacts, both floods are estimated to have "severe" to "catastrophic" economic consequence as per the example EGBC flood risk matrix, including severe receptor loss, several months business interruption, and greater than $1 million dollars of damage (EGBC, 2018). For the current project, both flood events have been assigned an economic consequence of "5-Severe".

7.4.3 Environment

The environmental impact of the flooding is based on the 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, depending on potential contamination risk from the wastewater treatment plant and septic fields in the Dallas neighbourhood. The 20-year and design floods have both been assigned a "4-High" consequence classification for environmental impacts.

7.4.4 Culture

The cultural impact presented in the report is expected to evolve as a better understanding of the receptors and their vulnerability are better understood through further consultation with the public. 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. This corresponds with ratings of "3-Moderate" and "4-High" for the 20-year and design flood events, respectively, using the suggested project risk matrix in Table 7.11. Community input is needed to refine rating for use in decision-making.

7.4.5 Risk Assessment Findings

The ratings discussed above are shown for each event on the flood risk matrices in Table 7.13 and Table 7.14. 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.

Table 7.13 Risk matrix for 20-year flood event.

Risk for "likely" 20-year flood event[1]	M	H	H	VH	VH
Consequence	**1-Negligible**	**2-Minor**	**3-Moderate**	**4-High**	**5-Severe**
People		X			
Economy					X
Environment				X	
Culture			X		

Notes:
1. As defined based on consequence and likelihood in Table 7.11.

Table 7.14 Risk matrix for design flood event.

Risk for "unlikely" design flood event[1]	VL	L	L	M	H
Consequence	**1-Negligible**	**2-Minor**	**3-Moderate**	**4-High**	**5-Severe**
People			X		
Economy					X
Environment				X	
Culture				X	

Notes:
1. As defined based on consequence and likelihood in Table 7.11.

7.5 Limitations

Limitations of the flood risk assessment include the following:

- The Vernon and Priest's Valley communities were 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;
- Population is based on 2016 Canadian census data (the latest available), but changes may have occurred since then;
- Impact to people has been calculated based on dwelling location to reflect potential evacuation requirements. In reality, more people use the flood impacted area than just residents, 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;
- Building 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 entirely representative;
- First floor ground elevation of buildings is not known, leading to significant potential for under or over-estimation of flood damage to buildings;
- Building characteristics were assumed for a selection of damage curves. An accurate building inventory could improve building damage estimates.
- Social vulnerability is not considered in this assessment. For decision-making based on this assessment, social vulnerability should be considered, and equity-based analysis of risk reduction plans implemented; and
- Cultural impacts were estimated based on exposed community facilities identified through a desktop study using mainly Google Maps. Community consultation is required to determine a

more complete assessment of cultural risk, particularly with respect to the local First Nations community in Priest's Valley and the surrounding region.

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 community receptors to develop a plan to minimize impacts. Table 8.1 outlines examples of structural and non-structural mitigation options that are commonly used in British Columbia.

Table 8.1 Examples of mitigation measures.

Non-Structural *Reducing Exposure & Vulnerability*	Structural *Reducing Flood Hazard*

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

There is a variety of both structural and non-structural flood risk reduction options presented in the following sections. 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 flood return periods and design life durations.

Return Period (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 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 Vernon.

8.1.1 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. Vernon should consider reviewing existing by-laws to include the FCL requirements for suitable developments.

The floodplain mapping provides the FCL and setback criteria typically applicable to watercourses within BC. During flood bylaw preparation the application of the results of this project may vary based on proposed land use to best reflect the risk tolerance of the local community. For example:

i. renovations and replacement of single-family homes may be required to follow the FCL and setback, whereas

ii. new homes and subdivisions may require site specific flood hazard assessments, and

iii. hospitals, schools, long term care homes, and storage of deleterious substances may require further mitigation (i.e. more extreme event, increased freeboard, or increased setback).

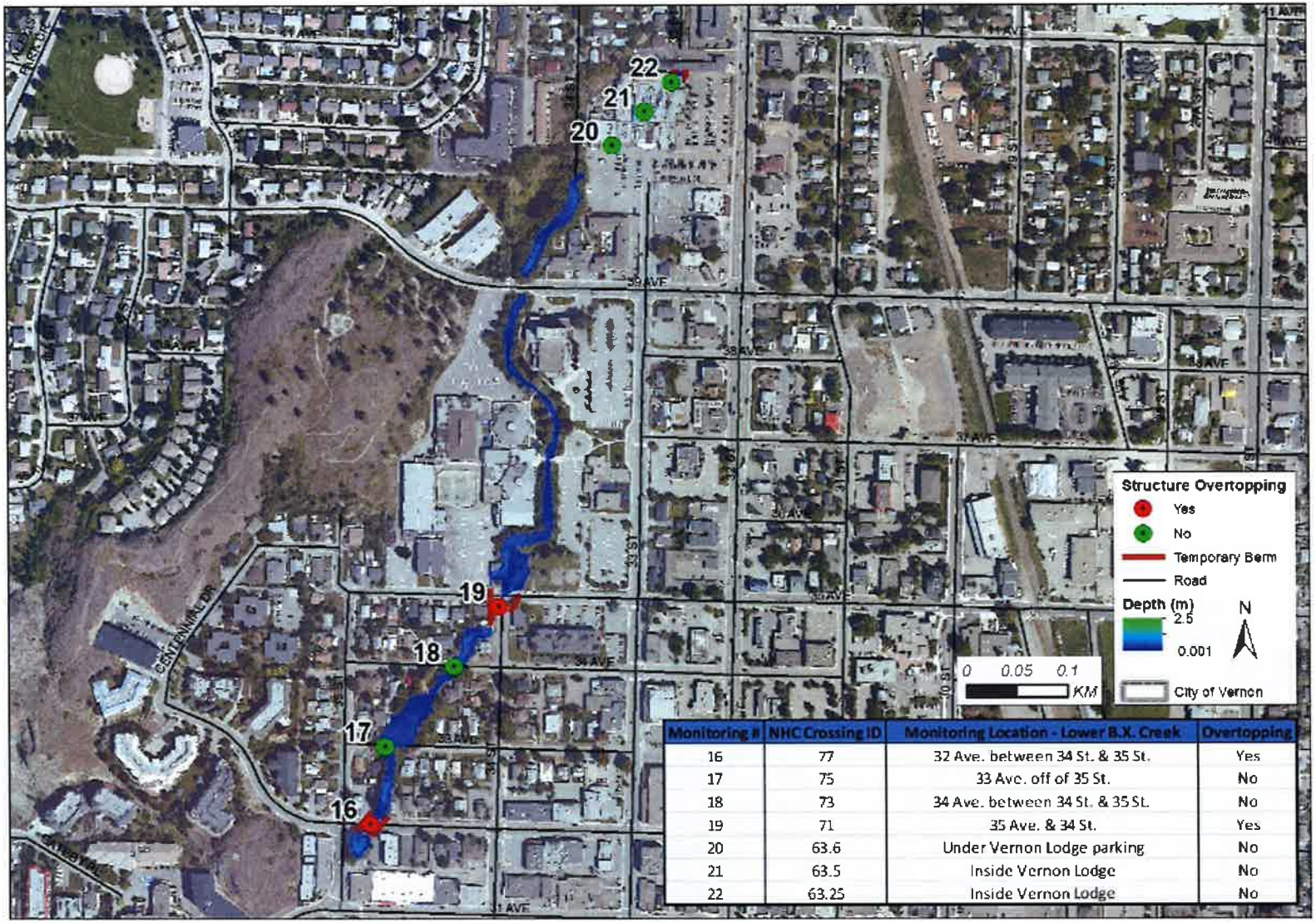
8.1.2 Emergency Response Planning

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

- Identify key locations to monitor flows / water levels 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.

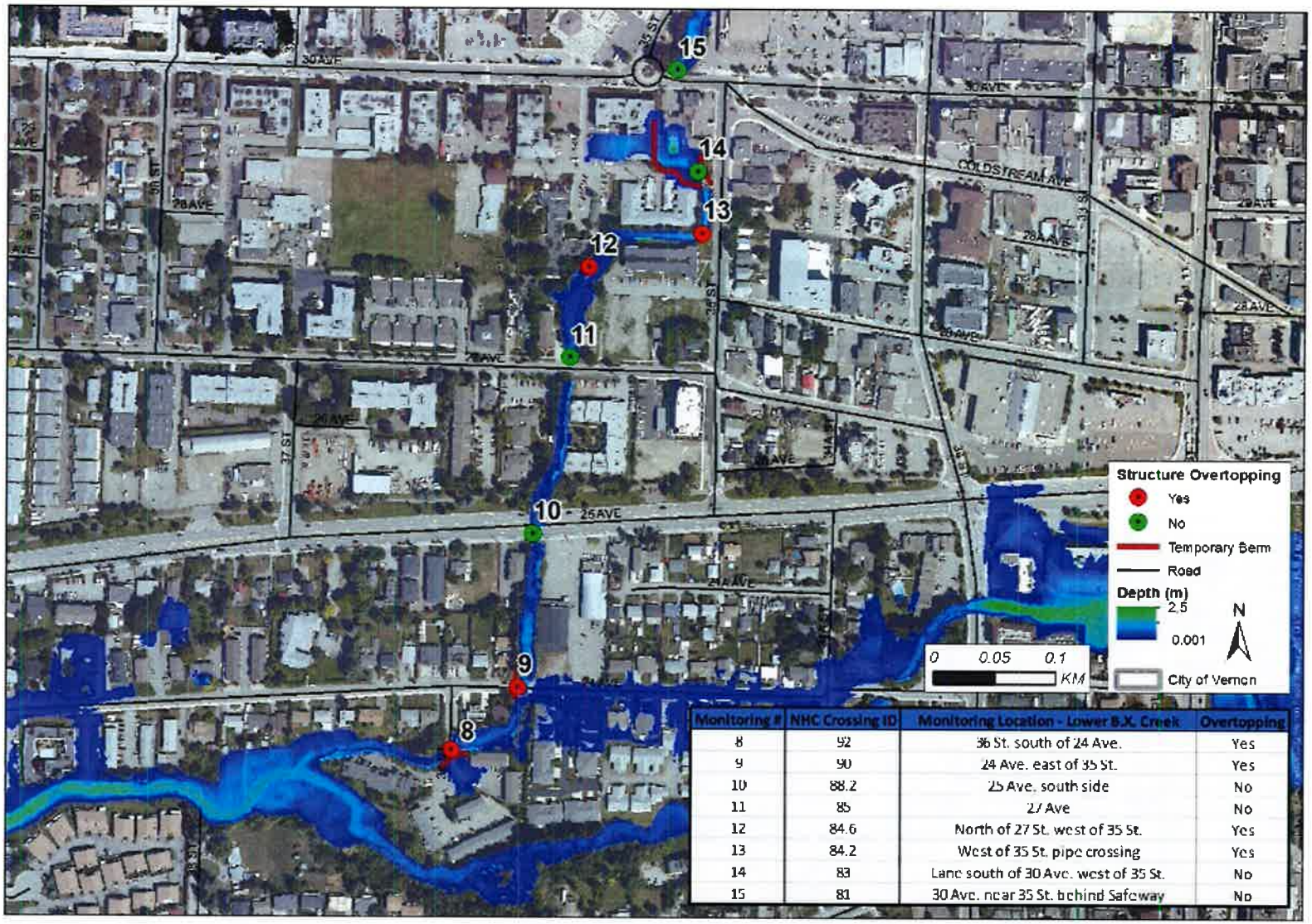
Figure 8.1 through Figure 8.8 are an examples of recommended monitoring locations and temporary flood barriers based on flooding or overtopping structures. Vernon should create a formal plan and accompanying map that describes what actions should be carried out at what stage of flooding, along with defined evacuation routes based on the hazard map results. Locations of temporary barriers should be selected by Vernon to best protect their receptors. 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, overtopping the structure, or backwatering the structure.

Figure 8.1 Suggested emergency response planning measures for lower B.X. Creek (1/3).



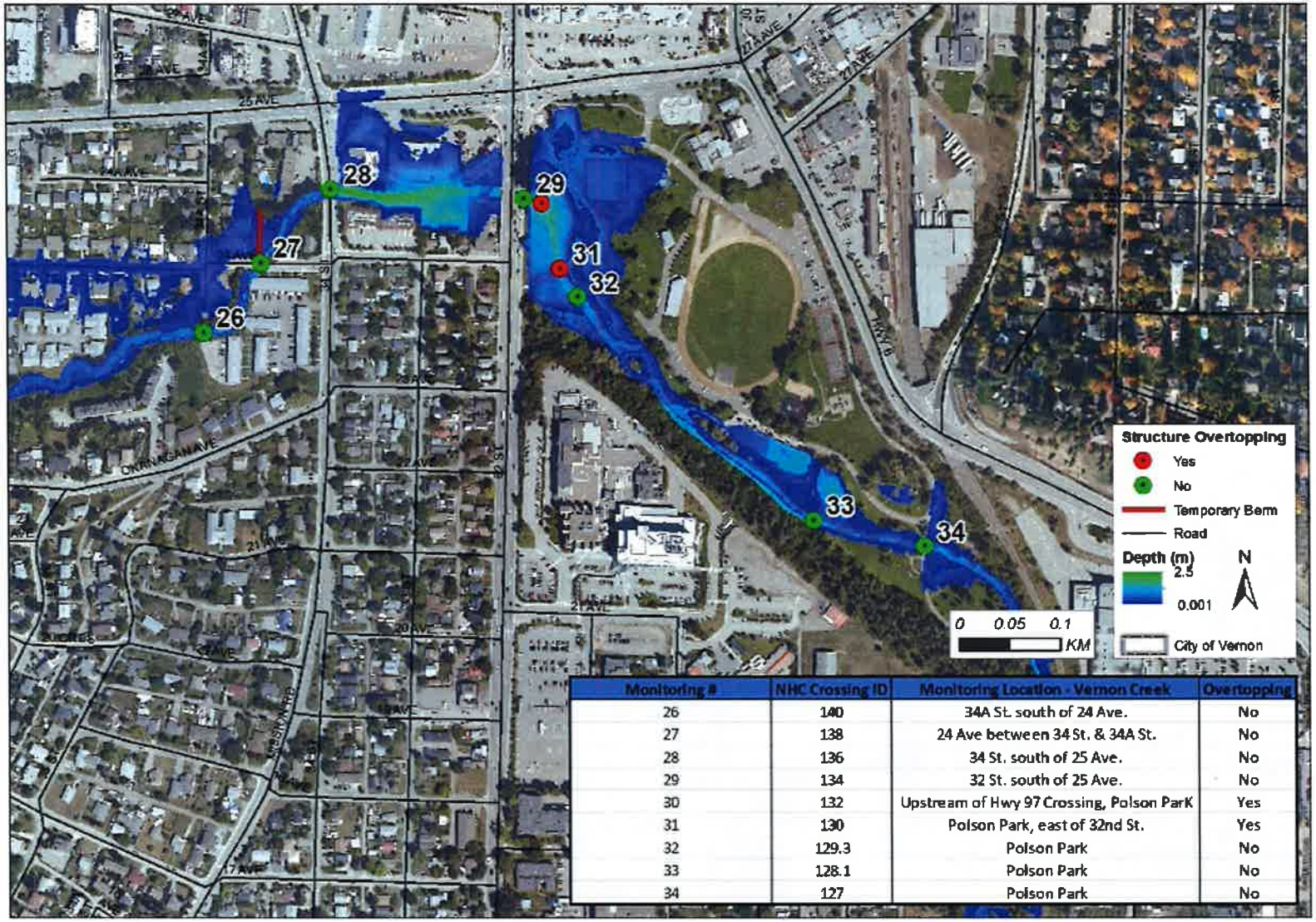
Monitoring #	NHC Crossing ID	Monitoring Location - Lower B.X. Creek	Overtopping
16	77	32 Ave. between 34 St. & 35 St.	Yes
17	75	33 Ave. off of 35 St.	No
18	73	34 Ave. between 34 St. & 35 St.	No
19	71	35 Ave. & 34 St.	Yes
20	63.6	Under Vernon Lodge parking	No
21	63.5	Inside Vernon Lodge	No
22	63.25	Inside Vernon Lodge	No

Figure 8.2 Suggested emergency response planning measures for lower B.X. Creek (2/3).



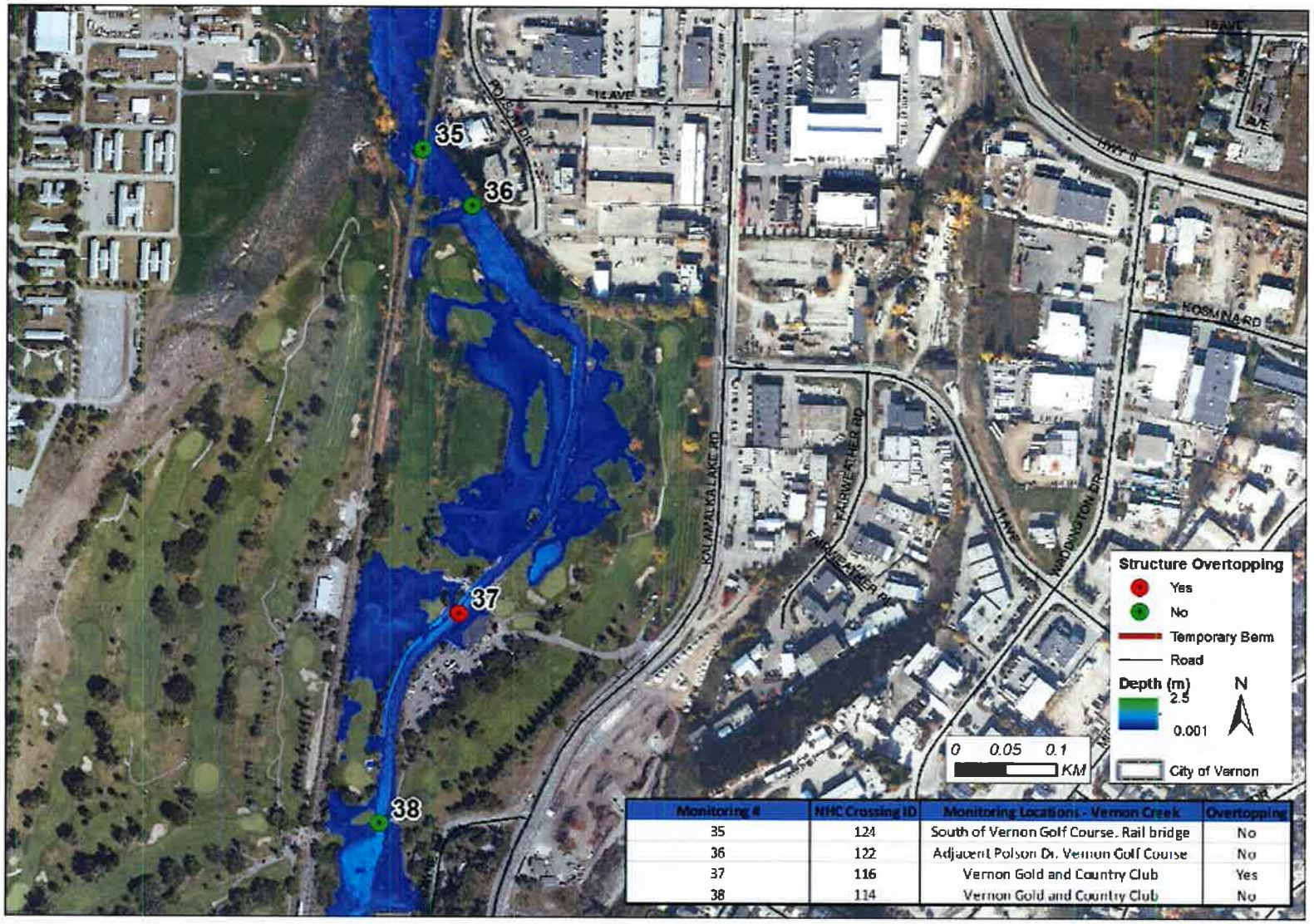
Monitoring #	NHC Crossing ID	Monitoring Location - Lower B.X. Creek	Overtopping
8	92	36 St. south of 24 Ave.	Yes
9	90	24 Ave. east of 35 St.	Yes
10	88.2	25 Ave. south side	No
11	85	27 Ave	No
12	84.6	North of 27 St. west of 35 St.	Yes
13	84.2	West of 35 St. pipe crossing	Yes
14	83	Lane south of 30 Ave. west of 35 St.	No
15	81	30 Ave. near 35 St. behind Safeway	No

Figure 8.3 Suggested emergency response planning measures for lower B.X. Creek (3/3).



Monitoring #	NHC Crossing ID	Monitoring Location - Vernon Creek	Overtopping
26	140	34A St. south of 24 Ave.	No
27	138	24 Ave between 34 St. & 34A St.	No
28	136	34 St. south of 25 Ave.	No
29	134	32 St. south of 25 Ave.	No
30	132	Upstream of Hwy 97 Crossing, Polson Park	Yes
31	130	Polson Park, east of 32nd St.	Yes
32	129.3	Polson Park	No
33	128.1	Polson Park	No
34	127	Polson Park	No

Figure 8.4 Suggested emergency response planning measures for upper Vernon Creek (1/3).



Monitoring #	NHC Crossing ID	Monitoring Locations - Vernon Creek	Overtopping
35	124	South of Vernon Golf Course. Rail bridge	No
36	122	Adjacent Polson Dr. Vernon Golf Course	No
37	116	Vernon Gold and Country Club	Yes
38	114	Vernon Gold and Country Club	No

Figure 8.5 Suggested emergency response planning measures for upper Vernon Creek (2/3).

Monitoring #	NHC Crossing ID	Monitoring Locations - Vernon Creek	Overtopping
39	112	Browne Rd.	Yes
40	110	Adjacent Browne Rd. Cul-de-sack	Yes
41	109.1	Adjacent Browne Rd. Housing subdivision	No
42	108	Adjacent Browne Rd. Housing subdivision	No
43	104	Kalamalka Lake Rd. North of lake	No

Figure 8.6 Suggested emergency response planning measures for upper Vernon Creek (3/3).

Figure 8.7 Suggested emergency response planning measures for lower Vernon Creek (1/2).

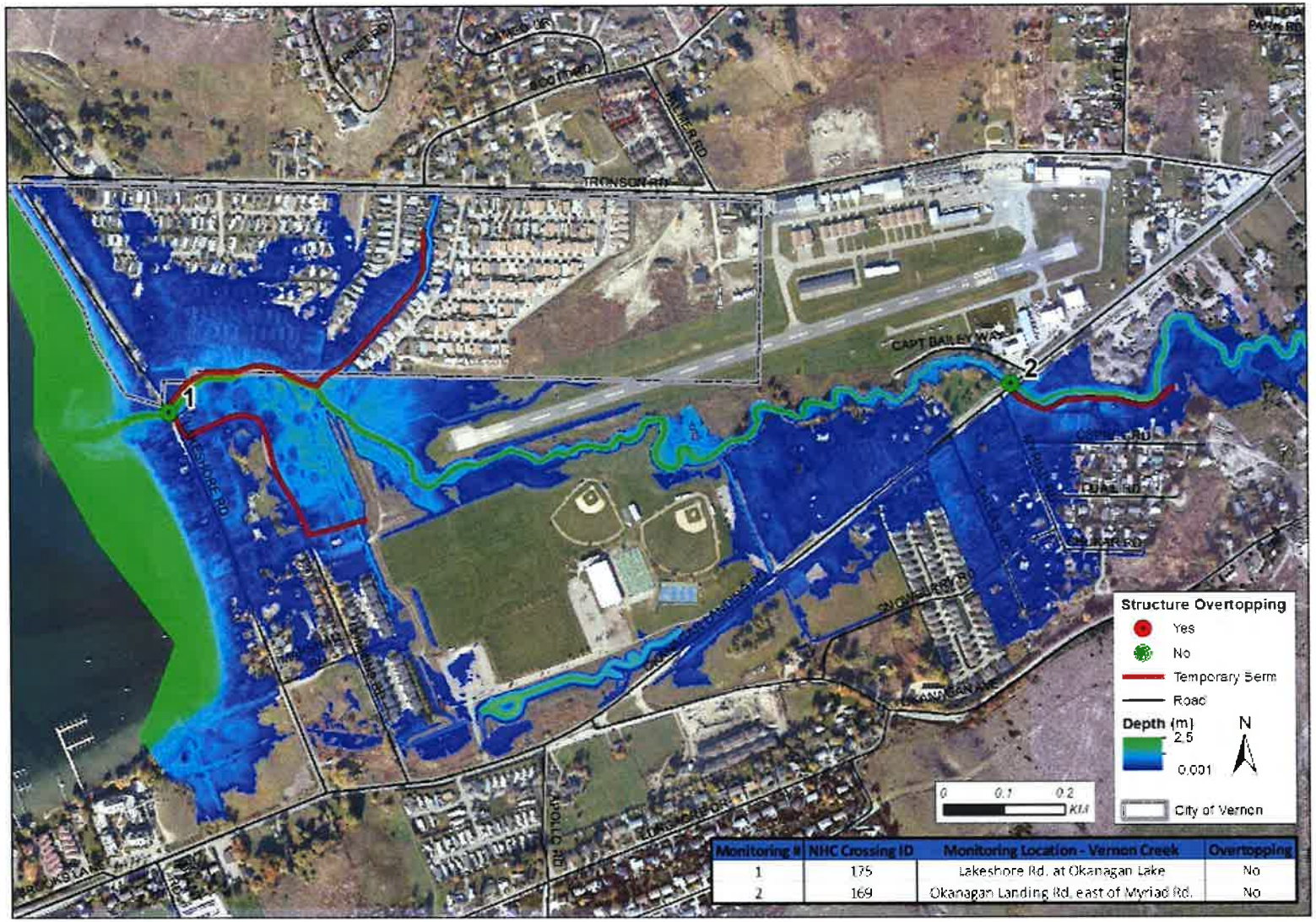


Figure 8.8 Suggested emergency response planning measures for lower Vernon Creek (2/2). Note that the eastern berm is intended to protect from high water levels on lower Vernon Creek, not from high levels on Okanagan Lake.

8.1.3 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 become flood prepared with respect to their home, family, and business. The development of a flood story map to digitally share the flood hazard information with the Vernon community has been undertaken. This will be a helpful medium to share information, and should be used alongside other outreach methods including highlights in community media (social and traditional), public meetings, and seasonal reminders. As these outreach methods are undertaken, 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 this year or 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 Vernon;
- 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 Vernon is doing to reduce community flood risk, including next steps for flood mitigation consultation.

Disaster financial assistance is generally only available for uninsurable assets. Ensuring the community is aware of their responsibility to acquire flood insurance where available is a critical step to improving the post disaster recovery.

8.1.4 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.

Vernon may want to consider pre-planning for recovery from floods and possibly incorporate this with recovery planning for a range of potential hazards (such as wildfires).

8.2 Structural Mitigation

Structural mitigation are engineering works that reduce flooding impacts. This can 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 flood boxes (EGBC, 2018).

For the Part 2 study area and flood events reviewed, the primary structural flood mitigation measures are upstream storage and improved conveyance. Upstream storage is currently provided by Swan, Wood, and Kalamalka Lakes. These reservoirs have been assessed for their ability to provide additional flood mitigation (Section 8.2.1). The large number of crossings (64) on lower B.X. Creek and Vernon Creek provide the greatest impediment to conveyance. Improvements to or replacements of the crossings have been investigated to improve conveyance (Sections 8.2.2 to 0).

Other structural mitigations, such as dikes, diversions, and pumping appear not be feasible in the Part 2 study area based on the current land use and design flow conditions. Locations where dikes or diversions could be useful are currently developed and the benefit of such measurers are not expected to warrant the cost, particularly in comparison to improving the most restrictive crossings.

For any mitigation options taken forward to detailed design, note that 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 Vernon once constructed. For any considered option, land tenure or acquisition should also be considered, as there is currently limited space along lower Vernon Creek.

8.2.1 Upstream Storage

Each model reaches in this study is bounded on the upstream end by a dammed lake. These lakes already provide an attenuating effect on the inflows from upstream. For example, the 1996 flood flow on upper B.X. Creek was estimated as 19.5 m^3/s, and this inflow resulted in a peak outflow from Swan Lake of 6.5 m^3/s. Similarly, in Kalamalka Lake, flows are typically managed with the intent of keeping flow into Vernon Creek below 6 m^3/s, even as peak (calculated, mean daily) inflows have often exceeded 15 m^3/s and are modelled to increase in the future (NHC, 2020d).

In the future, there may be flood mitigation opportunities for both B.X. Creek and Vernon Creek through an increase in live storage and upgrades in management methods of these lakes. However, each of these options currently have significant challenges associated with them and are likely not feasible at this time. Both of these options would require long term collaboration between Vernon and the province of B.C., the managers of both dams, and an extensive study of potential ecological effects (particularly for Swan Lake) and effects on citizens both inside outside of Vernon (particularly for Kalamalka Lake).

For Swan Lake, an increase in storage could be accomplished through raising of the Swan Lake dam. Due to the flat terrain, this would also require substantial widening of the dam through the wetland at the south end of the lake and an assessment of impacts of increased levels on the lakeshore. For Kalamalka Lake, any mitigation of downstream flooding would likely come through water level management updates (e.g., lowering of summer water levels) and lowering of the sill level of the dam into Vernon Creek. These changes would cause an impact on water supply during drought years, and have recreation impacts for residents that surround Kalamalka and Wood Lake.

8.2.2 Crossing Upgrades

NHC has closely examined the design flood modeling results at all 64 creek crossings within the Part 2 study area. Many of the crossings were identified as undersized and unable to effectively pass the design flood. The model results indicated water levels would be higher upstream due to the crossing constriction (backwatered), upstream banks would be overtopped, and in some cases, flow would overtop the crossing. The crossings with the greatest restriction to flow are culvert crossings. A detailed summary of the undersized crossings and relevant capacity issues is provided in Appendix E. The location of the undersized crossings is marked in Figure 8.1 through Figure 8.8. These crossings should be considered for future upgrades. Until upgraded, they should be monitored for obstruction and overbank inundation during flood flows.

Three crossing have been identified that would provide significant mitigative improvements if upgraded. They are all culvert crossings located on lower Vernon Creek (Figure 8.9 and Figure 8.10):

- 43rd Street culvert
- Okanagan Landing Road culvert
- Lakeshore Road culvert

These crossings are undersized and cause significant backwatering and raised upstream water levels that result in extensive flooding of roads and residential neighbourhoods. Crossing upgrades to reduce flood risk at these sites have been investigated to support Vernon on future risk reduction efforts. The type and size of replacement crossing is not part of the current study. However, for this evaluation, comparison was made between the current culvert crossings and replacement clear span bridges. This investigation included modeling the proposed mitigation measures and assessing the improvements, as well as identifying any transfer of risk to other locations. The assessment for each of the three crossing upgrades is presented in the following subsections.

An options assessment of the three crossing upgrades has also been completed to help Vernon prioritize which options should be considered (Sections 8.2.3 and 0).

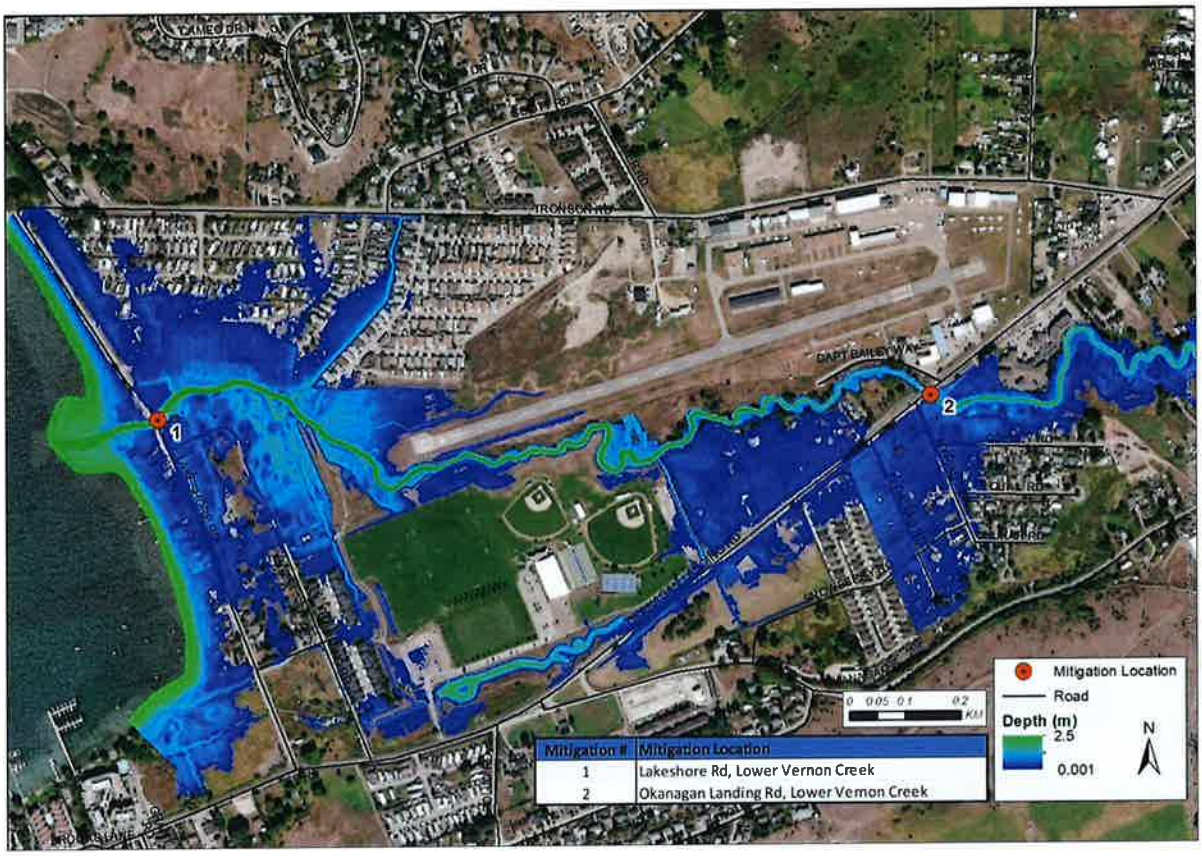


Figure 8.9 Recommended crossing upgrade locations for lower Vernon Creek (1/2).

Figure 8.10 Recommended crossing upgrade locations for lower Vernon Creek (2/2).

8.2.2.1 43rd Street

The existing crossing at 43rd Street is a 5.09 m by 2.06 m open bottom arch culvert with concrete headwalls (Figure 8.11). The crossing is undersized and backwaters the upstream channel. Under design flood conditions, this results in overbank flooding on both sides of the channel. On the right side (facing downstream), a large corner property and social services buildings are inundated. On the left side, overbank flooding extends onto 43rd Street, inundating the road southwest of the crossing as well as an industrial property. Flow on 43rd Street is conveyed further southwest and flooding directly affects approximately 50 houses in a residential neighbourhood. Flooding further affects six residential roads in the neighbourhood, blocking access to additional homes, before flows rejoin lower Vernon Creek around 16th Avenue (Figure 8.12).

Figure 8.11 Lower Vernon Creek at 43rd Street culvert crossing, facing downstream.

The recommended crossing improvements include replacing the culvert with an 18 m clear span bridge and widening the channel starting approximately 100 m upstream of the crossing. The channel would need to be widened to roughly the natural channel width of 5m. From modeling, these changes are shown to prevent overtopping of 43rd Street, protecting the currently affected houses and roads downstream. The industrial property and social services buildings remain impacted, but temporary berms are recommended at these locations, as shown in Figure 8.7. The impact on expected flood extent and depth of the proposed mitigation is illustrated in Figure 8.12.

Figure 8.12 Flood extents at 43rd Street crossing under current (top) and proposed improved (bottom) conditions based on model results for the design flood event. Blue gradient indicates depth of water (without freeboard) in meters.

8.2.2.2 Okanagan Landing Road

The existing Okanagan Landing Road crossing is a 4.15 m wide by 2.55 m high elliptical corrugated metal pipe (CMP) culvert (Figure 8.13). The CMP projects from the mechanically stabilised earth (MSE) headwalls.

Figure 8.13 Lower Vernon Creek at Okanagan Landing Road culvert crossing, facing upstream.

This crossing is undersized and backwaters the upstream channel, causing overbank flooding on both banks under the modeled design flood conditions. The left overbank flooding directly impacts approximately 70 homes in a residential neighbourhood, as well as five residential roads, before overtopping Okanagan Landing Road. From there, the overland flow continues to flood eight additional properties before rejoining lower Vernon Creek. A portion of the overbank flow continues southwest down Okanagan Landing Road, flooding parkland and minor roads and properties near Okanagan Lake.

The proposed crossing upgrade consists of replacing the culvert with a 19 m clear span bridge. With the increased capacity, left overbank flooding is almost entirely avoided. Approximately 10 houses and properties remain impacted, but the remaining level of inundation can likely be addressed through as-

needed protection measures such as sandbagging (Figure 8.8). The effectiveness of the proposed mitigation is exemplified in Figure 8.14.

Figure 8.14 Flood extents at Okanagan Landing Road under current (top) and proposed improved (bottom) conditions based on model results of the design flood. Crossing location indicated by red points. Blue gradient indicates depth of water (without freeboard) in meters.

8.2.2.3 Lakeshore Road

The existing Lakeshore Road crossing is a 4.3 m wide by 2.7 m high CMP arch culvert that projects from earth fill headwalls (Figure 8.15).

Figure 8.15 Lower Vernon Creek at Lakeshore Road culvert crossing, facing downstream.

This crossing located close to the outlet of Vernon Creek and is undersized. When the culvert is not backwatered by high levels on Okanagan Lake, creek flow is inlet controlled and the head loss as flood flows enter the pipe is sufficient to result in overbank flooding upstream. This also leads to the overtopping of Lakeshore Road and further flooding of properties adjacent to the crossing. Under design flood conditions, for which the downstream lake level is 343.9 m, flow through the culvert is downstream controlled, resulting in further overbank creek flooding in addition to lakeshore flooding.

The proposed crossing upgrade consists of replacing the existing culvert with a 15 m clear span bridge. To better understand the impacts resulting from Okanagan Lake shoreline flooding and backwatering versus overbank creek flooding from the undersized crossing, the crossing was modeled under four conditions for the design flow on lower Vernon Creek (25.6 m^3/s). The existing and proposed crossings

were modeled under the design water level in Okanagan Lake (343.9 m) as well as at a reduced water level to indicate no shoreline flooding (341.9 m; comparable to the lowest lake level likely to occur during the freshet period, near the end of April). Table 8.3 summarizes the modeling condition parameters as well as the number of flooded houses under each condition. The modeling results are illustrated in Figure 8.16.

Table 8.3 Model conditions for Lakeshore Road crossing under design flow on lower Vernon Creek.

Condition	Crossing Description	Okanagan Lake Water Level	Approx. Number of Flooded Homes
Condition 1	Existing culvert	343.9 m (design condition)	140
Condition 2	Proposed clear span bridge	343.9 m (design condition)	90
Condition 3	Existing culvert	341.9 m (2 m below design condition)	105
Condition 4	Proposed clear span bridge	341.9 m (2 m below design condition)	10

For both the design lake level and lowered lake level, the proposed bridge provides improvements compared to the existing culvert, as exemplified by the number of flooded homes summarized in the above table. Approximately 50 fewer homes are flooded with the improved crossing under the design lake level, and 95 fewer homes are flooded with the improved crossing under the lower lake level. This supports the decision to upgrade the crossing, as it indicates that the flooding in the Lakeshore Road area is largely a result of the existing undersized crossing, despite the additional influence of high lake levels.

The flood impacts from high levels on Okanagan Lake are still very significant, indicated by the 90 homes impacted under Condition 2 when the crossing is improved but lake levels still are high. Lakeshore flooding is less straightforward to mitigate; temporary as-needed flood protection measures such as sandbagging are recommended to protect houses and properties when lake levels are high.

Figure 8.16 Flood extents at Okanagan Landing Road for design Okanagan Lake water levels (left) and lowered lake levels (right) under current (top) and proposed (bottom) crossing conditions. Crossing location is indicated by red points. Blue gradient indicates depth of water (without freeboard) in meters.

8.2.3 Mitigation Options Assessment - Approach

The above structural mitigation measures have been evaluated using a qualitative risk and feasibility assessment. The risk component of the assessment assigns a score of the severity of risk avoided by the proposed mitigation. The feasibility component of the assessment assigns a score to represent the ease of implementation of the proposed mitigation. These two scores are then combined into a risk/feasibility ratio. A high risk avoided score and low feasibility score indicates the best scenario under this rating system. This information is provided to help inform decisions on the identified mitigations. Other factors (such as road improvements, age of crossing, condition of crossing, available funding, etc.) will further inform the decision on the mitigation option.

8.2.3.1 Scoring of Risk Avoidance

To identify the level of risk avoided through each mitigation option, a risk score was assigned based on the likelihood of the flood event overwhelming existing defences and the consequence of the flood event. For this component of the project, risk is determined through the matrix shown in Table 8.4.

Table 8.4 Scoring matrix for risk avoidance.

Likelihood of Reducing Hazard	Rating:	Risk Score		
Very likely to be highly effective	High – 3	**3**	**4**	**5**
Likely to be highly effective	Medium – 2	**2**	**3**	**4**
Likely to be moderately effective	Low – 1	**1**	**2**	**3**
Estimated Consequence without Proposed Mitigation		Minimal exposure of people, economic sociocultural, & ecological receptors/areas	Some exposure of people, economic sociocultural, & ecological receptors/areas	High exposure of people, economic sociocultural, & ecological receptors/areas
	Rating:	Low – 1	Medium – 2	High – 3

The likelihood of the adverse effect is evaluated based on the probability that a flood event will overwhelm existing defences and impact an area. The consequence is described for the area that would be defended by the mitigation. Consequence is estimated by an assessment of the people, receptors directly exposed to the flood hazard, and the potential extent of damage associated with the flood hazard which would be eliminated by the mitigation measure. Assessment of consequence aligns with the approach used in the flood risk assessment documented in Section 7.

The estimated, approximate protected area for each structural mitigation measure has been identified, based on flood mapping results. The impact to people, economy, environment, and cultural receptors was qualitatively categorized within the protected area. This matrix does not capture the importance to the community of the consequences estimated. Community consultation could further refine this matrix, through adjustment of the estimated consequence axis to better represent community values.

Based on the risk assessment, each feature is assigned a risk score between 1 to 5, based on the matrix shown in Table 8.4. A score of 5 indicates highest risk avoided or greatest benefit of the mitigation measure.

8.2.3.2 Scoring of Feasibility

The feasibility score quantifies the feasibility of each mitigation option. A low feasibility score represents a project which is easy to implement. The feasibility score has been estimated by applying the matrix in Table 8.5 to the two feasibility factors: ease of execution and cost of implementation.

Ease of execution includes considerations regarding design complexity, environmental constraints, land acquisition or easements, and impacts on property-owners or other stakeholders. The cost of implementation factor considers the estimated costs of the proposed works. Category descriptions are provided in the following table. Factors applied and the values assigned to the factors can be refined through stakeholder or community discussion and progressing the design and costing.

Table 8.5 Scoring matrix for feasibility factor.

Cost of Implementation	Rating:	Feasibility Score		
>$1,500,000	High – 3	**3**	**4**	**5**
$750,000 to $1,500,000	Medium – 2	**2**	**3**	**4**
<$750,000	Low – 1	**1**	**2**	**3**
Ease of Execution		Straightforward design and implementation. Minimal environmental impact. Does not require changes in land ownership. Minimal impact to stakeholders.	Somewhat complex design and implementation. May include moderate environmental impact. May require minor changes in land ownership. May have moderate impact on other stakeholders.	Complex design. May include substantial environmental impact. May require changes in land ownership. May substantially impact other stakeholders.
	Rating:	Low – 1	Medium – 2	High – 3

8.2.3.3 Approach for Cost Estimation

Cost estimation for structural mitigation measures has been carried out at a 'planning' level of estimating which is defined by BC Ministry of Transportation and Infrastructure (MoTI) (2013b) as being "based on sufficient knowledge of site conditions adequate to identify high level risk". The expected

accuracy range for this level of estimating is +/- 40%. Unit prices for construction items were obtained from recent NHC projects in the region.

Soft costs are typically 15% to 35% of construction costs. This is supported by provincial documentation by MoTI which suggests 25% (2013a). For this project we have adopted soft costs at the middle of this range, assuming some service costs are incorporated with the contractor's scope, such as environmental monitoring, surveying, and material testing. The distribution of this is as follows:

- Project management and planning: 3%
- Design: 15%
- Construction supervision and inspection: 7%

Costs were inflated to reflect the uncertainty of the estimate by a contingency rate of 40% of construction cost. This contingency rate is commensurate with the accuracy range of this project as per MoTI (2013b). The presented cost estimates only include design and construction costs. On-going monitoring and maintenance have not been included but should be budgeted for.

An additional 6% cost inflation for the COVID-19 pandemic has also been added to reflect pricing increases observed during the pandemic due to material shortages. This inflation cost is an estimate based on construction price increases for residential and commercial towers in Ontario (based on materials) (Cameron, 2021). This may not be reflective of the cost increase for infrastructure in BC but no credible sources have yet been published. This inflation may not impact the cost of the project at the time of construction if shortages and backlogs caused by the pandemic are resumed to normal levels.

8.2.3.4 Limitations

This assessment is based on the hydraulic model results of the existing conditions and assumed conditions of the structures along lower B.X. and Vernon Creek. Changes in bed conditions from those simulated will have an impact on the flood levels and extents. Based on the preliminary investigation of the identified mitigation measures, there is expected to be low transfer of flooding risk to other properties. However, this should be confirmed at the design phase for any structural work within a floodplain.

Cost estimates are based on results from the existing hydraulic model and coarse geometric generalizations. This level of uncertainty is reflected by the 40% contingency added to the total project costs. Survey and design of the mitigation measures are required to refine the estimate of quantities and costs. Costs and unit rates used in the estimates are based on other similar projects in the region and may differ from unit rates used in the detailed design and construction phase.

8.2.4 Mitigation Options Assessment - Results

Risk Avoidance Assessment

Likelihood

Enlarging the crossings would have a positive effect on flow conveyance through this reach of Vernon Creek. The likelihood of effectiveness at mitigating flooding in Vernon is a '3' or 'high' described as 'very likely to be highly effective' for all 3 crossings. Improving the conveyance at these sites may result in a local increase in velocity and sediment transport which will need to be considered in the design. However, it is not expected that these factors will affect the effectiveness or suitability for reducing flood levels.

Consequence

Implementing crossing upgrades would reduce flooding in several areas, as shown in Figure 8.12, Figure 8.14 and Figure 8.16. The receptors protected through this measure are characterized as '3' or 'high' and described as 'high exposure of people, economic, sociocultural, & ecological receptors/areas'. The consequence avoided through this measure is high as protection covers entire neighborhoods and avoids consequence for several commercial buildings and roads.

Risk Avoidance Score

Based on the matrices shown in Table 8.6 to Table 8.8, the overall risk avoidance score is a 5 for all three crossings.

Table 8.6 Risk avoidance score for 43rd Street crossing upgrades.

Proposed Measure	Risk Avoided Score			
	Factor	Factor Score	Factor Description	Overall Score
43 Street Crossing Upgrade	Likelihood	3	Very likely to be highly effective	5
	Consequence	3	High exposure of people, economic sociocultural, & ecological receptors/areas	

Table 8.7 Risk avoidance score for Okanagan Landing Road crossing upgrades.

Proposed Measure	Risk Avoided Score			
	Factor	Factor Score	Factor Description	Overall Score
Okanagan Landing Road Crossing Upgrade	Likelihood	3	Very likely to be highly effective	5
	Consequence	3	High exposure of people, economic sociocultural, & ecological receptors/areas	

Table 8.8 Risk avoidance score for Lakeshore Road crossing upgrades.

Proposed Measure	Risk Avoided Score			
	Factor	Factor Score	Factor Description	Overall Score
Lakeshore Road Crossing Upgrade	Likelihood	3	Very likely to be highly effective	5
	Consequence	3	High exposure of people, economic sociocultural, & ecological receptors/areas	

Feasibility Assessment

Ease of Execution

The ease of execution of the crossing upgrades along Vernon Creek is low, as they will require engineering design with challenges associated to working in and around watercourses as well as limiting impacts to adjacent roads, utilities, and buildings. The ease of execution is ranked as '3' or 'low' and described as 'Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly'.

Cost Estimate

For this assessment it has been assumed that the crossings would be upgraded to clear-span bridges. The need for bridges versus culverts has not been included in the current scope of this project and the type of replacement structures should be considered at the detailed design phase. The use of culverts may be suitable and result in reduced cost, however a newer, larger culvert may cost just as much as a bridge when all factors are considered (fish passage, debris blockage, ease of access, and equipment required for installation). The crossing structures should be designed with capacity and clearance suitable to pass the design flow plus the expected sediment and debris.

It is expected that the replacement of the 43rd Street crossing would require 43rd Street to be raised for approximately 170 m from the crossing heading south-west. The cost estimate for all structures has been created using a bridge construction cost (by deck area) estimate based on previous MoTI bridge replacement projects in the last 3 years.

It has been assumed that crossing upgrades would all be completed separately (no cost sharing). However, it was assumed that the road raising (for 43rd Street only) will be done with the crossing upgrade and therefore share in costs such as mobilization, demobilization, and traffic management. Costs are developed from other projects that had similar design constraints. However, it should be noted that these project costs are based on MoTI projects. Table 8.9 through Table 8.11 summarize the estimated cost of upgrading all three crossings.

Table 8.9 Cost estimate for crossing upgrades at 43rd Street.

Item	Quantity	Unit Rate	Cost
Mobilization and demobilization	1	$50,000	$50,000
Traffic management	1	$100,000	$100,000
Demolition of existing crossing	1	$100,000	$100,000
Bridge Construction (by deck area) (m^2)	151	$6,000	$908,280
Road Grading (m)	170	$3,500	$595,000
Channel Riprap (m^3)	208	$185	$38,480
Supplementary construction	1	$250,000	$250,000
Soft costs	25%	-	$510,440
Possible COVID-19 cost inflation	6%	-	$122,506
Contingency	40%	-	$816,704
		Total	$3,490,000

Table 8.10 Cost estimate for crossing upgrades at Okanagan Landing Road.

Item	Quantity	Unit Rate	Cost
Mobilization and demobilization	1	$50,000	$50,000
Traffic management	1	$100,000	$100,000
Demolition of existing crossing	1	$100,000	$100,000
Bridge Construction (by deck area) (m^2)	133	$6,000	$798,000
Road Grading (m)	0	$3,500	$0
Channel Riprap (m^3)	208	$185	$38,480
Supplementary construction	1	$250,000	$250,000
Soft costs	25%	-	$334,120
Possible COVID-19 cost inflation	6%	-	$80,189
Contingency	40%	-	$534,592
		Total	$2,290,000

Table 8.11 Cost estimate for crossing upgrades at Lakeshore Road.

Item	Quantity	Unit Rate	Cost
Mobilization and demobilization	1	$50,000	$50,000
Traffic management	1	$100,000	$100,000
Demolition of existing crossing	1	$100,000	$100,000
Bridge Construction (by deck area) (m^2)	105	$6,000	$630,000
Road Grading (m)	0	$3,500	$0
Channel Riprap (m^3)	208	$185	$38,480
Supplementary construction	1	$250,000	$250,000
Soft costs	25%	-	$292,120
Possible COVID-19 cost inflation	6%	-	$70,109
Contingency	40%	-	$467,392
		Total	$2,000,000

Feasibility Score

Based on the matrices shown in Table 8.12,

Table 8.13 and Table 8.14 the overall feasibility score for all crossings is a 5.

Table 8.12 Feasibility score for 43rd Street crossing upgrades.

Proposed Measure	Feasibility Score			
	Factor	Factor Score	Factor Description	Overall Score
43 Street Crossing Upgrade	Ease of execution	3	Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly	5
	Cost of implementation	3	>$1,500,000	

Table 8.13 Feasibility score for Okanagan Landing Road crossing upgrades.

Proposed Measure	Feasibility Score			
	Factor	Factor Score	Factor Description	Overall Score
Okanagan Landing Road Crossing Upgrade	Ease of execution	3	Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly	5
	Cost of implementation	3	>$1,500,000	

Table 8.14 Feasibility score for Lakeshore Road crossing upgrades.

Proposed Measure	Feasibility Score			
	Factor	Factor Score	Factor Description	Overall Score
Lakeshore Road Crossing Upgrade	Ease of execution	3	Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly	5
	Cost of implementation	3	>$1,500,000	

Overall Ratio Score

Table 8.15, Table 8.16, and Table 8.17 presents the risk to feasibility ratios for upgrading the 43rd Street, Okanagan Landing Road, and Lakeshore Road crossings on Vernon Creek. A high risk avoided score and a low feasibility score would indicate the best scenario. This project received a high risk avoidance score and a high feasibility score, resulting in a 5:5 Risk/Feasibility ratio for all crossings.

Table 8.15 Risk/Feasibility ratio for 43rd Street crossing upgrades.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk/ Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
43 Street Crossing Upgrade	Likelihood	3	5	Ease of execution	3	5	5:5
	Consequence	3		Cost of implementation	3		

Table 8.16 Risk/Feasibility ratio for Okanagan Landing Road crossing upgrades.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk/ Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Okanagan Landing Road Crossing Upgrade	Likelihood	3	5	Ease of execution	3	5	5:5
	Consequence	3		Cost of implementation	3		

Table 8.17 Risk/Feasibility ratio for Lakeshore Road crossing upgrades.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk/ Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Lakeshore Road Crossing Upgrade	Likelihood	3	5	Ease of execution	3	5	5:5
	Consequence	3		Cost of implementation	3		

8.2.5 Summary of Part 1 and 2 Structural Mitigation Options

The Part 2 options assessment introduced in Section 8.2.3 was previously applied to the structural mitigation options explored for the Part 1 study area. Five mitigation options were considered for the Part 1 study area on upper B.X. Creek:

- Sediment and debris management plan
- Diking near Pleasant Valley Road
- Crossing upgrades on 20th Street and 48th Avenue
- Diking between 20th Street and Deleenheer Road
- Highway 97 crossing upgrade

Details of the recommended structural mitigation options for upper B.X. Creek are provided in the Part 1 project report (NHC, 2020b). The full structural mitigation options assessment for Part 1 is provided in the *City of Vernon Flood Mapping, Risk Analysis and Mitigation Project, Part 1 Mitigation Evaluation* report (NHC, 2020c), submitted to Vernon on November 26, 2020.

Table 8.18 summarizes the final Risk/Feasibility ratios and estimated costs of the structural mitigation options assessed in both Parts 1 and 2 of this study.

Table 8.18 Summary of Structural Mitigation Options Assessment (Parts 1 and 2)

Creek	Structural Mitigation Measure	Risk/Feasibility Ratio	Cost
Upper B.X. Creek (Part 1 Study Area)	Sediment and debris management plan	3:3	$1,150,000
	Diking near Pleasant Valley Road	2:5	$1,510,000
	Crossing upgrades on 20th Street and 48th Avenue	4:5	$12,460,000
	Diking between 20th Street and Deleenheer Road	5:5	$2,570,000
	Highway 97 crossing upgrade	4:5	>$1,500,000
Lower Vernon Creek (Part 2 Study Area)	43rd Street crossing upgrade	5:5	$3,490,000
	Okanagan Landing Road crossing upgrade	5:5	$2,290,000
	Lakeshore Road crossing upgrade	5:5	$2,000,000

Of the above structural mitigation measures, the greatest risk avoidance is expected to be achieved by diking upper B.X. Creek between 20th Street and Deleenheer Road and upgrading the lower Vernon Creek crossings at 43rd Street, Okanagan Landing Road, and Lakeshore Road. However, these measures can be anticipated to be complicated to design and expensive to construct. Upper B.X. Creek crossing upgrades on 20th Street, 48th Avenue, and Highway 97 are anticipated to be the next most effective for risk avoidance, but also exhibit high costs and difficult feasibility. The sediment and debris management plan has moderate scores for both risk avoidance and feasibility. Diking near Pleasant Valley Road is anticipated to be somewhat helpful in flood mitigation, but will likely be very difficult and expensive to construct.

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 choose 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 structural and non-structural mitigation options identified for Part 1 and Part 2 of this project, the six that are anticipated to have the largest benefits are listed below.

1. Emergency Flood Response Plan (entire city)

The recommended first priority is the development of an Emergency Flood Response Plan that will guide Vernon 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. OCP and Zoning By-law update

The second non-structural mitigation, which is of equal priority to the first, is to establish flood by-laws that prevent development within the floodway and limit development within the floodplain. The limits to development should be dependent on the risk, that is the proposed land use and identified hazard.

3. Sediment and Debris Management Plan (upper B.X. Creek)

The development of a sediment and debris management plan is recommended prior to the design and construction of other structural mitigation options on upper B.X. Creek, 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.

4. Diking between 20th Street and Deleenheer Road (upper B.X. Creek)

Two structural mitigation options discussed in the Part 1 project report for flood risk reduction on upper B.X. Creek were (1) crossing upgrades on 20th Street and 48th Avenue and (2) diking of the downstream channel between 20th Street and Deleenheer Road. Both options are large capital projects that will include property acquisition and construction of sizeable infrastructure; however, diking of the downstream channel is anticipated to have a lower capital cost and a higher reduction of flood risk. The design of this mitigation option should assume that the upstream crossing upgrades will be completed in the future, increasing flow and sediment transport to the downstream channel where the dike is proposed.

5. Crossing upgrades on 43rd Street, Okanagan Landing Road, and Lakeshore Road (lower Vernon Creek)

The three crossing upgrades recommended for lower Vernon Creek (Section 8.2) are all 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 possible property acquisitions. Despite the high costs, the improved crossings are anticipated to greatly reduce flood risk at all locations.

6. Crossing upgrades on 20th Street and 48th Avenue (upper B.X. Creek)

Like the lower Vernon Creek crossing upgrades, the upper B.X. Creek crossing upgrades at 20th Street and 48th Avenue are considered large capital projects that will have very high costs. The cost of this mitigation option is anticipated to be much greater than the downstream diking between 20th Street and

Deleenheer Road, and to 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.

In making implementation decisions regarding the recommended mitigation measures, conversations about priorities for mitigation should include public consultation and the priorities of Vernon.

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APPENDIX A

DESIGN FLOW ESTIMATION TECHNICAL MEMO

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nhc
northwest hydraulic consultants ltd

NHC Ref. No. 3005032

8 April 2021

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

Attention: **Mathew Keast, PEng**
Project Manager, Water Resource Engineer

Via email: mkeast@vernon.ca

Re: **City of Vernon: Detailed Flood Mapping, Risk Analysis and Mitigation**
Design Flow Estimation - Part 2: Lower B.X. and Vernon Creek

Dear Mr. Keast:

This memo contains our hydrologic analysis methods and results for the City of Vernon – Part 2: Lower B.X. and Vernon Creek floodplain study. The following describes how the design flow estimates for Lower B.X. Creek and Vernon Creek (between Kalamalka and Okanagan Lake) were developed. Lower B.X. Creek and Vernon Creek are a part of the heavily regulated Okanagan Basin. Because of this, alternative methods (to traditional flood frequency analysis) for estimating design flows on this system had to be used.

1 INTRODUCTION

In July 2020, NHC completed part 1 of the City of Vernon's detailed floodplain mapping, risk analysis and mitigation study. Part 1 focused on Upper B.X. Creek, from the city limits to the point where B.X. Creek flows into Swan Lake (NHC, 2020a). Part 2 began directly after completion of part 1 and focuses on Lower B.X. Creek, from Swan Lake to the confluence of Vernon Creek, and Vernon Creek, from Kalamalka Lake to Okanagan Lake.

This report details the methods for estimating design flows (including climate change impacts) for input to the 2-dimensional hydraulic model of Lower B.X. and Vernon Creek within the City of Vernon. Design flows were estimated in three parts: 1) outflows from Kalamalka Lake into Vernon Creek; 2) outflows from Swan Lake into Lower B.X. Creek; and, 3) local flows generated within the City of Vernon. The stream layout is shown in Figure 1, and details on the Water Survey of Canada (WSC) gauges used in the analysis are shown in Table 1.

In part 1, the observed flood event from June 1996 on B.X. Creek was used as the design event, as it was estimated to have a return period greater than 500 years. The flood of 1996 on Upper B.X. Creek was caused by intense rainfall (~45 mm in at most two days in the City of Vernon, and likely more within upper B.X. Creek) on top of a melting snowpack in the upper reaches of B.X. Creek. In part 2, the 1996 flood event was again used as the inflow to Swan Lake which was then routed through the lake and into Lower B.X. Creek.

Kalamalka Lake levels respond much more slowly than B.X. Creek, as the total watershed area is much larger, and the storage of Ellison, Wood, and Kalamalka Lake slow the hydrograph response. The highest lake levels (and thus largest outflows into Vernon Creek) are likely to occur when a synoptic scale (e.g. covering the entire watershed) rainstorm occurs on top of melt from a very large snowpack, such as the peak lake outflows that occurred in the Spring of 1997, one of the highest snowpack years on record.

Though the 1996 B.X. Creek event was shorter and more intense than what would cause maximum outflow from Kalamalka Lake, it occurred on June 1, which is within the time of year for maximum Kalamalka Lake levels. Thus, we use a more traditional 200-year flow on Vernon Creek (from Kalamalka Lake) as a design flow that occurs at the same time as the 1996 routing on Lower B.X. Creek.

Table 1 WSC Gauge Summary

ID	Name	Watershed area (km^2)	Variables	Time range
08NM020	B.X. Creek above Vernon intake	53.2 (NHC Est.)	Flow, Level	1921-1927 1959-1999
08NM065	Vernon Creek at outlet of Kalamalka Lake	572 (NHC Est.)	Flow, Level	1927-1930 1959-Present
08NM123	B.X. Creek below Swan Lake control dam	120 (WSC Est.)	Flow, Level	1959-1978
08NM143	Kalamalka Lake at Vernon pumphouse	571 (NHC Est.)	Level	1967-Present
08NM160	Vernon Creek near the mouth	751 (WSC Est.)	Flow, Level	1969-1999

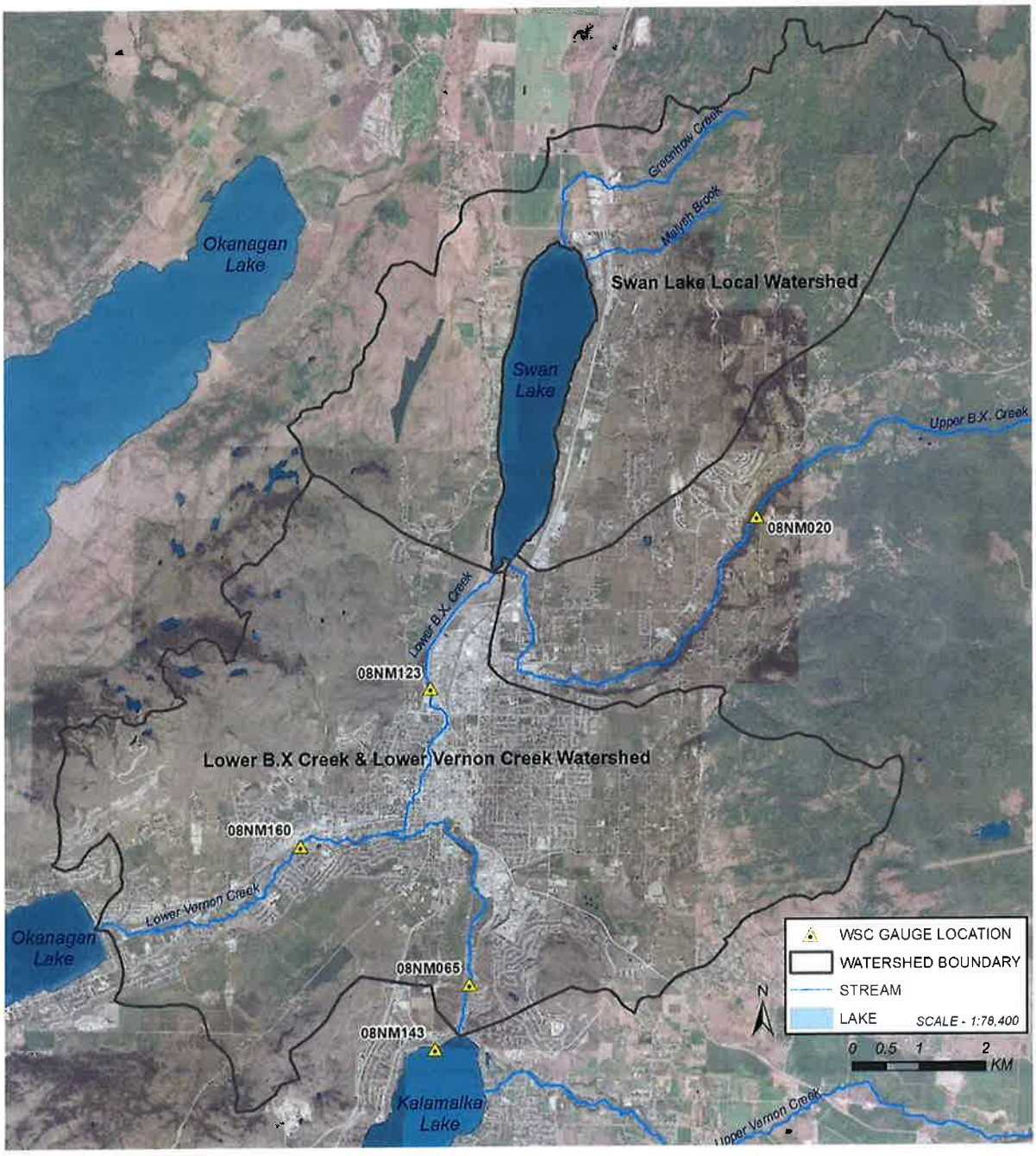

Figure 1 Location Map.

2 KALAMALKA LAKE INTO VERNON CREEK

As described in the part 1 report, NHC developed a hydrologic and reservoir operations model for the entire Okanagan River mainstem, from Ellison Lake to Osoyoos Lake (NHC, 2020b). This hydrologic

model, developed in the Raven platform (Craig et al., 2020), uses an ensemble of 50 synthetically generated weather timeseries, from 1950-2100, to simulate the combination of natural hydrology and corresponding reservoir operation responses to these conditions in order to model reservoir levels.

As in part 1, this model was modified for direct application to the City of Vernon and used for estimating outflows from Kalamalka Lake into Vernon Creek. Kalamalka Lake outflows are regulated by a set of three 5-foot (1.52 m) wide sluice gates at the outlet of the lake. The operation of these gates is controlled by the BC FLNRORD Okanagan reservoir manager in order to meet a combination of lake level and streamflow targets throughout the year. Lake level targets are determined based on forecasts of total spring freshet inflows into Kalamalka Lake; freshet inflows are forecast by the BC River Forecast Centre and supplied to the reservoir manager on a monthly basis from January – May. The full operations guidelines of Kalamalka Lake are detailed in AE (2017). The most significant portion of the operations guidelines applies to late winter target levels. When the freshet inflows are forecast to be large (primarily due to buildup of a large winter snowpack), the reservoir manager aims to bring the lake levels down to lower pre-melt levels than if the inflow forecast is small. This allows for a balance between preventing lake flooding and keeping enough water in the lake for summer demand and environmental flow needs.

Target release flow rates are only capped at the lower end in the Kalamalka Lake operations guidelines, in order to meet environmental flow needs. However, discussions with the reservoir manager indicated that the maximum release from Kalamalka Lake should not exceed approximately 6 m^3/s; higher flows are likely to cause infrastructure damage along Vernon Creek at present (Shaun Reimer, BC FLNRORD, pers. comm. Jan. 2020). Due to the higher risk of damage from moving water than high lake levels, this maximum flow release cap is given a higher priority than reaching target lake levels.

Though there is no intent to allow releases higher than 6 m^3/s into Vernon Creek from Kalamalka Lake, NHC has followed the approach adopted for the Okanagan mainstem flood mapping work to simulate a more conservative 'open gates' scenario for Kalamalka Lake releases. In NHC (2020b), design flows on Okanagan River were determined by allowing free flowing water out of Okanagan Lake for the ensemble hydrologic model simulation. We have followed this approach for flows into Vernon Creek, assuming the Kalamalka Lake outlet gates are left fully open for the entire spring freshet.

The open gate scenario is a more conservative assumption[1] than capping all releases into Vernon Creek at 6 m^3/s and maintains continuity with design flow estimates along the Okanagan River. While there is no intent to exceed 6 m^3/s, it is possible that normal operations could be compromised. Potential operations malfunctions at the outlet of Kalamalka Lake could make closing gates impossible, or extreme lake levels could risk damaging the dam itself if water is not released as quickly as possible. Thus, the

[1] The open gates scenario is more conservative for Vernon Creek flows (producing higher flows) but likely less conservative for estimating Kalamalka Lake design levels. Hence, the regulation rules were used when simulating design lake levels in NHC (2020b).

open gates scenario can help to account for these potential operations outside of normal conditions on Vernon Creek.

In order to use an open gates simulation in the Raven model, it was necessary to develop a rating curve for the Kalamalka Lake release structure. NHC constructed this rating curve through a combination of two methods: 1) an empirical rating curve based on data from the 1997 freshet, when gates were left fully open for the duration of the freshet, and 2) an inline structure hydraulic model for extreme levels if lake levels reached the top of the open gates.

The empirical rating curve was developed through a comparison of flow at the Water Survey of Canada (WSC) gauge 08NM065 – Vernon Creek at outlet of Kalamalka Lake and stage at 08NM143 – Kalamalka Lake at Vernon pumphouse. The empirical rating curve is likely to provide a more realistic stage-discharge relationship for the range of observed flows as it implicitly accounts for obstructions and flow influences aside from the dam structure alone. For example, it was indicated by the reservoir manager (Shaun Reimer, BC FLNRORD, pers. comm., Sep 2020) that sediment has built up in front of the release structure and is likely slowing releases from the lake; additionally, flows may be controlled in the channel downstream of Kalamalka lake, underneath the train tracks (approximately 50 m downstream). A comparison of stage-discharge in 1997 and 2020 indicated evidence of sedimentation buildup that is slowing outflow from the lake. In other words, the same lake stage would result in a lower flow in 2020 than it would have in 1997. However, this issue is under investigation by FLNRORD and dredging around the release structure in Kalamalka is likely. Thus, the 1997 rating curve is more appropriate for use over the long term than the 2020 relationship. The fitted empirical curve is shown in black in Figure 2 up to a stage of approximately 392.4 (the highest stage reached in 1997).

The most extreme lake levels and discharges, where the gates become completely submerged and water flows round the structure, have thankfully not been reached since the structure was built, so the empirical curve does not cover these situations. Thus, we estimated the upper end of the rating curve, which could potentially be needed in the ensemble simulations of 50 members from 1945-2100, using an inline structure in HEC-RAS (Brunner, 2016). We created a rating curve via incrementally increasing lake levels to simulate flow through and over the submerged dam gates above the observed conditions. The HEC-RAS rating curve begins in Figure 2 (in black) at the flat spot; this flat section, where stage increases with little effect on flows, indicates the submerged gate orifice flow. Eventually, the stage rises high enough to simulate flow over the top of the gates (when the flat area ends and flows again begin to increase). Weir flow over the gates in a flood situation assumed that Kalamalka Lake was confined and could not spill around the gates, only overtop. This scenario is likely; in most extreme lake level situations (e.g. 2017) sandbags would be placed around the dam to route lake water through, rather than around, the release structure.

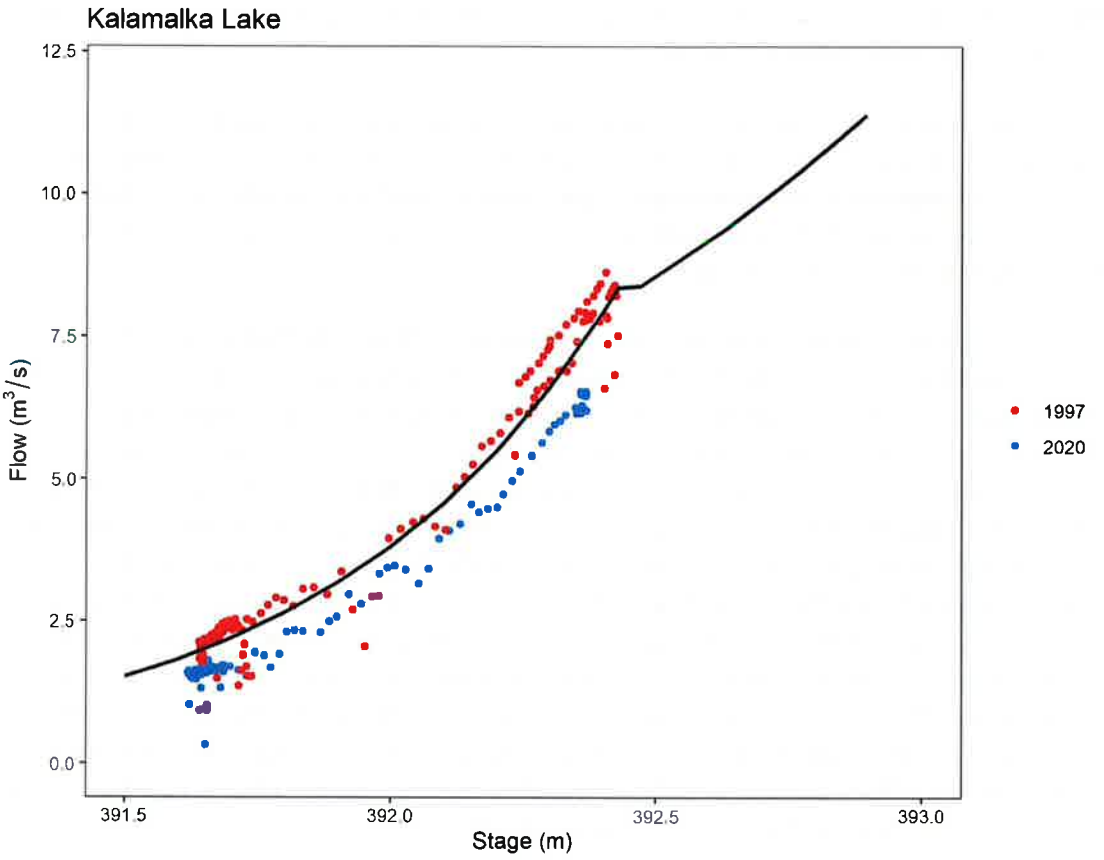

Figure 2 **Empirical rating curve (in black) fit for Kalamalka Lake outflow from 1997 up to 392.4 m, and developed in HEC-RAS above.**

After building the combined empirical/simulated rating curve, this curve was integrated into NHC's full Okanagan reservoir model, and the full ensemble set of 50 members from 1950-2100 was run. In order to conservatively simulate the gates being opened once the lake was already at target levels, we restricted minimum lake levels to the monthly target levels for a high inflow year from the operations plan (AE, 2017). Above this level, free flow from the open gates was allowed.

As in part 1 (for both B.X. Creek and Swan Lake), the annual maximum outflow from Kalamalka Lake was extracted for each year and ensemble member, resulting in 7500 total annual maximum outflows into Vernon Creek. Also as in part 1, we divided these outflows into 30-year blocks of pseudo-stationary outflow datasets, with each block containing 1500 simulated years of outflow. Each time block was analyzed using empirical flood frequency analysis to determine design flows for the present day (defined as 2020 +/- 15 years and two future time periods. An example empirical frequency analysis is shown in Figure 3, and design flow results are shown in Table 2. NHC recommends that the end of century model flows are used to best account for potential climate change impacts.

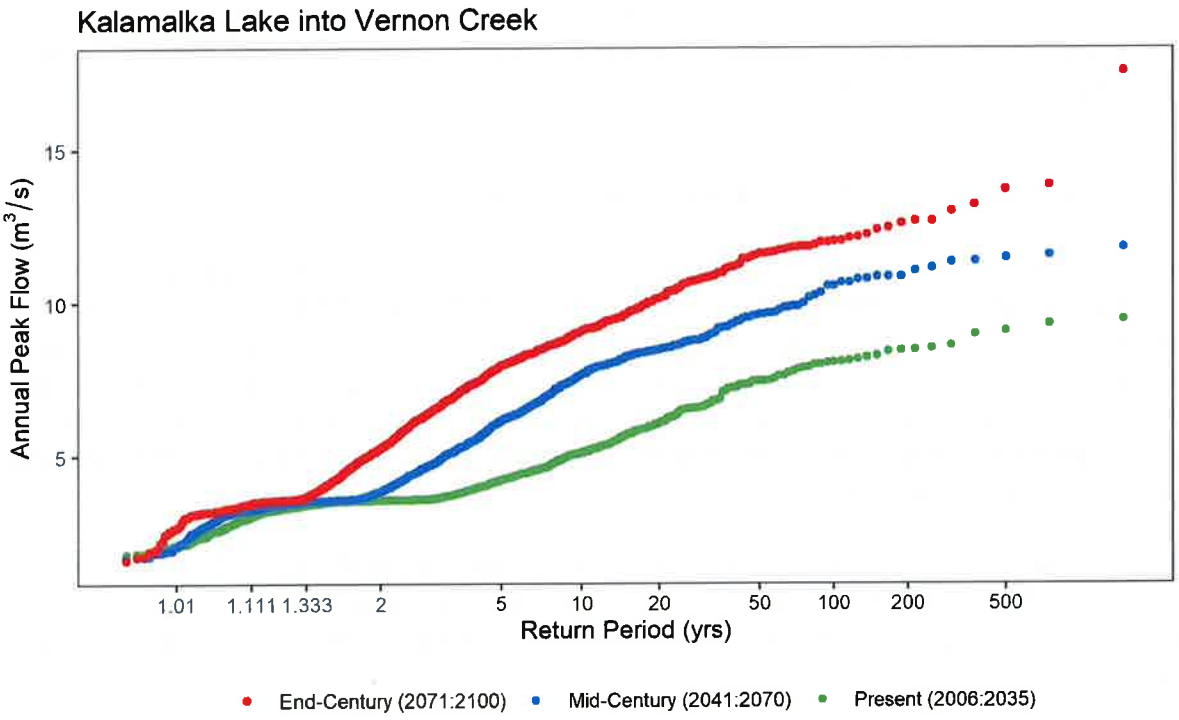

Figure 3 **Empirical frequency analysis of annual maximum releases from Kalamalka Lake into Vernon Creek for the three analysis periods in the NHC Okanagan Mainstem model.**

Table 2 **Mean daily peak Kalamalka Lake releases (m^3/s) into Vernon Creek from NHC Okanagan Mainstem Raven model using the open gates scenario. Recommended hydraulic model inputs is shown in bold.**

Return Period (yr)	Present (2006-2035)	Future (2041-2070)	Future (2071-2100)
10	5.1	7.7	9.1
20	6.1	8.5	10.1
100	8.0	10.5	12.0
200	8.4	10.9	**12.6**

The Raven Okanagan mainstem model runs on a daily timestep, and as such these peak outflows are mean daily outflows. However, Kalamalka Lake and its corresponding outflows are a relatively slow responding system. The highest observed flows on the WSC gauge 08NM065: Vernon Creek at outlet of Kalamalka Lake are 8.71 m^3/s (instantaneous) and 8.63 m^3/s (daily), both on June 12, 1997.

Additionally, there is no correlation between the difference between instantaneous and daily Kalamalka Lake levels and the maximum annual level in the WSC record. The average difference between

instantaneous and annual maximum level on Kalamalka Lake is 1.5 cm, corresponding to a difference in peak outflow of less than 0.2 m^3/s. Thus, we recommend the mean daily flows as the design input from Kalamalka Lake into Vernon Creek.

3 SWAN LAKE INTO LOWER B.X. CREEK

The City of Vernon part 1 report for Upper B.X. Creek (NHC, 2020a) used the instantaneous maximum peak flow from the June 1, 1996 event on Upper B.X. Creek (WSC gauge 08NM020). The observed instantaneous maximum was 13.2 m^3/s, which was above the 500-year flow estimate (12.9). As such, NHC recommended the use of this value as a design flow instead of the typical 200-year calculated flow. The value was scaled up (via area-based scaling) to the top of the model reach (for the part 1, Upper B.X. Creek hydraulic model) for a flow of 17.7 m^3/s for the present day and 19.5 m^3/s with an additional 10% safety factor due to climate change.

For part 2, we routed the 17.7 and 19.5 m^3/s flows through Swan Lake within NHC's Okanagan Mainstem Raven model to determine the maximum outflow from Swan Lake into Lower B.X. Creek. In addition to these B.X. Creek design flows, local inflows generated within the Raven model were included in the Swan Lake inflows.

The Raven model was run for the May 15 – June 15, 1996 period at a one-hour timestep. The model inflows to Swan Lake were overridden by a hydrograph based on interpolation of the instantaneous maximum and mean daily observations on B.X. Creek, upscaled to the same size as flows used in part 1 (for the upper end of the part 1 model reach). All other inflows to Swan Lake were modelled directly within Raven using weather observations from the May 15 - June 15, 1996 period, however the inflows from B.X. Creek were the dominant input to the lake. A sample inflow/outflow routing result is shown in Figure 4 using the present day 1996 inflow estimate and the Swan Lake local inflows.

Routing the 1996 event through Swan Lake required further investigation into the rating curves for the outlet of Swan Lake. Ecora (2019) provided rating curves for the different stoplog configurations on the weir (from 0 to 6 logs). However, these rating curves were developed (via hydraulic modelling) prior to the removal of the three culverts downstream of the Swan Lake weir. These culverts had previously provided a backwater effect during high flows and thus were likely to lower the outflow rate while increasing lake levels.

As a sensitivity test, NHC compared model routing results of the June 1996 peak flows between the Ecora calculated stage-discharge rating curve and a broad crested weir equation, which is likely to better simulate unconstrained outflow from Swan Lake (C = 0.6, crest length = 3.6 m). Both methods used a conservative assumption of 5 stoplogs in place on the Swan Lake dam. The number of stoplogs in place did not effect the peak outflow, but did affect the peak lake level reached within the event. Results are shown in Table 3. As the results are from an instantaneous peak inflow to the model, run with an hourly timestep, they should be considered instantaneous peaks. As expected, the Ecora rating curves, which assume downstream flow constriction, result in lower peak flows but higher maximum lake levels. NHC recommends using the weir equation results as design flows from Swan Lake into Lower B.X. Creek.

Comparatively, the highest observed outflow from Swan Lake (WSC Gauge 08NM123: B.X. Creek below Swan Lake Control Dam) was a mean daily flow of 2.94 m^3/s on April 26, 1973. However, no instantaneous peak flows have been reported; additionally, the period of record is quite short (~1960-1975) and occurred prior to installation of the current outflow structure in 1975 (Ecora, 2019).

As a final check, we empirically calculated maximum outflows from Swan Lake directly from Raven (using the ensemble simulation as in Vernon Creek/Kalamalka Lake). Results showed an end of century 200-year peak flow of 5.2 m^3/s, indicating that the 1996 event is still the most conservative design event for inflows to Lower B.X. Creek.

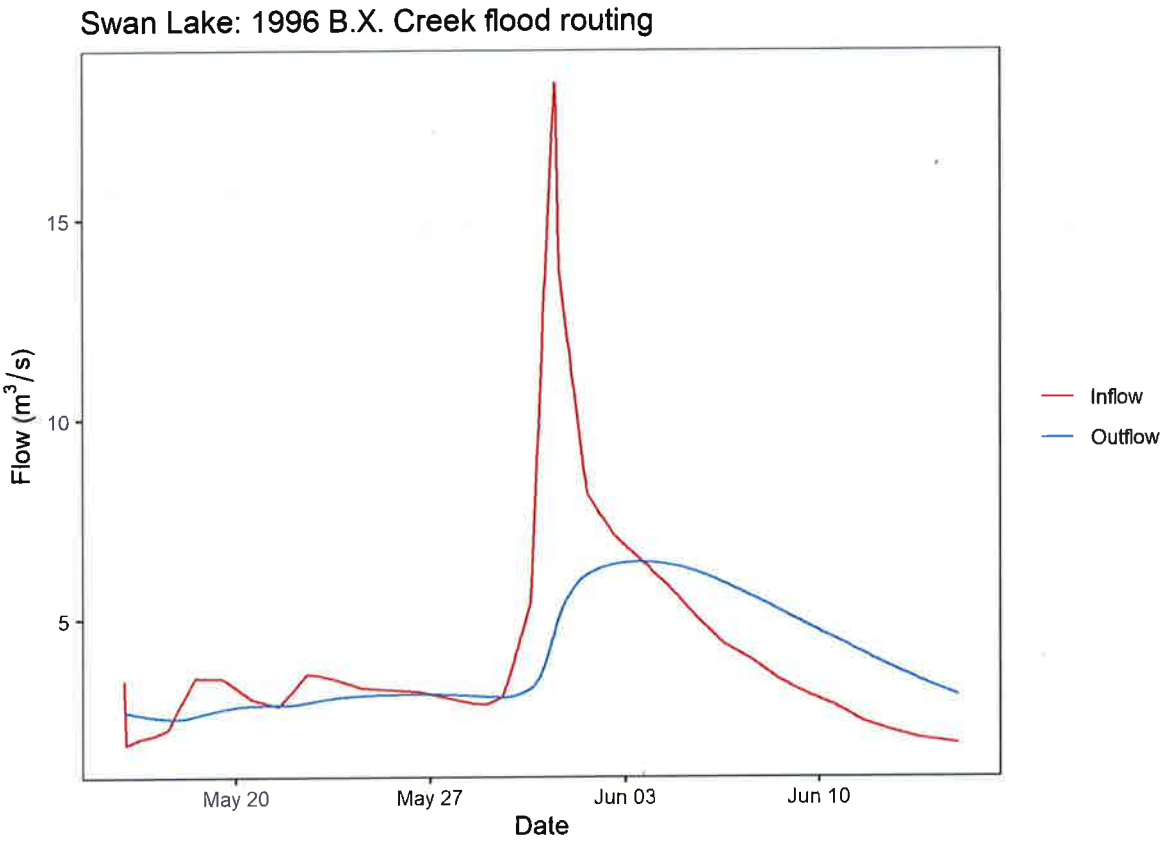

Figure 4 **Routing of the 1996 B.X. Creek flood through Swan Lake in the NHC Okanagan Mainstem Raven model. Inflows include both design flow input from Upper B.X. Creek and modelled local Swan Lake inflows.**

Table 3 **Routing results for the 1996 flood through Swan Lake. RC = rating curve. Recommended hydraulic model input is shown in bold. Future inflows are based on the climate change adjustment for the 1996 B.X. Creek flow described in NHC (2020a).**

Maximum	Ecora (2019) RC, present day inflow	Ecora (2019) RC, future inflow	Weir EQ (5 logs), present inflow	Weir EQ, (5 logs), future inflow
Flow (m^3/s)	5.8	5.8	6.4	**6.5**
Level (m)	390.62	390.63	390.26	390.27

4 LOCAL INFLOWS

Local inflows to B.X. and Vernon Creek were simulated for present and future conditions for the primarily urban local watershed area from Swan and Kalamalka Lake into Okanagan Lake (60.3 km^2, labelled as Lower B.X. and Lower Vernon in Figure 1). This watershed area is substantially flatter and lower elevation than the watershed areas draining into Kalamalka and Swan Lakes, and hence the hydrologic drivers are quite different.

We investigated peak flows in this area by two methods. First, we used streamflow observations in the overlapping time period from approximately 1970 to 1979, where observations on WSC Gauges:

- 08NM160 – Vernon Creek near the mouth
- 08NM065 – Vernon Creek at outlet of Kalamalka Lake
- 08NM123 – B.X. Creek below Swan Lake Control Dam

were all available. We subtracted the flows on 08NM065 and 08NM123 from 08NM160 to estimate local inflows within this area. The maximum estimated mean daily local inflow was 2.6 m^3/s on October 12, 1976 at the 08NM160 gauge. While this record is quite short, not recent, and only based on daily data, it illustrated that peak inflows in the local areas of B.X. Creek have occurred throughout the year, and are not necessarily coordinated with peak flows on the mountain snowmelt and rainfall driven upper reaches of B.X. Creek and Vernon Creek.

As a second step, we extracted local flows for the area between Swan, Kalamalka and Okanagan Lake from the NHC Okanagan Mainstem Raven model. Results also indicated that peak flows along this reach can occur at many different times of the year and are not necessarily synchronized with the maximum (and larger) outflows from either Swan or Kalamalka Lake.

As the gauge record was too short for frequency analysis of observed data, we instead extracted the annual maximum peak daily inflows from the local watershed along B.X. and Vernon Creek from the Okanagan Raven. We empirically calculated design flows from the annual inflows as was done with the Kalamalka Lake outlets to Vernon Creek

We then estimated an increase to move from the daily timestep Raven model to instantaneous flows using gauge data from the deactivated 08NM160 WSC gauge. Since both upstream tributaries come

from slow responding lakes (Swan and Kalamalka), it is likely that the majority of instantaneous increases at the 08NM160 gauge are due to local stormflow within Vernon. The largest difference between annual maximum daily and maximum instantaneous flow during the freshet season was 3.2 m3/s on the 08NM160 gauge in 1980. We applied this increase directly to the design flow results from Raven for the present day (2006-2035 period).

To estimate potential local stormflow increases due to climate change, we investigated 24-hour duration IDF storm data for the City of Vernon using Western University's IDF-CC tool[2]. Ensemble median results were less than 10% increases in 24-hour 100 year peak rainfall (the highest return period supplied) for both the RCP 4.5 and 8.5 (moderate and high emissions scenarios) and for both the mid century and end of century periods. Thus, we increased the 3.2 m3/s instantaneous offset by a 10% factor of safety for both future periods (3.5 m3/s).

Local design flow results are shown in Table 4. It must be emphasized that these local inflows are only intended for use in conjunction with the design flows on B.X. and Vernon Creek stated above. Additionally, estimates of future increases in instantaneous peak flows do not take into account urban expansion of the City of Vernon. For assessment specific to an event within the City of Vernon, stormwater drainage, urban development, and shorter duration storms should be assessed.

Table 4 **Mean daily peak local inflows (m^3/s) within the City of Vernon in the NHC Okanagan Mainstem Raven model. Present estimates include an instantaneous increase factor of 3.2 m^3/s. Future periods include an instantaneous increase factor of 3.5 m^3/s. Recommended hydraulic model input is shown in bold.**

Return Period (yr)	Present (2006-2035)	Future (2041-2070)	Future (2071-2100)
10	4.8	5.2	5.5
20	5.1	5.5	5.9
100	5.8	6.3	6.8
200	6.1	6.6	**7.1**

As a final check on the total design flows within the city, we compared the total flows estimated for each reach with a standard flood frequency analysis of the WSC gauge 08NM160. The heavy influence of regulation on this gauge mean that it is not appropriate for design flow calculation; however, it can be used as a secondary reality check of other methods. A frequency analysis (using the Gumbel distribution, fitted via l-moments) to this gauge gave an instantaneous 200-year flow estimate of 16.5 m^3/s. This result lends credibility to our total estimate (combining the three methods above) of 20.9 m^3/s for the design flow into Okanagan Lake for the present day.

[2] https://www.idf-cc-uwo.ca/

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6 CLOSURE

The purpose of this report is to provide a summary of the hydrologic analysis completed for Part 2: Lower B.X. and Vernon Creek flood mapping. The design flows described here are intended for use as hydraulic inputs to the 2-d hydraulic model of Lower B.X. and Vernon Creek.

Feel free to contact the undersigned by telephone (250.851.9262) or email (jtrubilowicz@nhcweb.com) with any questions.

Sincerely,

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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 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.

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APPENDIX B

CROSSING INVENTORY

CROSSING INVENTORY

Structure	Station	NHC Xing - ID	Location	Description	Width (m)*	Height (m)**
Culvert	4616.856	XING 95	Westkal Rd. Kalamalka Lake Outlet	Concrete arch with debris rack	4.19	2.45
Bridge	4578.317	XING 96.4	Cafe, N of Westkal Rd	Wooden building platform	3.80	1.46
Bridge	4475.247	XING 97	Trestle Train Bridge, Kalamalka Lake Rd.	Wooden trestle train bridge	N/A	3.56
Culvert	4273.147	XING 100	College Way Rd.	Open bottom arch culvert.	8.80	1.17
Bridge	4158.332	XING 102	Campground, Kalamalka Lk Rd.	Wood vehicle bridge in Campground.	4.76	0.75
Bridge	4094.027	XING 103.1	Campground, Kalamalka Lk Rd.	Wood vehicle bridge in Campground.	4.76	0.93
Culvert	3836.261	XING 104	Kalamalka Lake Rd north of lake	Triple Concrete Culverts	1.40	1.40
Bridge	3654.377	XING 106	Adjacent Okanagan Skate Shop and Kalamalka Lk Rd.	Concrete bridge	5.62	0.51
Bridge	3423.115	XING 108	Adjacent Browne Rd. housing subdivision	Concrete laneway bridge	6.20	1.61
Bridge	3384.414	XING 109.1	Adjacent Browne Rd. housing subdivision	Concrete laneway bridge	8.40	1.36
Bridge	3315.935	XING 110	Adjacent Browne Rd. cul-de-sac	Concrete bridge with 16" Diam CSP pipe	3.68	1.03
Culvert	3195.824	XING 112	Browne Rd.	Triple barrel riveted CSP arch	1.78	1.12
Bridge	2994.117	XING 114	Vernon Golf and Country Club	Mason and stone bridge	3.58	0.43
Bridge	2761.935	XING 116	Vernon Golf and Country Club	Small concrete arch pedestrian bridge	2.25	1.13
Bridge	2700.969	XING 118	Vernon Golf and Country Club	Concrete arched pedestrian bridge	3.43	1.61
Bridge	2475.642	XING 120	Vernon Golf and Country Club	Small wooden golf cart crossing	2.18	1.25
Bridge	2280.252	XING 122	Adjacent Polson Dr. on Vernon Golf and Country Club	Concrete vehicle bridge	4.16	1.47
Bridge	2205.388	XING 124	South of Golf Course, rail bridge	Wooden Rail Bridge	3.60	1.43
Bridge	1466.079	XING 127	Polson Park	Wooden pedestrian walking bridge	4.79	1.51
Bridge	1353.909	XING 128.1	Polson Park	Pedestrian bridge, small concrete slab	1.72	1.39
Bridge	1108.269	XING 129.1	Polson Park	Pedestrian Bridge, wooden, arched.	1.15	1.51
Bridge	1022.389	XING 129.3	Polson Park	Pedestrian Bridge, concrete	1.73	1.15

Structure	Station	NHC Xing - ID	Location	Description	Width (m)*	Height (m)**
Bridge	989.642	XS 130	Polson Park, east of 32 St.	Small concrete pedestrian bridge	1.63	1.58
Bridge	920.9241	XS 132	Upstream of Hwy 97 Crossing, Polson Park	Wooden with concrete deck	3.68	0.79
Culvert	894.2007	XING 134	32 St. south of 25 Ave.	Single barrel arch bridge inlet, elliptical culvert	2.84	1.91
Bridge	710.7551	XS 136	34 St. south of 25 Ave.	Bridge with CSP pipes mounted below	17.90	2.19
Culvert	604.8765	XING 138	24 Ave. between 34 St. and 34A St.	Double barrel CSP arch	2.38	2.20
Culvert	506.6482	XING 140	34A St. south 24 Ave.	Double barrel CSP	2.20	2.20
Culvert	5979.23	XING 145	39 St, South of 24 Ave.	Double Barrel CSP Culvert	2.10	2.05
Bridge	5476.521	XING 148	Behind storage yard at 24 St.	Concrete bridge with lock blocks, private	8.84	1.60
Culvert	5186.983	XING 150	43 St.	Single barrel open bottom arch	5.09	2.06
Bridge	5053.388	XING 152	Vernon Water Reclamation Centre, west of 43 St.	Steel walking bridge with pipe below	1.79	2.26
Bridge	4965.482	XING 154	Vernon Water Reclamation Centre, west of 43 St.	Sewage pipe cage crossing the creek	3.91	3.32
Bridge	4849.412	XING 155.3	Southeast of 25 Ave.	Concrete Pedestrian footbridge pipe centered below (LC)	1.10	1.23
Bridge	4668.692	XING 156	West of 25 Ave.	Concrete Pedestrian Bridge	1.11	1.54
Bridge	3522.726	XING 162	Fulton Rd.	Bridge, two lanes, concrete	9.34	1.80
Culvert	1928.232	XING 169	Okanagan Landing Rd.	Single barrel arch	4.15	2.55
Culvert	84.574	XING 175	Lakeshore Rd.	Single barrel pipe arch	4.30	2.70
Culvert	2288.473	XING 57	34 St north and south of 43 Ave.	Concrete box culvert	2.30	2.30
Bridge	2158.991	XING 59	Parking entrance bridge - 32 St., south of 43 Ave.	Bridge at parking entrance	3.60	1.04
Bridge	2138.277	XING 61	Below Blue Stream Motel, 32 St. Hwy 97	Box culvert, wall platform, concrete channel	3.59	0.97
Culvert	2039.897	XING 63	42 Ave. west of 32 St.	Concrete culvert	2.20	2.20
Culvert	1950.997	XING 63.25	Upstream entrance below Vernon Lodge	Concrete box culvert	1.85	0.90
Bridge	1918.011	XING 63.5	Vernon Lodge restaurant platform	Restaurant bridge platform	16.50	1.92
Culvert	1864.705	XING 63.6	Under Vernon Lodge parking	Twin CIP concrete box culvert	1.85	0.90
Culvert	1697.572	XING 65	39 Ave.	Culvert double barrel pipe	1.83	1.83

Structure	Station	NHC Xing - ID	Location	Description	Width (m)*	Height (m)**
Bridge	1633.76	XING 67	Curling rink lot	Pedestrian bridge, concrete	1.73	0.89
Bridge	1576.884	XING 68	Performing Arts Centre	Pedestrian bridge	1.66	1.39
Bridge	1503.537	XING 69	Performing Arts Centre	Concrete pedestrian bridge	4.14	2.08
Culvert	1322.1	XING 71.1	35 Ave. and 34 St.	Single barrel arch culvert	2.50	1.50
Culvert	1247.662	XING 73.1	34 Ave. between 34 St. and 35 St.	Single barrel arch culvert	2.61	1.79
Bridge	1128.901	XING 75	33 Ave. off 35 St.	Concrete pedestrian bridge	1.14	1.17
Culvert	1045.117	XING 77	32 Ave. between 34 St. and 35 St.	Single barrel arch culvert, concrete	2.70	1.59
Culvert	966.8643	XING 79	31 Ave. and 35 St.	Single barrel arch culvert (2.45m)	2.40	1.60
Culvert	829.7076	XING 81	30 Ave. near 35 St. behind Safeway	CIP Concrete arch, CSP pipe outlet	3.80	1.63
Culvert	739.0903	XING 83	Lane south 30 Ave., west 35 St.	Single barrel CSP culvert. KWL 2016	1.80	1.80
Bridge	692.5181	XING 84.2	Along 35 St.	Sheet metal box with plastic pipe, metal grate	1.00	1.04
Bridge	585.0482	XING 84.6	North of 27 St., west of 35 St.	Wooden Pedestrian footbridge	1.15	1.28
Culvert	496.6529	XING 85	27 Ave.	Box Culvert, low pipe inside	1.73	1.40
Bridge	382.5153	XING 87	25 Ave.	Pedestrian/cycle bridge, steel.	2.60	1.58
Bridge	370.3364	XING 88	25 Ave. (north side)	Bridge, concrete, highway (two lane)	10.59	1.22
Culvert	354.9673	XING 88.2	25 Ave. (south side)	Single barrel arch culvert	2.58	1.14
Culvert	227.6941	XING 90	24 Ave., east 35 St.	Single barrel CSP pipe culvert	2.10	2.10
Culvert	140.1855	XING 92	36 St., south of 24 Ave.	Double barrel riveted CSP pipe arch	1.65	1.20

* 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.

APPENDIX C

FLOOD MAPS

Notes to Users:

1. Please refer to **Disclaimer** below.
2. Please review the associated project report before using the floodplain and hazard maps:
   a. 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.
   b. Northwest Hydraulic Consultants Ltd. (NHC). 2021. "City of Vernon Detailed Flood Mapping, Risk Analysis and Mitigation Part 2 - Lower B.X. Creek and Vernon Creek". Report prepared for the City of Vernon (CoV). 2021 August 06. NHC project number 3005032.
3. Map sheet layout shown on this map applies to 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, data, and analysis.
   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, flood fringe, and setbacks. Floodway is considered the primary flow path during a flood event. Flood fringe is considered part of the floodplain that does not contribute substantially to conveyance and where depth and velocity are generally low (< 1 m and < 1 m/s). Setbacks are provided as a recommended no-build zones to maintain flood conveyance and limit risk to development from channel hazards (e.g., high velocity flow, erosion, scour, channel migration, etc.).
6. Hazard maps depict the simulated flood depths and velocities during the design event. No freeboard has been added to flood depths. Hazard maps show modelled flood depths and velocities for both 1D and 2D areas. Low velocity zones are indicted on the hazard maps with the smallest arrow. Areas where velocity arrows are not shown, are indicative of areas where velocity has not been calculated (i.e., overbank areas simulated using 1D model).
   a. Flood depths include a generalized description of the potential consequence. These descriptions are not based on assessment of exposure or vulnerability within the study area, and therefore may not be accurate.
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 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 those indicated on the maps.
8. The calculated water level has been extended perpendicular to flow across the floodplain, thus mapping inundation of isolated areas regardless of likelihood of inundation. Isolated areas may become inundated due to dike failure, seepage, or local inflows. Site specific judgement by a Qualified Professional is required to determine validity of isolated inundation.
9. Filtering was used to remove isolated inundation areas smaller than 100 m^2 as well as isolated "islands" in the inundation extent less than 100 m^2. Isolated inundation areas larger than 100 m^2 within 40 m of adjacent inundation are mapped as inundated areas.
10. 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.
11. 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.

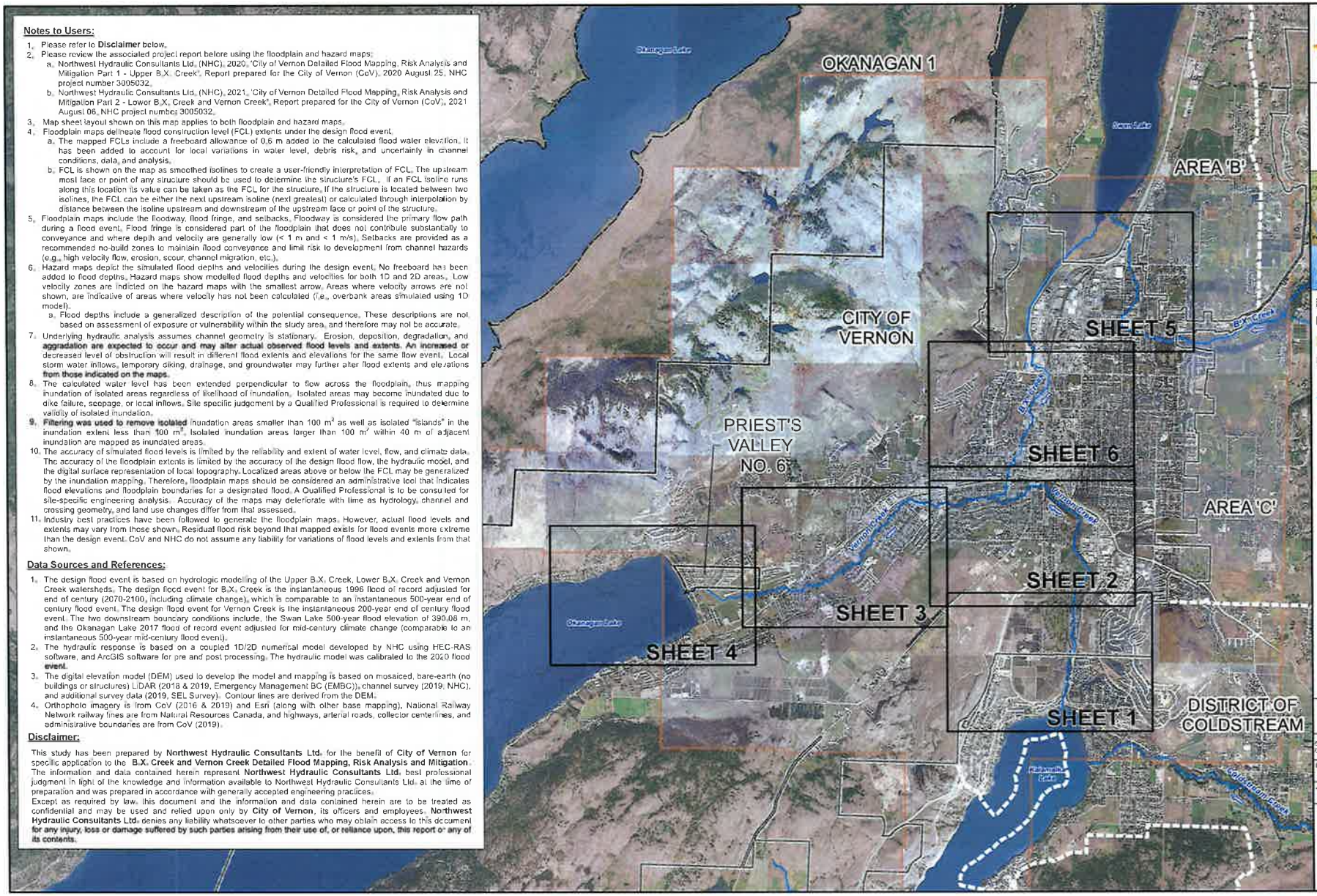
Data Sources and References:

1. The design flood event is based on hydrologic modelling of the Upper B.X. Creek, Lower B.X. Creek and Vernon Creek watersheds. The design flood event for B.X. Creek 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 design flood event for Vernon Creek is the instantaneous 200-year end of century flood event. The two downstream boundary conditions include, the Swan Lake 500-year flood elevation of 390.08 m, and the Okanagan Lake 2017 flood of record event adjusted for mid-century climate change (comparable to an instantaneous 500-year mid-century flood event).
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. The hydraulic model was calibrated to the 2020 flood event.
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 & 2019) 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 **B.X. Creek and Vernon 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.

Except as required by law, this document and the information and data contained herein are to be treated as confidential and may be used and relied upon only by **City of Vernon**, its officers and employees. **Northwest Hydraulic Consultants Ltd.** denies any liability whatsoever to other parties who may obtain access to this document **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
FLOOD MAPPING
B.X. CREEK & VERNON CREEK
SHEET INDEX

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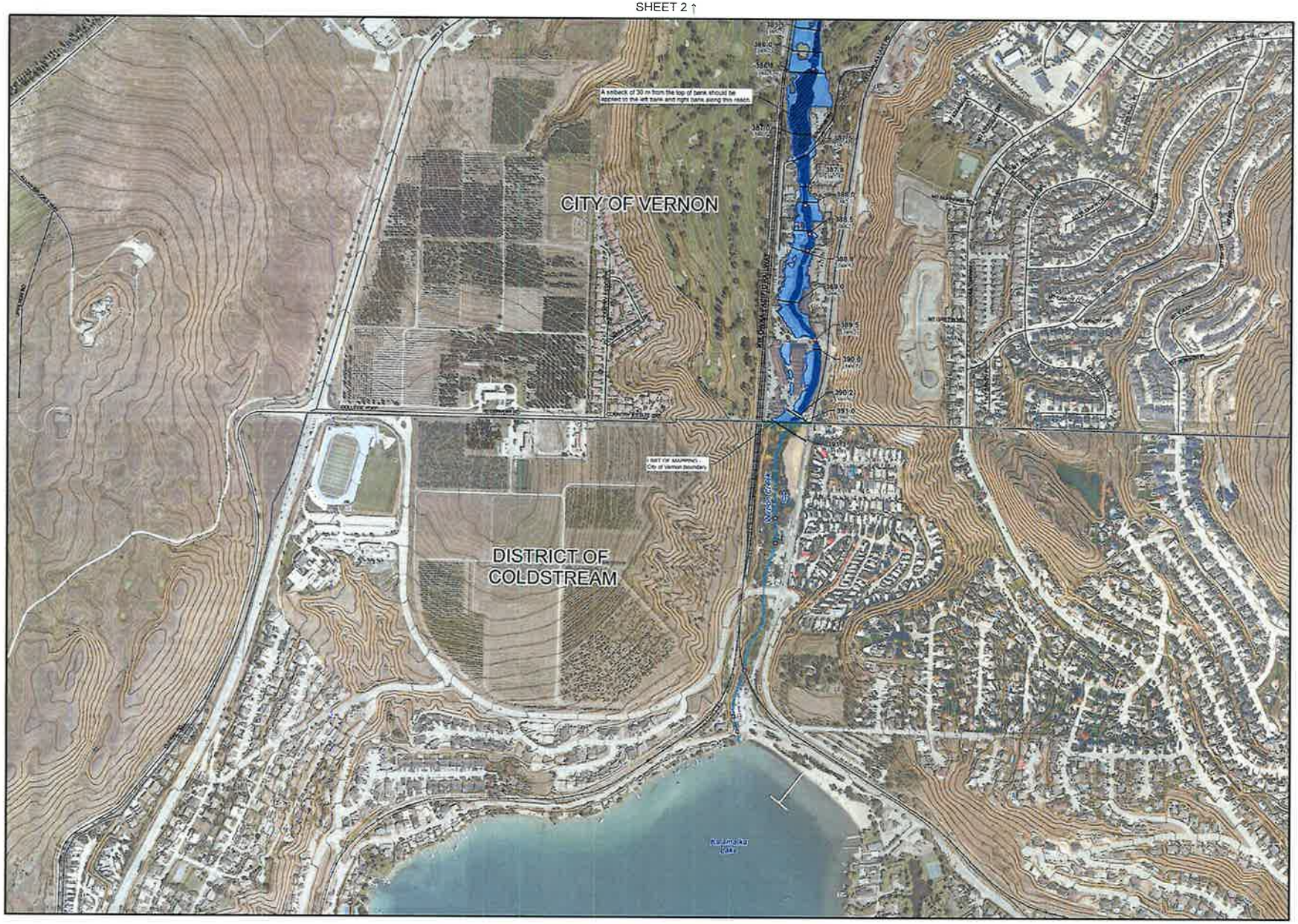
SHEET 2 ↑



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- FLOW DIRECTION
- CITY OF VERNON
- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL *Labelled with elevation in metres*
- MINOR CONTOUR AT 1 METRE
- 2019 ORTHOPHOTO EXTENT
- RAILWAY LINE
- ROAD
- STREAM
- 123.4 (123.1) FLOOD CONSTRUCTION LEVEL (FCL) *Labelled with FCL in metres CGVD2013 (FCL in CGVD28)*
- LIMIT OF MAPPING

INUNDATION EXTENT - 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*
- FLOODWAY *30 m top of bank setback*
- FLOOD FRINGE
- OKANAGAN LAKE SHORELINE ZONE *Due to wave effects an FCL of 345.5 m CGVD2013 (or 345.2 m CGVD28) should be applied to this area*

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

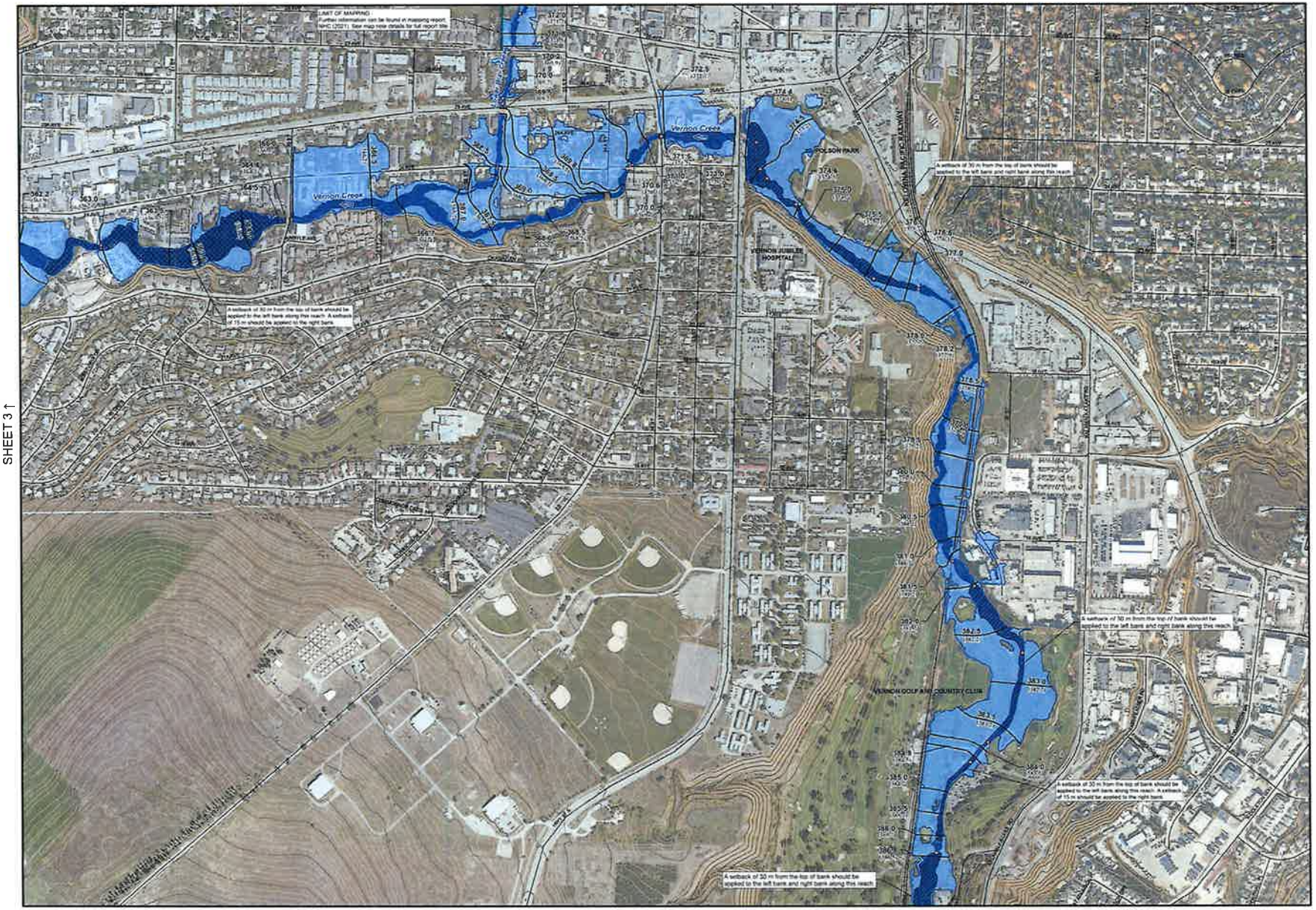
Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	13-OCT-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 1 OF 6

SHEET 6 ↑

SHEET 3 ↑



SHEET 1 ↓

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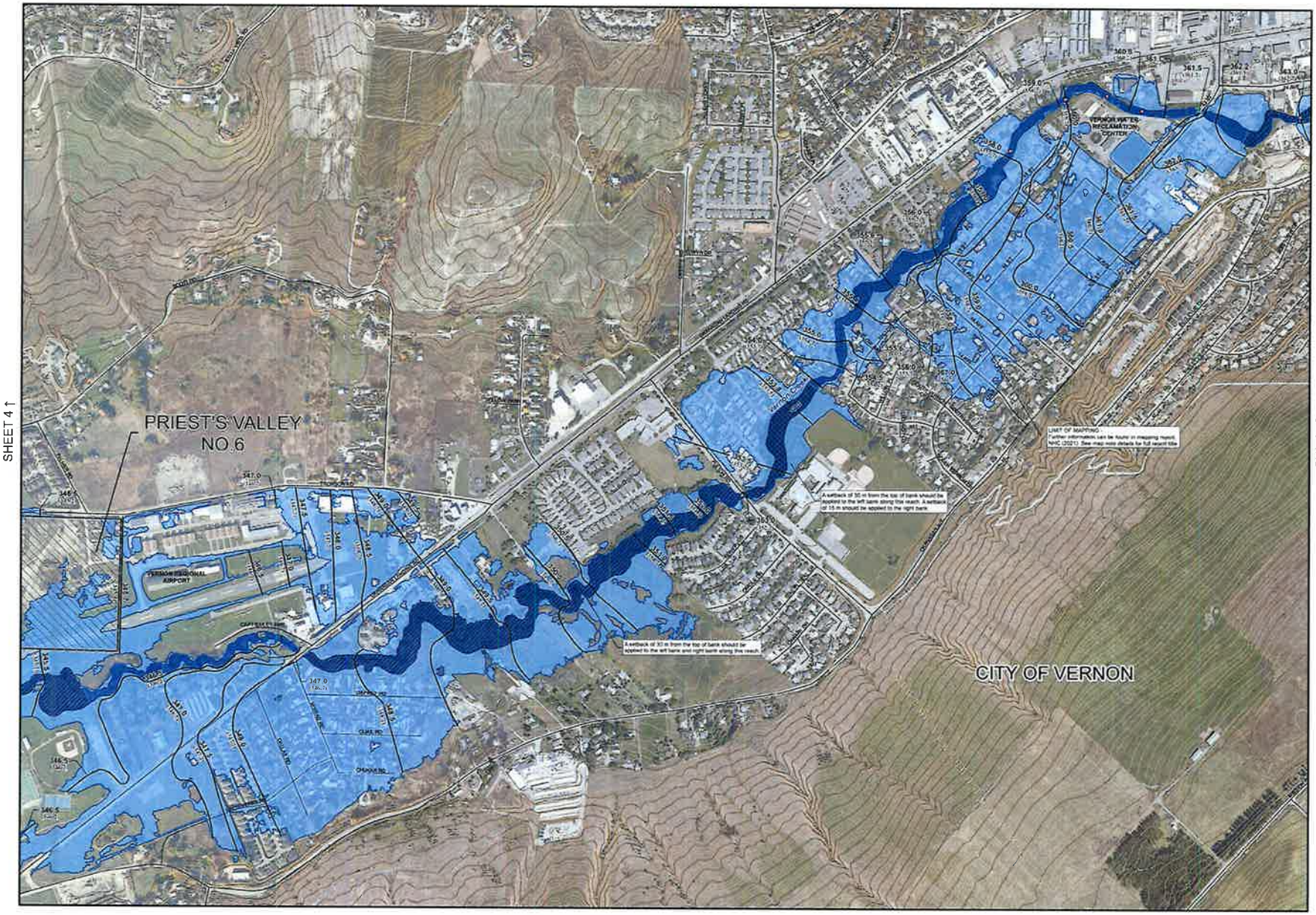
Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 2 OF 6



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PLEASE REFER TO NOTES ON SHEET INDEX

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Coordinate System: NAD 1983 CSRS UTM ZONE 11N
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Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
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CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 3 OF 6

SHEET 3 →

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- FLOW DIRECTION
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- STREAM
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- OKANAGAN LAKE SHORELINE ZONE *Due to wave effects an FCL of 346.5 m CGVD2013(or 345.2 m CGVD28) should be applied to this area*

PLEASE REFER TO NOTES ON SHEET INDEX

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Coordinate System: NAD 1983 CSRS UTM ZONE 11N
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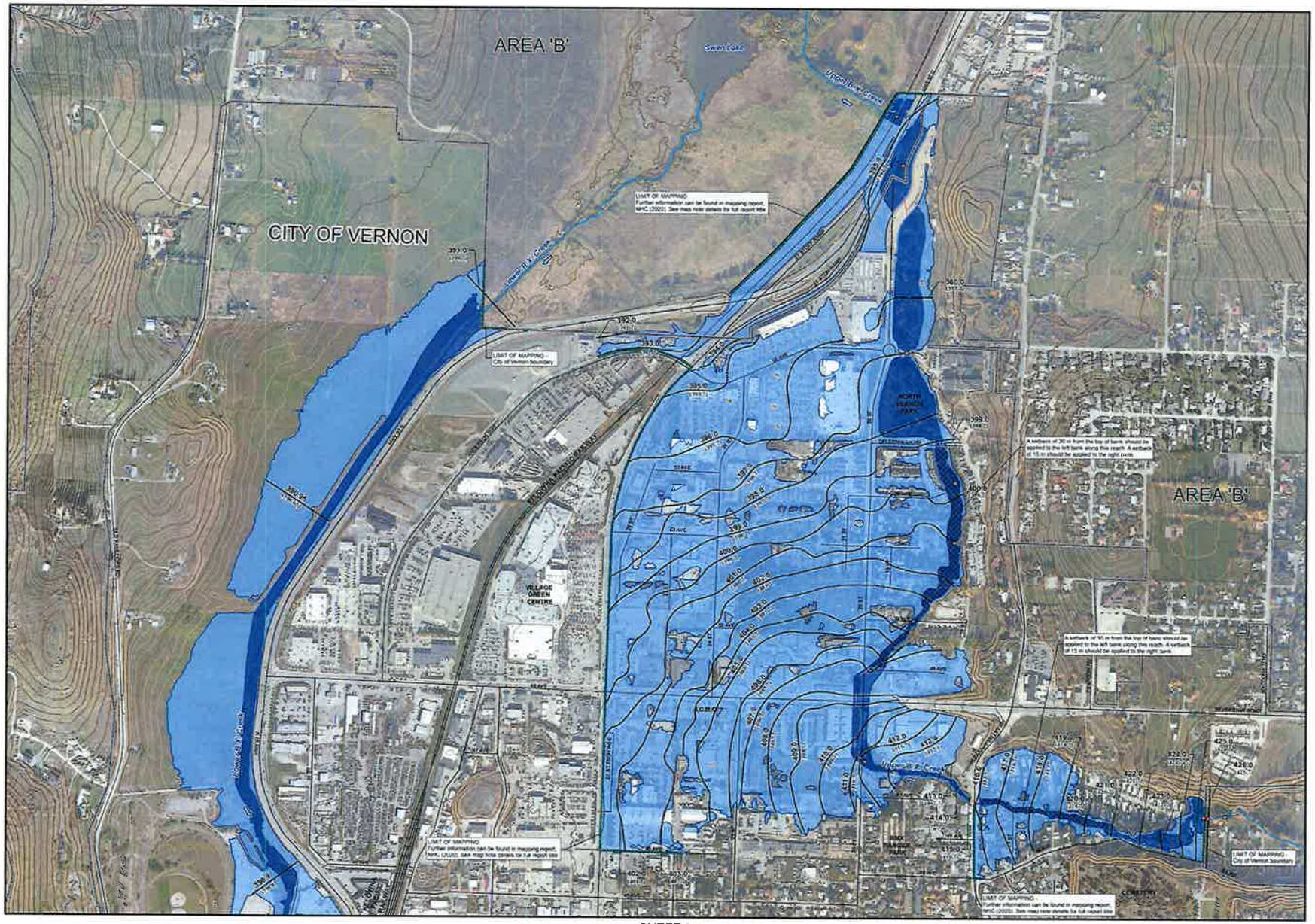
Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 4 OF 6



SHEET 6 ↓

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INUNDATION EXTENT - DESIGN EVENT WITH FREEBOARD

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PLEASE REFER TO NOTES ON SHEET INDEX

SCALE = 1:4,000
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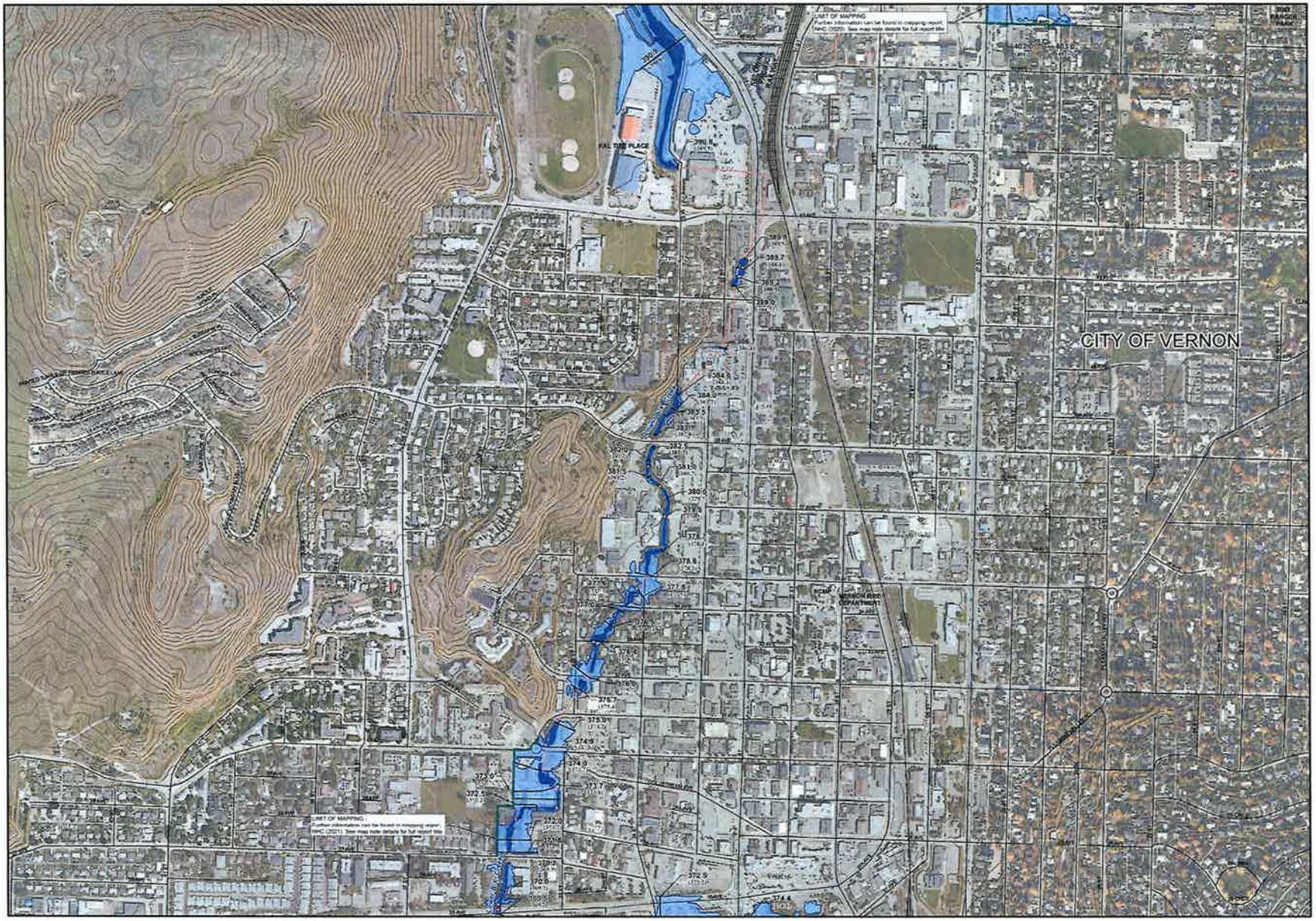
Coordinate System: NAD 1983 CSRS UTM ZONE 11N
Units: METRES, Vertical Datum: CGVD2013

Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 5 OF 6

SHEET 5 ↑



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- FLOW DIRECTION
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- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL
  Labelled with elevation in metres
- MINOR CONTOUR AT 1 METRE
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- ROAD
- STREAM
- 123.4 (121.4) FLOOD CONSTRUCTION LEVEL (FCL)
  Labelled with FCL in metres CGVD2013 (FCL in CGVD28)
- LIMIT OF MAPPING

INUNDATION EXTENT - 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
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- FLOOD FRINGE
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  Due to wave effects an FCL of 345.5 m CGVD2013(or 345.2 m CGVD28) should be applied to this area

PLEASE REFER TO NOTES ON SHEET INDEX

SCALE - 1:4,000
0 100 200 M
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Job Number	Date
3005032	12-OCT-2021

CITY OF VERNON
FLOOD MAPPING
B.X. CREEK &
VERNON CREEK
FLOODPLAIN
SHEET 6 OF 6

SHEET 2 ↓

SHEET 2 ↑

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- FLOW DIRECTION
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- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL Labeled with elevation in metres
- MINOR CONTOUR AT 1 METRE INTERVAL
- 2018 ORTHOPHOTO EXTENT
- RAILWAY LINE
- ROAD
- STREAM
- LIMIT OF MAPPING

VELOCITY AND DEPTH = DESIGN EVENT WITHOUT FREEBOARD

VELOCITY (m/s)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1.5
- 1.5 - 2.5

Areas where velocity arrows are not shown are indicative of areas where velocity has not been calculated

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, electrically failed, vehicles are commonly carried off roadways
- 1.0 - 2.0 — ground floor flooded, residents and workers evacuate
- > 2.0 (River) — 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

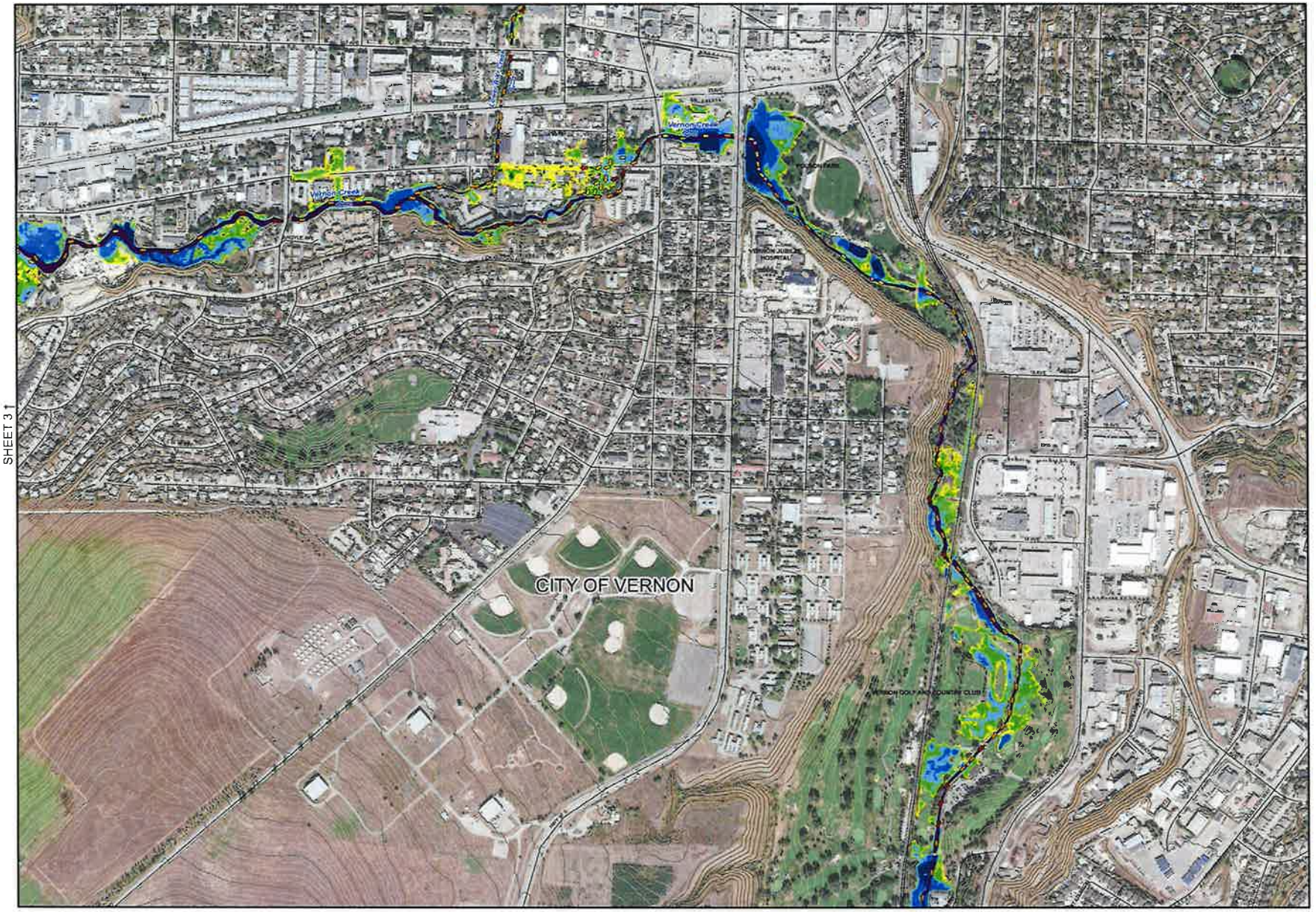
Engineer	GIS	Reviewed
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	13-OCT-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK

HAZARD MAP SHEET 1 OF 6

SHEET 6 ↑



SHEET 3 ↑

SHEET 1 ↓

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FLOW DIRECTION
CITY OF VERNON
FIRST NATIONS RESERVE
BRIDGE
CULVERT
MAJOR CONTOUR AT 5 METRE INTERVAL (Labelled with elevation in metres)
MINOR CONTOUR AT 1 METRE INTERVAL
2019 ORTHOPHOTO EXTENT
RAILWAY LINE
ROAD
STREAM
LIMIT OF MAPPING

VELOCITY AND DEPTH - DESIGN EVENT WITHOUT FREEBOARD

VELOCITY (m/s)

< 0.1	Areas where velocity arrows are not shown are indicative of areas where velocity has not been calculated.
0.1 - 0.5	
0.5 - 1.5	
1.5 - 2.5	

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; River	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
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON
FLOOD MAPPING
B.X. CREEK &
VERNON CREEK

HAZARD MAP
SHEET 2 OF 6

SHEET 4
SHEET 2
PRIEST'S VALLEY NO. 6
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VERNON REGIONAL AIRPORT
MARSHALL FIELD
VERNON WATER RECLAMATION CENTRE
CITY OF VERNON
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STREAM
LIMIT OF MAPPING
VELOCITY AND DEPTH - DESIGN EVENT
WITHOUT FREEBOARD
VELOCITY (m/s)
< 0.1
0.1 - 0.5
0.5 - 1.5
1.5 - 2.5
Areas where velocity arrows are not shown are indicative of areas where velocity has not been calculated
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; River 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 VCCM
GIS RLM
Reviewer JWT/DPM
Job Number 3005032
Date 18-AUG-2021
CITY OF VERNON
FLOOD MAPPING
B.X. CREEK &
VERNON CREEK
HAZARD MAP
SHEET 3 OF 6

CITY OF Vernon

nhc
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- FLOW DIRECTION
- CITY OF VERNON
- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL
  Labeled with elevation in metres
- MINOR CONTOUR AT 1 METRE INTERVAL
- 2019 ORTHOPHOTO EXTENT
- RAILWAY LINE
- ROAD
- STREAM
- LIMIT OF MAPPING

VELOCITY AND DEPTH - DESIGN EVENT WITHOUT FREEBOARD

VELOCITY (m/s)

< 0.1	*Areas where velocity arrows are not shown are indicative of areas where velocity has not been calculated*
0.1 - 0.5	
0.5 - 1.5	
1.5 - 2.5	

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, River	*first floor and often higher levels covered by water; residents and workers evacuate*

PLEASE REFER TO NOTES ON SHEET INDEX

SCALE - 1:4,000
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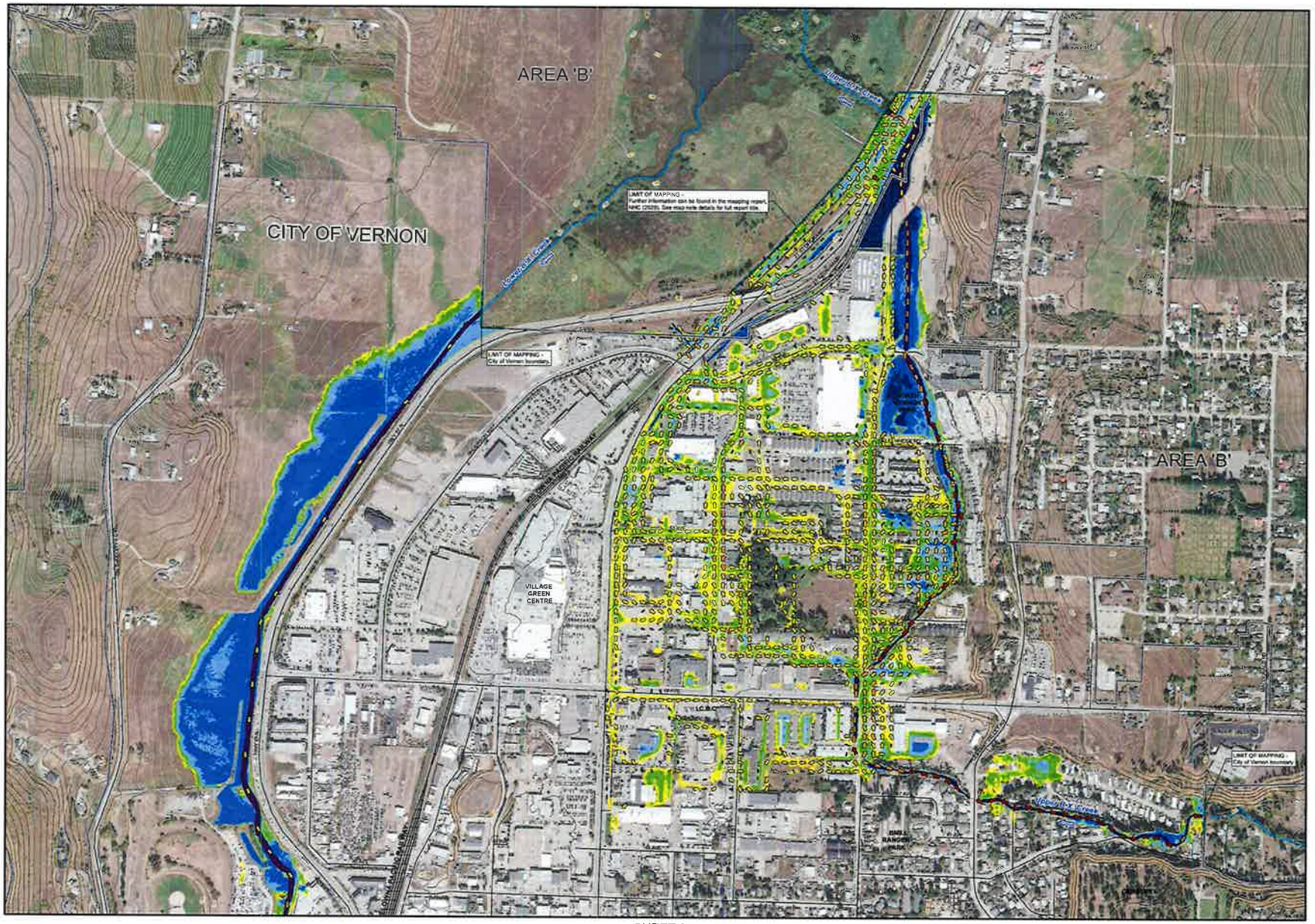
Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK

HAZARD MAP SHEET 4 OF 6



SHEET 6 ↓

CITY OF Vernon

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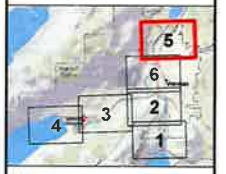


FLOW DIRECTION
CITY OF VERNON
FIRST NATIONS RESERVE
BRIDGE
CULVERT
MAJOR CONTOUR AT 5 METRE INTERVAL
Labeled with elevation in metres
MINOR CONTOUR AT 1 METRE INTERVAL
2019 ORTHOPHOTO EXTENT
RAILWAY LINE
ROAD
STREAM
LIMIT OF MAPPING

VELOCITY AND DEPTH - DESIGN EVENT WITHOUT FREEBOARD

VELOCITY (m/s)

< 0.1	Areas where velocity arrows are not shown are indicative of areas where velocity has not been calculated
0.1 - 0.5	
0.5 - 1.5	
1.5 - 2.5	

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 or moving water or driving is potentially dangerous; underground infrastructure and basements may be flooded
0.3 - 0.6	water may enter ground floor of buildings; walking or moving in still water or driving is dangerous; underground infrastructure and basements may be flooded
0.6 - 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; Red	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

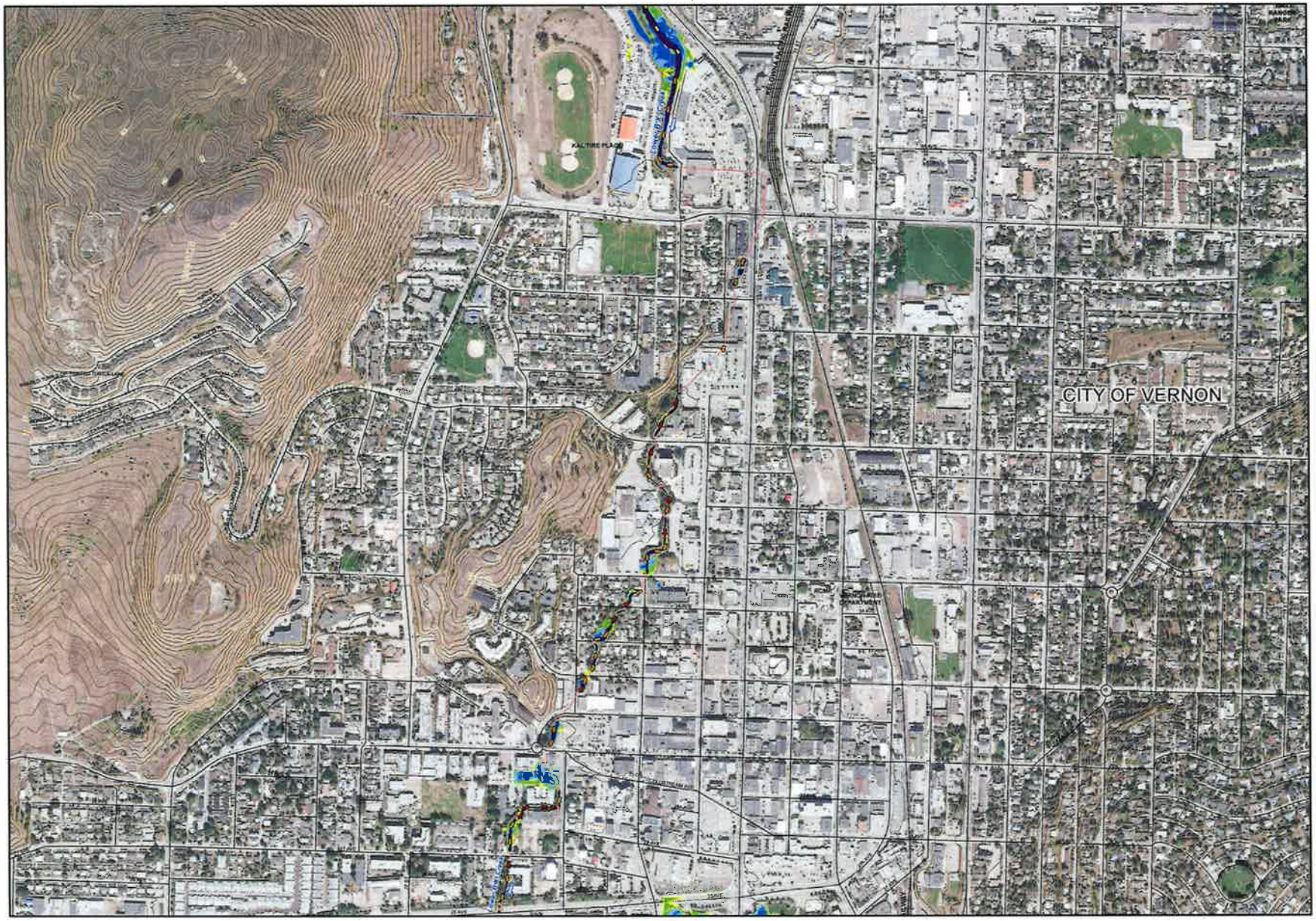
Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON
FLOOD MAPPING
B.X. CREEK &
VERNON CREEK

HAZARD MAP
SHEET 5 OF 6

SHEET 5 ↑



SHEET 2 ↓

CITY OF VERNON

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FLOW DIRECTION
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MAJOR CONTOUR AT 5 METRE INTERVAL
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LIMIT OF MAPPING

VELOCITY AND DEPTH - DESIGN EVENT WITHOUT FREEBOARD

VELOCITY (m/s)

↑ < 0.1	Areas where velocity arrows are not shown are indicative of areas where velocity has not been calculated
↑ 0.1 - 0.5	
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↑ 1.5 - 2.5	

DEPTH (m)

< 0.1	most buildings expected to be dry; underground services 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, River	first floor and often higher levels covered by water, residents and workers evacuate

PLEASE REFER TO NOTES ON SHEET INDEX

SCALE - 1:4,000
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Coordinate System: NAD 1983 CSRS UTM ZONE 11N
Units: METRES; Vertical Datum: CGVD2013

Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3006032	12-OCT-2021

CITY OF VERNON
FLOOD MAPPING
B.X. CREEK &
VERNON CREEK

HAZARD MAP
SHEET 6 OF 6

APPENDIX D

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.

- Stormwater pipe infrastructure (Tables D1 and D2) was obtained from the CoV Open Data Catalogue (City of Vernon, 2021).
- Road segment data (Tables D3 and D4) was provided to NHC by CoV.
- Building data (Tables D5 and D6) was provided to NHC by CoV.

Stormwater

Table D1 Stormwater Pipes Inundated by 20-year Flood.

Stormwater Pipes Inundated by 20-year Flood					
Pipe ID	Diameter (mm)	Material	Facility ID	Location	Length (m)
1037	900	CONC	STMM008202		208.4
1527	300	CONC	STMM001527	2424 32 St	62.8
1872	250	AC	STMM001872	3465 34 Ave	96.9
1985	350	AC	STMM001985		20.9
2002	200	HAND FRMD CONC	STMM002002	4502 15 AVE	74.7
2003	600	CONC	STMM002003	1600 45 St	40.9
2017	400	AC	STMM002017		72.5
2201	750	PVC-RIB	STMM008852	2336 39 St	13.7
3808	600	CONC	STMM003808	2413 Fulton Rd	10.9
4383	600	CONC	STMM004383	2428 Fulton Rd	7.9
4468	450	CONC	STMM004468		53.0
4624	2500	CSP	STMM004624	4284 32 St	142.1
4742	300	PVC	STMM004742	6328 Captain Bailey Pl	23.7
4748	300	PVC	STMM004748	6302 Captain Bailey Pl	21.5
4752	600	CONC	STMM004752	6293 Okanagan Landing Rd	15.2
4753	600	PVC	STMM004753	2491 Myriad Rd	100.8
4754	600	CONC	STMM004754	2451 Myriad Rd	94.6
4755	600	CONC	STMM004755	2411 Myriad Rd	57.6
4756	400	PERF-PVC	STMM004756	2349 Myriad Rd	25.5
4757	400	PERF-PVC	STMM004757	6273 Chukar Rd	59.8
4762	450	CONC	STMM004762	1723 Snowberry Rd	116.0
4763	375	CONC	STMM004763	2344 Dallas Rd	87.0
4766	300	CONC	STMM004766	6298 Osprey Rd	4.5
4767	300	CONC	STMM004767	6298 Osprey Rd	4.3
4768	300	CONC	STMM004768	2425 Myriad Rd	4.5
4769	300	CONC	STMM004769	2425 Myriad Rd	4.3
4770	300	CONC	STMM004770	2383 Myriad Rd	2.2
4772	375	CONC	STMM004772	2404 Dallas Rd	4.5
5359	600	CSP	STMM005359	6579 Okanagan Landing Rd	24.8

Stormwater Pipes Inundated by 20-year Flood					
Pipe ID	Diameter (mm)	Material	Facility ID	Location	Length (m)
5400	450	PVC	STMM005400	6496 Okanagan Landing Rd	105.2
5446	450	PVC	STMM005446	6548 Okanagan Landing Rd	120.3
5487	2300	CONC	STMM008912	4391 34 St	20.4
5493	450	PVC	STMM005493	6470 Okanagan Landing Rd	14.2
5510	300	PVC-RIB	STMM005510	3543 25 Ave	119.9
5569	300	PVC	STMM005569	6448 Okanagan Landing Rd	85.4
6198	900	CONC	STMM008229		63.7
6205	450	CSP	STMM008217	2370 39 St	91.4
6296	375	PVC-RIB	STMM006296	6900 MARSHALL RD	37.8
6367	250	PVC	STMM006367	2437 34 St	8.9
6492	600	PVC	STMM006492		22.9
6989	300	CONC	STMM006989	2447 34 St	9.9
8478	300	PVC-RIB	STMM008478	6450 OKANAGAN LANDING RD	81.4
8540	1050	CONC	STMM008540	6723 Okanagan Landing Rd	28.8
8543	900	PVC	STMM008543		177.4
8821	600	CSP	STMM008821	4504 Hwy 97	49.7
8825	3000	CSP	STMM008825		280.9
8830	1850	CSP	STMM008830	3352 39 Ave	16.1
8831	1850	CSP	STMM008831	3354 39 Ave	15.8
8832	2500	CONC	STMM008832	3481 34 St	49.1
8833	3000	CONC	STMM008833	3428 34 Ave	7.7
8834	2600	CONC	STMM008834	3483 32 Ave	26.2
8835	1800	CSP	STMM008835		56.8
8836	1800	CSP	STMM008836	2928 35 St	16.8
8838	2000	CONC	STMM008838	3569 27 Ave	22.1
8839	2600	CONC	STMM008839	3582 25 Ave	11.4
8844	1800	CSP	STMM008844	469 Browne Rd	11.5
8845	1800	CSP	STMM008845	467 Browne Rd	11.6
8846	1800	CSP	STMM008846	467 Browne Rd	10.7
8847	3100	CMP	STMM008847	2451 32 St	29.7
8848	2100	CSP	STMM008848	3404 24 Ave	18.0
8849	2150	CSP	STMM008849	2332 34A St	12.2
8850	2200	CSP	STMM008850	2337 39 St	19.2
8851	2200	CSP	STMM008851	2339 39 St	19.2
8853	2400	CSP	STMM008853	6287 Okanagan Landing Rd	12.4
8854	4000	CSP	STMM008854	2701 Lakeshore Rd	16.7
8897	250	PVC	STMM008897	3565 27 Ave	10.2
8913	300	CSP	STMM008913	6578 Okanagan Landing Rd	5.4
9035	250	CMP	STMM009035	2404 34A St	78.1
9036	250	CMP	STMM009036	2367 34A St	63.4

Stormwater Pipes Inundated by 20-year Flood					
Pipe ID	Diameter (mm)	Material	Facility ID	Location	Length (m)
9073	300	PVC	STMM009073		18.2
9169	600	PVC	STMM009169	2453 32 St	4.7
9180	1800	CONC	STMM009180		31.0
9185	1800	CONC	STMM009185		39.3
9209	600	AC	STMM009209	2453 32 St	7.6
9331	250	PVC	STMM009331		26.8

Table D2 Stormwater Pipes Inundated by Design Flood.

Stormwater Pipes Inundated by Design Flood					
Pipe ID	Diameter (mm)	Material	Facility ID	Location	Length (m)
1037	900	CONC	STMM008202		208.4
1468	200	VIT	STMM001468		86.3
1476	450	AC	STMM009024	2469 32 St	9.0
1527	300	CONC	STMM001527	2424 32 St	62.8
1589	200	VIT	STMM009039	3554 24 Ave	31.4
1589	200	VIT	STMM009038	3532 24 Ave	34.8
1593	200	VIT	STMM001593	3504 24 Ave	58.4
1645	250	AC	STMM001645	3802 24 Ave	95.2
1646	250	AC	STMM008214	3874 24 Ave	93.0
1872	250	AC	STMM001872	3465 34 Ave	96.9
1920	200	TILE	STMM001920	1651 43 St	220.9
1927	200	TILE	STMM001927	1626 43 St	34.5
1981	250	AC	STMM001981	1842 44 St	106.7
1982	250	AC	STMM001982	4450 18 Ave	99.4
1983	350	AC	STMM001983	1768 45 St	76.3
1984	350	AC	STMM001984	1614 45 ST	47.1
1985	350	AC	STMM001985		20.9
1992	200	AC	STMM008317	1654 44 St	79.2
2002	200	HAND FRMD CONC	STMM002002	4502 15 AVE	74.7
2003	600	CONC	STMM002003	1600 45 St	40.9
2017	400	AC	STMM002017		72.5
2149	200	TILE	STMM002149	2218 43 St	106.7
2150	300	AC	STMM008942	2320 43 St	26.9
3808	600	CONC	STMM003808	2413 Fulton Rd	10.9
4383	600	CONC	STMM004383	2428 Fulton Rd	7.9
4468	450	CONC	STMM004468		53.0
4499	500	CSP	STMM004499	3463 48 Ave	123.9
4500	500	CSP	STMM004500	3461 48 Ave	124.7
4624	2500	CSP	STMM004624	4284 32 St	142.1
4742	300	PVC	STMM004742	6328 Captain Bailey Pl	23.7
4748	300	PVC	STMM004748	6302 Captain Bailey Pl	21.5
4752	600	CONC	STMM004752	6293 Okanagan Landing Rd	15.2
4753	600	PVC	STMM004753	2491 Myriad Rd	100.8
4754	600	CONC	STMM004754	2451 Myriad Rd	94.6

Stormwater Pipes Inundated by Design Flood					
Pipe ID	Diameter (mm)	Material	Facility ID	Location	Length (m)
4755	600	CONC	STMM004755	2411 Myriad Rd	57.6
4756	400	PERF-PVC	STMM004756	2349 Myriad Rd	25.5
4757	400	PERF-PVC	STMM004757	6273 Chukar Rd	59.8
4762	450	CONC	STMM004762	1723 Snowberry Rd	116.0
4763	375	CONC	STMM004763	2344 Dallas Rd	87.0
4764	300	CONC	STMM004764		33.0
4766	300	CONC	STMM004766	6298 Osprey Rd	4.5
4767	300	CONC	STMM004767	6298 Osprey Rd	4.3
4768	300	CONC	STMM004768	2425 Myriad Rd	4.5
4769	300	CONC	STMM004769	2425 Myriad Rd	4.3
4770	300	CONC	STMM004770	2383 Myriad Rd	2.2
4772	375	CONC	STMM004772	2404 Dallas Rd	4.5
4811	250	PVC-RIB	STMM004811	6993 Cummins Rd	79.4
4812	375	PVC-RIB	STMM004812	6984 Cummins Rd	47.7
4814	250	PVC-RIB	STMM004814	6949 Cummins Rd	81.7
4816	200	PVC-RIB	STMM004816	6936 Cummins Rd	13.6
4817	250	PVC-RIB	STMM004817	6999 Cummins Rd	9.4
4818	250	PVC-RIB	STMM004818	6999 Cummins Rd	13.8
5359	600	CSP	STMM005359	6579 Okanagan Landing Rd	24.8
5400	450	PVC	STMM005400	6496 Okanagan Landing Rd	105.2
5446	450	PVC	STMM005446	6548 Okanagan Landing Rd	120.3
5487	2300	CONC	STMM008912	4391 34 St	20.4
5493	450	PVC	STMM005493	6470 Okanagan Landing Rd	14.2
5510	300	PVC-RIB	STMM005510	3543 25 Ave	119.9
5569	300	PVC	STMM005569	6448 Okanagan Landing Rd	85.4
6053	250	PVC	STMM006053	6944 Marshall Rd	5.0
6054	250	PVC	STMM006054	6945 Marshall Rd	14.4
6055	250	PVC	STMM006055	6900 MARSHALL RD	96.9
6056	250	PVC	STMM006056	6900 MARSHALL RD	9.0
6198	900	CONC	STMM008229		63.7
6296	375	PVC-RIB	STMM006296	6900 MARSHALL RD	37.8
6367	250	PVC	STMM006367	2437 34 St	8.9
6380	250	PVC	STMM006380	1902 44 St	22.7
6381	250	PVC	STMM006381	4389 19 Ave	26.4
6492	600	PVC	STMM006492		22.9
6989	300	CONC	STMM006989	2447 34 St	9.9
8478	300	PVC-RIB	STMM008478	6450 OKANAGAN LANDING RD	81.4
8540	1050	CONC	STMM008540	6723 Okanagan Landing Rd	28.8
8543	900	PVC	STMM008543		177.4
8603	600	CONC	STMM008603		3.1
8607	250	PVC	STMM008607		42.1

Stormwater Pipes Inundated by Design Flood					
Pipe ID	Diameter (mm)	Material	Facility ID	Location	Length (m)
8608	250	PVC	STMM008608		3.0
8628	450	PVC	STMM008628		7.1
8635	375	PVC	STMM008635		7.5
8636	375	PVC	STMM008636		23.0
8821	600	CSP	STMM008821	4504 Hwy 97	49.7
8825	3000	CSP	STMM008825		280.9
8829	350	PVC	STMM008829	3359 39 Ave	13.2
8830	1850	CSP	STMM008830	3352 39 Ave	16.1
8831	1850	CSP	STMM008831	3354 39 Ave	15.8
8832	2500	CONC	STMM008832	3481 34 St	49.1
8833	3000	CONC	STMM008833	3428 34 Ave	7.7
8834	2600	CONC	STMM008834	3483 32 Ave	26.2
8835	1800	CSP	STMM008835		56.8
8836	1800	CSP	STMM008836	2928 35 St	16.8
8838	2000	CONC	STMM008838	3569 27 Ave	22.1
8839	2600	CONC	STMM008839	3582 25 Ave	11.4
8844	1800	CSP	STMM008844	469 Browne Rd	11.5
8845	1800	CSP	STMM008845	467 Browne Rd	11.6
8846	1800	CSP	STMM008846	467 Browne Rd	10.7
8847	3100	CMP	STMM008847	2451 32 St	29.7
8848	2100	CSP	STMM008848	3404 24 Ave	18.0
8849	2150	CSP	STMM008849	2332 34A St	12.2
8850	2200	CSP	STMM008850	2337 39 St	19.2
8851	2200	CSP	STMM008851	2339 39 St	19.2
8853	2400	CSP	STMM008853	6287 Okanagan Landing Rd	12.4
8854	4000	CSP	STMM008854	2701 Lakeshore Rd	16.7
8911	600	CSP	STMM008911	4579 Hwy 97	34.4
8913	300	CSP	STMM008913	6578 Okanagan Landing Rd	5.4
9035	250	CMP	STMM009035	2404 34A St	78.1
9036	250	CMP	STMM009036	2367 34A St	63.4
9072	250	PVC	STMM009072		53.7
9073	300	PVC	STMM009073		18.2
9074	250	PVC	STMM009074		4.1
9171	600	PVC	STMM009171	2471 32 St	4.5
9172	600	PVC	STMM009172	2467 32 St	6.2
9177	600	PVC	STMM009177	2461 32 St	11.1
9180	1800	CONC	STMM009180		31.0
9185	1800	CONC	STMM009185		39.3
9209	600	AC	STMM009209	2453 32 St	7.6
9331	250	PVC	STMM009331		26.8
1037	900	CONC	STMM008202		208.4
1468	200	VIT	STMM001468		86.3
1476	450	AC	STMM009024	2469 32 St	9.0
1527	300	CONC	STMM001527	2424 32 St	62.8
1589	200	VIT	STMM009039	3554 24 Ave	31.4
1589	200	VIT	STMM009038	3532 24 Ave	34.8

Stormwater Pipes Inundated by Design Flood					
Pipe ID	Diameter (mm)	Material	Facility ID	Location	Length (m)
1593	200	VIT	STMM001593	3504 24 Ave	58.4
1645	250	AC	STMM001645	3802 24 Ave	95.2
1646	250	AC	STMM008214	3874 24 Ave	93.0
1872	250	AC	STMM001872	3465 34 Ave	96.9
1920	200	TILE	STMM001920	1651 43 St	220.9
1927	200	TILE	STMM001927	1626 43 St	34.5
1981	250	AC	STMM001981	1842 44 St	106.7
1982	250	AC	STMM001982	4450 18 Ave	99.4
1983	350	AC	STMM001983	1768 45 St	76.3
1984	350	AC	STMM001984	1614 45 ST	47.1
1985	350	AC	STMM001985		20.9
1992	200	AC	STMM008317	1654 44 St	79.2
2002	200	HAND FRMD CONC	STMM002002	4502 15 AVE	74.7
2003	600	CONC	STMM002003	1600 45 St	40.9
2017	400	AC	STMM002017		72.5
2149	200	TILE	STMM002149	2218 43 St	106.7
2150	300	AC	STMM008942	2320 43 St	26.9
3808	600	CONC	STMM003808	2413 Fulton Rd	10.9
4383	600	CONC	STMM004383	2428 Fulton Rd	7.9
4468	450	CONC	STMM004468		53.0
4499	500	CSP	STMM004499	3463 48 Ave	123.9
4500	500	CSP	STMM004500	3461 48 Ave	124.7
4624	2500	CSP	STMM004624	4284 32 St	142.1
4742	300	PVC	STMM004742	6328 Captain Bailey Pl	23.7
4748	300	PVC	STMM004748	6302 Captain Bailey Pl	21.5
4752	600	CONC	STMM004752	6293 Okanagan Landing Rd	15.2
4753	600	PVC	STMM004753	2491 Myriad Rd	100.8
4754	600	CONC	STMM004754	2451 Myriad Rd	94.6
4755	600	CONC	STMM004755	2411 Myriad Rd	57.6

Roads

Table D3 Road Segments Inundated by 20-year Flood.

Road Segments Inundated by 20-year Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
Vernon Roads												
1	10410	CHUKAR RD	MYRIAD RD	EOP	LOCAL	<Null>	2	TRDS010410	7.0	0.1	0.1	147.8
2	10420	QUAIL RD	MYRIAD RD	CUL DE SAC	LOCAL	<Null>	2	TRDS010420	8.5	0.4	0.1	250.3
3	10430	OSPREY RD	MYRIAD RD	EOP	LOCAL	<Null>	2	TRDS010430	6.0	0.9	0.1	324.6
4	50070	ROW NE OF WILLOW BAY	WILLOW DR	VERNON CREEK	SROW	<Null>	0	TRDS050070	5.0	0.6	0.2	94.4
5	4390	33 AVE	35 ST	34 ST	LOCAL	<Null>	2	TRDS004390	9.5	0.1	0.0	181.0
6	1950	24 AVE	34A ST	34 ST	LOCAL	BUS	2	TRDS001950	10.1	0.6	0.1	154.8
7	4880	34A ST	EOP (S)	24 AVE	LOCAL	<Null>	2	TRDS004880	8.0	0.3	0.1	68.8
8	4890	34A ST	24 AVE	24A AVE	LOCAL	<Null>	2	TRDS004890	8.5	0.2	0.1	105.9
9	51440	ROW (SEWER) CNR	POLSON PARK	BROWNE RD	SROW	<Null>	0	TRDS051440	5.0	0.4	0.1	1363.4
10	51920	ROW 307 BROWNE RD	BROWNE RD	CREEK	SROW	<Null>	0	TRDS051920	5.0	0.6	0.4	73.0
11	51940	ROW AT 307 KAL LAKE RD	KAL LAKE RD	<Null>	SROW	<Null>	0	TRDS051940	5.0	0.8	0.5	124.2
12	51950	ROW @ 407 BROWNE RD	BROWNE RD	<Null>	SROW	<Null>	0	TRDS051950	5.0	1.0	0.3	93.5
13	51960	ROW @ 112 KAL LAKE RD	<Null>	<Null>	SROW	<Null>	0	TRDS051960	5.0	0.4	0.1	106.0
14	10390	SNOWBERRY RD	OKANAGAN AVE	DALLAS RD	LOCAL	<Null>	2	TRDS010390	8.8	0.5	0.1	410.5
15	10395	SNOWBERRY RD	DALLAS RD	MYRIAD RD	LOCAL	<Null>	2	TRDS010395	7.0	0.5	0.2	125.7
16	10380	DALLAS RD	SNOWBERRY RD	OKANAGAN LANDING RD	LOCAL	<Null>	2	TRDS010380	6.0	0.7	0.2	243.8

Road Segments Inundated by 20-year Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
17	10385	DALLAS RD	CUL DE SAC	SNOWBERRY RD	LOCAL	<Null>	2	TRDS010385	8.1	0.4	0.2	110.6
18	10405	MYRIAD RD	SNOWBERRY RD	CHUKAR RD	LOCAL	<Null>	2	TRDS010405	7.0	0.3	0.1	57.9
19	10400	MYRIAD RD	OKANAGAN LANDING RD	OSPREY RD	LOCAL	<Null>	2	TRDS010400	7.0	0.6	0.2	105.1
20	10401	MYRIAD RD	OSPREY RD	QUAIL RD	LOCAL	<Null>	2	TRDS010401	7.0	0.7	0.2	117.2
21	10403	MYRIAD RD	QUAIL RD	SNOWBERRY RD	LOCAL	<Null>	2	TRDS010403	7.0	0.3	0.1	81.2
22	9657	OKANAGAN LANDING RD	CAPTAIN BAILEY WAY	TRONSON RD	ARTERIAL	BUS	2	TRDS009657	13.8	0.6	0.4	562.5
23	9653	OKANAGAN LANDING RD	DALLAS RD	MYRIAD RD	ARTERIAL	BUS	2	TRDS009653	11.0	0.2	0.1	140.0
24	9655	OKANAGAN LANDING RD	MYRIAD RD	CAPTAIN BAILEY WAY	ARTERIAL	BUS	2	TRDS009655	10.0	2.6	1.2	89.4
25	9820	TRONSON RD	PALMER RD	SCOTT RD (W)	COLLECTOR	<Null>	2	TRDS009820	9.0	0.8	0.3	506.5
26	10360	LAKESHORE RD	CUMMINS RD (N)	TRONSON RD	LOCAL	BUS	2	TRDS010360	6.5	3.1	1.7	607.0
27	9690	CUMMINS RD	OKANAGAN LANDING RD	MARSHALL RD	LOCAL	<Null>	2	TRDS009690	11.0	0.2	0.1	265.1
28	9695	CUMMINS RD	MARSHALL RD	EOP (N)	LOCAL	<Null>	2	TRDS009695	10.5	0.4	0.1	226.9
29	53390	SROW NW OF 15 AVE	15 AVE	<Null>	SROW	<Null>	0	TRDS053390	5.0	0.5	0.2	93.2
30	9645	OKANAGAN LANDING RD	CUMMINS RD	APOLLO RD	COLLECTOR	BUS	2	TRDS009645	11.5	0.1	0.1	269.7
31	54230	WESTKAL RD	EOP	EOP	SROW	<Null>	0	TRDS054230	5.0	1.0	0.3	973.1
32	7150	BROWNE RD	CNR CROSSING	KALAMALKA LAKE RD	LOCAL	<Null>	2	TRDS007150	6.0	0.8	0.3	360.0

Road Segments Inundated by 20-year Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
33	54725	OKANAGAN LANDING RD	OKANAGAN AVE	6545 OKANAGAN LANDING RD	ARTERIAL	BUS	2	TRDS054725	12.0	1.0	0.2	414.2
34	54750	TRONSON RD	6800 BLK TRONSON RD	SCOTT RD	COLLECTOR	BUS	2	TRDS054750	9.0	0.3	0.1	375.2
35	10365	LAKESHORE RD	MARHSHALL RD	CUMMINS RD (N)	LOCAL	BUS	2	TRDS010365	7.5	0.5	0.1	478.7
36	54730	OKANAGAN LANDING RD	6545 OKANAGAN LANDING RD	DALLAS RD	ARTERIAL	BUS	2	TRDS054730	12.8	0.8	0.1	416.7
Priest's Valley 6 Roads												
2	389470	Lakeshore Rd	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.10	0.04	30.6
3	389471	Lakeshore Rd	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.52	0.18	195.0
4	389472	Lakeshore Rd	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.13	0.06	73.9
5	389473	Lakeshore Rd	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.31	0.09	265.6

Table D4 Road Segments Inundated by Design Flood.

Road Segments Inundated by Design Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
Vernon Roads												
1	10800	MARSHALL RD	CUMMINS RD	EOP (E)	LOCAL	<Null>	2	TRDS010800	8.1	0.3	0.1	108.7
2	10410	CHUKAR RD	MYRIAD RD	EOP	LOCAL	<Null>	2	TRDS010410	7.0	0.2	0.1	147.8
3	10420	QUAIL RD	MYRIAD RD	CUL DE SAC	LOCAL	<Null>	2	TRDS010420	8.5	0.5	0.1	250.3
4	10430	OSPREY RD	MYRIAD RD	EOP	LOCAL	<Null>	2	TRDS010430	6.0	1.0	0.2	324.6
5	50320	ROW ACROSS VGCC NOT REGISTERED	COUNTRY CLUB ESTATES	BROWNE RD	SROW	<Null>	0	TRDS050320	5.0	1.2	0.3	651.5
6	50270	ROW NE OF 18 AVE	45 ST	25 AVE	SROW	<Null>	0	TRDS050270	5.0	0.8	0.2	188.1
7	50240	ROW SW OF 18 AVE	45 ST	72M NORTH WEST	SROW	<Null>	0	TRDS050240	5.0	0.7	0.3	88.0
8	50070	ROW NE OF WILLOW BAY	WILLOW DR	VERNON CREEK	SROW	<Null>	0	TRDS050070	5.0	0.8	0.3	94.4
9	4390	33 AVE	35 ST	34 ST	LOCAL	<Null>	2	TRDS004390	9.5	0.4	0.3	181.0
10	4960	35 AVE	34 ST	33 ST	COLLECTOR	BUS	2	TRDS004960	10.5	0.1	0.1	165.8
12	4840	34 ST	34 AVE	35 AVE	COLLECTOR	<Null>	2	TRDS004840	11.5	0.4	0.1	106.7
13	950	18 AVE	43 ST	42A ST	LOCAL	<Null>	2	TRDS000950	8.5	0.2	0.1	102.3
14	940	18 AVE	44 ST	45 ST	LOCAL	<Null>	2	TRDS000940	8.8	0.5	0.2	127.0
15	6710	44 ST	18 AVE	19 AVE	LOCAL	<Null>	2	TRDS006710	9.2	0.4	0.1	155.0
16	6700	44 ST	16 AVE	CUL DE SAC	LOCAL	<Null>	2	TRDS006700	10.5	0.4	0.1	163.6
17	5700	38 ST	OKANAGAN AVE	END OF GRAVEL (N)	LOCAL	<Null>	2	TRDS005700	2.6	1.5	1.0	132.6
18	5980	39 ST	24 AVE	25 AVE	COLLECTOR	<Null>	2	TRDS005980	12.0	0.2	0.1	148.3
19	5370	36 ST	CUL DE SAC	24 AVE	LOCAL	<Null>	2	TRDS005370	12.9	0.8	0.2	119.5
20	2150	25 AVE	37 ST	35 ST	ARTERIAL	<Null>	4	TRDS002150	21.3	0.8	0.3	415.8
21	10810	MARSHALL RD	LAKESHORE RD	CUMMINS RD	LOCAL	<Null>	2	TRDS010810	7.5	0.4	0.2	152.9

Road Segments Inundated by Design Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
22	2290	25 AVE	34 ST	HWY 97 (32 ST)	ARTERIAL	<Null>	4	TRDS002290	20.1	0.4	0.1	254.3
23	1950	24 AVE	34A ST	34 ST	LOCAL	BUS	2	TRDS001950	10.1	0.8	0.2	154.8
24	4880	34A ST	EOP (S)	24 AVE	LOCAL	<Null>	2	TRDS004880	8.0	0.4	0.2	68.8
25	4890	34A ST	24 AVE	24A AVE	LOCAL	<Null>	2	TRDS004890	8.5	0.3	0.1	105.9
27	52420	ROW E OF 34 ST (25 AVE TO S)	25 AVE	CREEK	SROW	<Null>	0	TRDS052420	5.0	2.1	0.6	111.9
28	1940	24 AVE	39 ST	36 ST	LOCAL	TBAN	2	TRDS001940	8.0	0.4	0.1	435.9
29	1945	24 AVE	36 ST	34A ST	LOCAL	TBAN	2	TRDS001945	8.5	0.8	0.1	338.8
30	5970	39 ST	ARGYLE AVE	24 AVE	COLLECTOR	<Null>	2	TRDS005970	12.5	1.9	0.6	193.7
31	51350	POLSON PARK LANE 2	<Null>	<Null>	PRIVATE	<Null>	1	TRDS051350	5.0	0.3	0.1	115.2
32	51360	POLSON PARK LANE 4	<Null>	<Null>	PRIVATE	<Null>	1	TRDS051360	5.0	0.5	0.1	254.9
33	51440	ROW (SEWER) CNR	POLSON PARK	BROWNE RD	SROW	<Null>	0	TRDS051440	5.0	0.6	0.2	1363.4
34	51820	EASEMENT W OF KAL LAKE RD	KAL LAKE RD	CITY LIMITS	SROW	<Null>	0	TRDS051820	5.0	1.3	1.0	106.8
35	51920	ROW 307 BROWNE RD	BROWNE RD	CREEK	SROW	<Null>	0	TRDS051920	5.0	0.7	0.5	73.0
36	51940	ROW AT 307 KAL LAKE RD	KAL LAKE RD	<Null>	SROW	<Null>	0	TRDS051940	5.0	0.9	0.5	124.2
37	51950	ROW @ 407 BROWNE RD	BROWNE RD	<Null>	SROW	<Null>	0	TRDS051950	5.0	1.1	0.3	93.5
38	51960	ROW @ 112 KAL LAKE RD	<Null>	<Null>	SROW	<Null>	0	TRDS051960	5.0	0.6	0.2	106.0
39	51990	EASEMENT COUNTRY ESTATES N	COUNTRY ESTATES PL	<Null>	SROW	<Null>	0	TRDS051990	5.0	0.7	0.4	1333.4

Road Segments Inundated by Design Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
40	52100	REC CENTRE ROW	35 AVE	REC CENTRE	SROW	<Null>	0	TRDS052100	5.0	0.7	0.3	121.0
41	52140	OFFSHORE SEWER INT ROW	<Null>	<Null>	SROW	<Null>	0	TRDS052140	5.0	0.3	0.1	2938.7
42	10390	SNOWBERRY RD	OKANAGAN AVE	DALLAS RD	LOCAL	<Null>	2	TRDS010390	8.8	0.6	0.2	410.5
43	10395	SNOWBERRY RD	DALLAS RD	MYRIAD RD	LOCAL	<Null>	2	TRDS010395	7.0	0.5	0.2	125.7
44	10380	DALLAS RD	SNOWBERRY RD	OKANAGAN LANDING RD	LOCAL	<Null>	2	TRDS010380	6.0	0.8	0.2	243.8
45	10385	DALLAS RD	CUL DE SAC	SNOWBERRY RD	LOCAL	<Null>	2	TRDS010385	8.1	0.5	0.2	110.6
46	10405	MYRIAD RD	SNOWBERRY RD	CHUKAR RD	LOCAL	<Null>	2	TRDS010405	7.0	0.4	0.1	57.9
47	10400	MYRIAD RD	OKANAGAN LANDING RD	OSPREY RD	LOCAL	<Null>	2	TRDS010400	7.0	0.7	0.2	105.1
48	10401	MYRIAD RD	OSPREY RD	QUAIL RD	LOCAL	<Null>	2	TRDS010401	7.0	0.7	0.2	117.2
49	10403	MYRIAD RD	QUAIL RD	SNOWBERRY RD	LOCAL	<Null>	2	TRDS010403	7.0	0.4	0.2	81.2
50	9657	OKANAGAN LANDING RD	CAPTAIN BAILEY WAY	TRONSON RD	ARTERIAL	BUS	2	TRDS009657	13.8	0.7	0.4	562.5
51	9653	OKANAGAN LANDING RD	DALLAS RD	MYRIAD RD	ARTERIAL	BUS	2	TRDS009653	11.0	0.2	0.1	140.0
52	9655	OKANAGAN LANDING RD	MYRIAD RD	CAPTAIN BAILEY WAY	ARTERIAL	BUS	2	TRDS009655	10.0	2.6	0.8	89.4
53	9820	TRONSON RD	PALMER RD	SCOTT RD (W)	COLLECTOR	<Null>	2	TRDS009820	9.0	1.0	0.5	506.5
54	10360	LAKESHORE RD	CUMMINS RD (N)	TRONSON RD	LOCAL	BUS	2	TRDS010360	6.5	3.4	0.5	607.0

Road Segments Inundated by Design Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
55	9690	CUMMINS RD	OKANAGAN LANDING RD	MARSHALL RD	LOCAL	<Null>	2	TRDS009690	11.0	0.3	0.1	265.1
56	9695	CUMMINS RD	MARSHALL RD	EOP (N)	LOCAL	<Null>	2	TRDS009695	10.5	0.7	0.2	226.9
57	650	16 AVE	44 ST	43 ST	LOCAL	<Null>	2	TRDS000650	8.5	0.1	0.0	125.8
58	653	16 AVE	45 ST	44 ST	LOCAL	<Null>	2	TRDS000653	8.5	0.2	0.1	126.7
59	655	16 AVE	EOP (N)	45 ST	LOCAL	<Null>	2	TRDS000655	8.5	0.6	0.3	69.5
60	6595	43 ST	17 AVE	18 AVE	COLLECTOR	BUS	2	TRDS006595	8.5	0.3	0.1	173.2
61	6600	43 ST	19 AVE	24 AVE	COLLECTOR	BUS	2	TRDS006600	9.7	1.8	0.3	389.9
62	6605	43 ST	18 AVE	19 AVE	COLLECTOR	BUS	2	TRDS006605	8.5	0.1	0.0	151.2
63	6800	45 ST	16 AVE	18 AVE	LOCAL	<Null>	2	TRDS006800	9.0	0.4	0.1	249.8
64	53330	EASEMENT 43 ST AND OK AVE	43 ST	OKANAGAN AVE	SROW	<Null>	0	TRDS053330	5.0	0.4	0.2	178.6
65	53390	SROW NW OF 15 AVE	15 AVE	<Null>	SROW	<Null>	0	TRDS053390	5.0	0.7	0.2	93.2
66	53410	SROW SW OF WILLOW BAY	WILLOW DR	<Null>	SROW	<Null>	0	TRDS053410	5.0	0.6	0.4	60.4
67	7070	34 ST	43 AVE	45 AVE	LOCAL	<Null>	2	TRDS007070	10.9	0.7	0.2	463.0
68	9645	OKANAGAN LANDING RD	CUMMINS RD	APOLLO RD	COLLECTOR	BUS	2	TRDS009645	11.5	0.1	0.0	269.7
70	54230	WESTKAL RD	EOP	EOP	SROW	<Null>	0	TRDS054230	5.0	1.2	0.5	973.1
71	7150	BROWNE RD	CNR CROSSING	KALAMALKA LAKE RD	LOCAL	<Null>	2	TRDS007150	6.0	1.1	0.2	360.0
72	51810	ROW W OF KAL LAKE RD	CITY LIMITS	RAILWAY	SROW	<Null>	0	TRDS051810	5.0	1.1	0.8	242.7
73	54725	OKANAGAN LANDING RD	OKANAGAN AVE	6545 OKANAGAN LANDING RD	ARTERIAL	BUS	2	TRDS054725	12.0	1.0	0.2	414.2

Road Segments Inundated by Design Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
74	54750	TRONSON RD	6800 BLK TRONSON RD	SCOTT RD	COLLECTOR	BUS	2	TRDS054750	9.0	0.5	0.3	375.2
75	55412	34 ST	24 AVE	25 AVE	ARTERIAL	BUS	2	TRDS055412	11.0	2.1	0.9	193.2
76	55606	LANE S OF 19 AVE (W OF 43 ST)	EOP (S)	19 AVE	LANE	<Null>	1	TRDS055606	4.0	0.5	0.2	92.6
77	1150	19 AVE	44 ST	43 ST	LOCAL	<Null>	2	TRDS001150	9.2	0.3	0.1	127.6
78	51240	LANE S OF 30 AVE	35 ST	EOP	LANE	<Null>	1	TRDS051240	5.0	0.4	0.1	189.7
79	10365	LAKESHORE RD	MARHSHALL RD	CUMMINS RD (N)	LOCAL	BUS	2	TRDS010365	7.5	0.7	0.1	478.7
80	55963	SRW BLUE JAY MAIN	<Null>	<Null>	SROW	<Null>	<Null>	TRDS055963	5.0	0.4	0.2	1738.2
81	54730	OKANAGAN LANDING RD	6545 OKANAGAN LANDING RD	DALLAS RD	ARTERIAL	BUS	2	TRDS054730	12.8	0.9	0.1	416.7
Priest's Valley 6 Roads												
1	526371	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.2	0.1	5.9
2	333002	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.2	0.1	72.5
3	333006	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.3	0.1	70.1
4	389466	LAKESHORE RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.5	0.2	47.4
5	389469	LAKESHORE RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.4	0.3	147.6
6	389470	LAKESHORE RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.8	0.4	30.6
7	389471	LAKESHORE RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.4	0.2	195.0
8	389472	LAKESHORE RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.6	0.2	73.9

Road Segments Inundated by Design Flood												
Object ID	Section ID	Road Name	From Street	To Street	Road Function Class	Bus Route	Number of Lanes	Facility ID	Road Width (m)	Max Flood Depth (m)	Mean Flood Depth (m)	Road Segment Length (m)
9	389473	LAKESHORE RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.2	0.1	265.6
10	389477	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.5	0.2	184.2
11	389478	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.3	0.1	204.9
12	389482	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.1	0.0	59.1
13	389485	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.1	0.1	242.7
14	389486	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.5	0.2	191.2
15	389489	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.6	0.3	80.4
16	389490	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.4	0.1	36.7
17	1630205	TRONSON RD	N/A	N/A	LOCAL	N/A	2	N/A	N/A	0.1	0.1	280.9

Buildings

Table D5 Buildings Inundated by 20-year Flood.

Buildings Inundated by 20-year Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
Vernon							
1	0.050	386.79	PARKS & OPEN SPACE	TEMPORARY LODGING	0	0.5%	1.8%
2	0.003	384.99	COMMUNITY COMMERCIAL	NURSING HOME	121	0.1%	0.4%
3	0.174	348.77	RESIDENTIAL - LOW DENSITY	NURSING HOME	70	1.1%	6.2%
6	0.121	359.99	PUBLIC & INSTITUTIONAL	INSTITUTIONAL	0	2.8%	15.1%
7	0.481	361.16	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	GENERAL SERVICES (GOV)	0	12.7%	104.8%
8	0.441	361.28	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	GENERAL SERVICES (GOV)	0	12.3%	101.0%
9	0.005	361.43	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	LIGHT INDUSTRY	0	1.1%	0.1%
10	0.408	370.46	PARKS & OPEN SPACE	DUPLEX	2	37.0%	45.0%
11	0.193	369.13	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	15.6%	19.6%
14	0.050	369.08	RESIDENTIAL - MEDIUM DENSITY	RETAIL TRADE	0	2.3%	5.9%
15	0.050	370.38	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
16	0.285	369.81	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	20.9%	17.9%
17	0.398	369.57	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	32.5%	34.1%
18	0.180	369.58	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	20.2%	17.2%
19	0.050	370.55	RESIDENTIAL - HIGH DENSITY	NURSING HOME	75	4.0%	21.6%
22	0.523	385.83	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	34.6%	37.0%
23	0.214	387.79	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	15.7%	20.4%
24	0.497	387.69	PARKS & OPEN SPACE	TEMPORARY LODGING	0	8.3%	32.1%
26	0.050	387.90	PARKS & OPEN SPACE	TEMPORARY LODGING	0	0.5%	1.8%
27	0.050	377.53	PARKS & OPEN SPACE	RETAIL TRADE	0	2.3%	5.9%
28	0.072	344.45	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	19.5%	16.5%
29	0.048	343.82	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	19.3%	16.3%

Buildings Inundated by 20-year Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
30	0.071	343.87	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	19.5%	16.5%
32	0.361	343.85	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	31.9%	33.3%
34	0.212	343.62	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	20.4%	17.4%
35	0.251	343.81	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	20.6%	17.6%
36	0.447	343.62	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	33.3%	35.3%
37	0.243	343.98	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	20.6%	17.6%
39	0.157	343.75	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.0%	17.0%
69	0.230	347.35	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.5%	17.5%
72	0.183	347.47	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	30.8%	17.4%
73	0.213	347.59	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.4%	17.4%
74	0.166	347.38	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	29.0%	16.1%
76	0.166	347.64	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	29.0%	16.1%
77	0.017	347.61	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	12.9%	4.4%
78	0.072	347.52	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	18.8%	8.7%
79	0.083	347.62	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	19.9%	9.5%
86	0.031	347.94	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	14.3%	5.4%
93	0.175	347.96	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	30.0%	16.8%
94	0.152	347.74	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	27.4%	15.0%
95	0.082	347.81	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	19.8%	9.4%
100	0.137	347.81	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	25.8%	13.8%
102	0.395	347.62	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.6%	77.5%
103	0.686	347.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	105.5%	112.7%
104	0.801	347.17	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	109.3%	118.4%
105	0.462	347.79	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	91.8%	82.4%
106	0.546	347.53	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	97.0%	88.4%
107	0.803	347.41	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	109.3%	118.5%
108	0.080	347.71	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	19.7%	9.3%

Buildings Inundated by 20-year Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
109	0.236	347.49	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	36.6%	21.6%
110	0.063	347.82	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	17.8%	7.9%
111	0.105	347.67	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	22.3%	11.2%
112	0.220	347.57	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	34.8%	20.3%
113	0.238	347.44	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	36.8%	21.8%
114	0.315	347.44	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82.7%	71.8%
115	0.317	347.47	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82.8%	71.9%
117	0.272	347.57	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	40.4%	24.4%
118	0.264	347.63	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	39.6%	23.8%
119	0.432	347.56	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	89.9%	80.2%
120	0.305	347.35	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82.0%	71.0%
122	0.344	347.46	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	84.5%	73.8%
124	0.452	347.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	91.1%	81.6%
126	0.214	347.42	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	34.2%	19.9%
127	0.361	347.34	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85.5%	75.1%
128	0.244	347.39	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	37.4%	22.2%
129	0.620	346.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	103.3%	109.5%
130	0.548	347.04	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	97.2%	88.6%
131	0.587	346.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	99.6%	91.4%
132	0.572	347.22	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	98.7%	90.3%
133	0.565	347.60	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	98.2%	89.8%
134	0.565	347.04	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	98.2%	89.8%
136	0.479	347.22	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	92.9%	83.6%
139	0.284	347.27	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	41.7%	25.4%
140	0.363	347.25	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85.6%	75.2%
143	0.071	346.92	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.5%	16.5%
145	0.159	347.08	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.0%	17.0%
146	0.168	346.98	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.1%	17.1%
148	0.200	346.66	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.3%	17.3%
155	0.049	346.88	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
157	0.053	346.49	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
160	0.214	346.17	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.4%	17.4%

Buildings Inundated by 20-year Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
162	0.180	346.16	RESIDENTIAL - LOW DENSITY	CHURCHES	0	5.9%	48.4%
164	0.218	345.85	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.4%	17.4%
165	0.109	346.01	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.7%	16.7%
166	0.162	346.01	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.1%	17.1%
175	0.164	347.25	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.1%	17.1%
176	0.168	347.12	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.1%	17.1%
177	0.135	347.21	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.9%	16.9%
178	0.099	347.19	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.6%	16.6%
179	0.206	347.00	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	20.3%	17.3%
188	0.125	347.29	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.8%	16.8%
189	0.228	347.15	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.5%	17.5%
190	0.216	347.10	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.4%	17.4%
199	0.033	347.59	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.2%	16.2%
200	0.185	347.40	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.2%	17.2%
201	0.176	347.34	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.2%	17.2%
202	0.147	347.36	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.0%	17.0%
203	0.041	347.36	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
204	0.584	347.49	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	99.4%	91.2%
205	0.365	347.72	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85.8%	75.4%
209	0.006	348.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	11.7%	3.5%
212	0.002	348.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	11.2%	3.2%
219	0.435	347.54	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	33.1%	35.0%
221	0.223	353.09	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	35.1%	20.5%
222	0.205	352.89	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33.2%	19.2%
223	0.222	352.94	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	35.0%	20.5%
224	0.230	352.95	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	35.9%	21.1%
225	0.095	353.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	21.3%	10.5%
226	0.114	353.19	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.3%	11.9%
227	0.181	352.93	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	30.6%	17.2%
228	0.224	352.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	35.2%	20.6%
229	0.236	352.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	36.5%	21.6%
230	0.330	352.96	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	83.6%	72.8%

Buildings Inundated by 20-year Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
231	0.206	352.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33.3%	19.2%
232	0.054	353.32	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	16.8%	7.2%
233	0.084	353.24	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	20.1%	9.6%
234	0.122	353.20	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	24.2%	12.6%
235	0.122	353.19	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	24.2%	12.6%
236	0.111	353.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.0%	11.7%
237	0.545	352.29	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	34.9%	37.5%
238	0.088	354.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	20.5%	9.9%
240	0.138	355.02	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	26.0%	13.9%
241	0.122	354.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	24.2%	12.6%
242	0.050	357.32	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.2%	14.0%
243	0.193	355.89	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.6%	19.6%
244	0.356	354.99	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.5%	43.5%
245	0.348	354.54	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.3%	43.3%
246	0.350	354.51	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.3%	43.3%
247	0.043	354.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	15.6%	6.4%
248	0.499	354.14	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	94.1%	85.0%
249	0.029	354.51	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	14.2%	5.3%
250	0.401	369.11	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	32.6%	34.2%
253	0.327	362.35	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	LIGHT INDUSTRY	0	19.4%	38.0%
254	0.328	362.64	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	TRIPLEX/QUAD	4	34.7%	42.7%
255	0.050	375.61	PARKS & OPEN SPACE	RETAIL TRADE	0	2.3%	5.9%
256	0.050	377.06	PARKS & OPEN SPACE	SINGLE FAMILY DWELLING	1	19.3%	16.3%
257	0.318	373.97	RESIDENTIAL - HIGH DENSITY	MULTI-DWELLINGS, 50 +	56	34.4%	42.4%
260	0.552	361.08	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	GENERAL SERVICES (GOV)	0	13.4%	111.5%
261	0.083	361.67	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	LIGHT INDUSTRY	0	3.2%	2.5%
262	0.210	347.84	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33.7%	19.5%
263	0.136	347.38	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	25.7%	13.7%
265	0.560	360.14	PUBLIC & INSTITUTIONAL	INSTITUTIONAL	0	15.5%	100.4%

Buildings Inundated by 20-year Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
Priest's Valley 6							
266	0.081	344.11	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	19.8%	9.4%
267	0.081	344.08	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	19.8%	9.4%
268	0.190	343.95	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	31.6%	18.0%
269	0.190	343.90	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	31.6%	18.0%
270	0.112	344.08	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.1%	11.8%
271	0.292	343.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	42.6%	26.0%
272	0.183	343.90	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	30.8%	17.4%
273	0.136	343.93	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	25.7%	13.7%
274	0.159	343.95	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	28.2%	15.5%
275	0.042	344.08	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	15.5%	6.3%
276	0.058	344.17	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	17.2%	7.5%
277	0.026	344.23	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	13.9%	5.1%
278	0.086	344.10	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	20.3%	9.7%
279	0.088	344.13	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	20.5%	9.9%
280	0.281	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	41.5%	25.2%
281	0.194	343.90	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	32.0%	18.3%
282	0.476	343.76	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	92.6%	83.3%
283	0.225	343.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	35.3%	20.7%
284	0.203	343.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33.0%	19.0%
286	0.598	343.56	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	100.3%	92.2%
288	0.104	344.12	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	22.2%	11.2%
289	0.915	343.49	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	103.0%	100.0%
290	0.274	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	40.6%	24.6%
291	0.115	343.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.4%	12.0%
292	0.110	343.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.0%	11.7%
293	0.105	344.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	22.4%	11.3%
294	0.153	344.00	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	27.6%	15.1%
295	0.187	343.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	31.2%	17.7%
296	0.139	343.82	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	26.0%	13.9%
297	0.237	343.82	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	36.6%	21.6%
298	0.141	343.89	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	26.2%	14.1%

Buildings Inundated by 20-year Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
299	0.090	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	20.8%	10.1%
300	0.111	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.0%	11.7%
301	0.286	343.76	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	42.0%	25.6%
302	0.180	343.85	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	30.5%	17.2%
303	0.209	344.00	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33.6%	19.4%
304	0.321	343.70	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	83.0%	72.2%
305	0.154	343.89	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	27.6%	15.1%
306	0.192	343.89	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	31.8%	18.1%
307	0.311	343.72	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82.4%	71.4%
308	0.341	343.71	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	84.2%	73.6%
309	0.356	343.73	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85.2%	74.7%
310	0.254	343.73	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	38.5%	23.0%
311	0.113	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.2%	11.9%
312	0.238	343.84	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	36.8%	21.8%
313	0.796	343.42	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	109.1%	118.2%
314	0.683	343.37	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	105.4%	112.6%
315	0.819	343.48	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	109.9%	119.3%
316	0.807	343.42	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	109.5%	118.7%
317	0.681	343.43	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	105.4%	112.5%
318	0.578	343.73	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	99.0%	90.7%
319	0.434	343.82	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	90.1%	80.3%
320	0.145	343.94	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	26.7%	14.4%
321	0.692	343.72	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	105.7%	113.0%
322	0.229	343.94	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	35.8%	21.1%
323	0.260	344.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	39.1%	23.5%
324	0.167	343.97	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	29.0%	16.1%
325	0.213	344.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	34.1%	19.8%
326	0.010	344.10	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	12.1%	3.8%
327	0.033	344.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	14.6%	5.6%

Table D6 Buildings Inundated by Design Flood.

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
Vernon							
2	0.314	390.47	COMMUNITY COMMERCIAL	RETAIL TRADE	0	19.2%	58.5%
3	0.084	386.79	PARKS & OPEN SPACE	TEMPORARY LODGING	0	0.8%	3.0%
4	0.042	384.99	COMMUNITY COMMERCIAL	NURSING HOME	121	1.0%	5.2%
9	0.234	348.77	RESIDENTIAL - LOW DENSITY	NURSING HOME	70	5.4%	29.2%
18	0.126	361.12	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.4%	17.0%
19	0.016	360.82	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.1%	12.6%
21	0.115	360.47	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.4%	16.5%
24	0.021	359.84	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.1%	12.8%
25	0.258	359.52	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.8%	22.2%
26	0.399	359.26	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	36.8%	44.8%
27	0.416	359.20	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	37.3%	45.3%
28	0.385	359.27	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	36.4%	44.4%
29	0.161	359.82	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.5%	18.3%
31	0.064	359.98	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.2%	14.5%
32	0.166	360.07	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.5%	18.6%
33	0.168	360.13	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.5%	18.6%
34	0.254	360.29	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.8%	22.0%
36	0.056	360.69	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.2%	14.2%
37	0.228	360.58	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.7%	21.0%
38	0.313	360.27	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	34.2%	42.2%
42	0.049	359.91	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.2%	13.9%
43	0.337	359.28	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.0%	43.0%
44	0.184	359.42	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.6%	19.3%
47	0.400	359.27	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	36.8%	44.8%
50	0.146	359.61	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.0%	17.0%
51	0.247	359.49	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.8%	21.7%
52	0.271	359.35	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.9%	22.7%
55	0.184	359.70	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.6%	19.2%
56	0.276	359.41	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.8%	17.8%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
57	0.353	359.42	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	31.8%	33.1%
58	0.179	359.67	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.2%	17.2%
64	0.030	359.13	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.2%	16.2%
65	0.022	359.14	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.1%	16.1%
81	1.122	359.26	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	34.7%	48.4%
82	0.200	360.06	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.7%	19.9%
84	0.129	360.35	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.4%	17.1%
85	0.091	360.42	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.3%	15.6%
86	0.113	360.60	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.4%	16.5%
87	0.443	360.22	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	38.1%	46.1%
89	0.094	361.86	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	LIGHT INDUSTRY	0	3.5%	2.8%
96	0.330	359.99	PUBLIC & INSTITUTIONAL	INSTITUTIONAL	0	13.2%	83.8%
114	0.167	357.16	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.5%	18.6%
115	0.340	356.96	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.0%	43.0%
117	0.097	357.36	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.3%	15.8%
118	0.340	357.24	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.0%	43.0%
119	0.272	356.68	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.9%	22.7%
120	0.306	356.70	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	34.0%	42.0%
122	0.340	356.92	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.0%	43.0%
123	0.340	356.81	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.0%	43.0%
124	0.340	357.27	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.0%	43.0%
127	0.143	358.14	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.5%	17.6%
129	0.092	357.52	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.3%	15.6%
131	0.156	357.81	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.5%	18.1%
134	0.298	359.39	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	16.0%	23.7%
135	0.234	359.97	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.8%	21.2%
138	0.692	361.16	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	GENERAL SERVICES (GOV)	0	29.4%	123.1%
139	0.655	361.28	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	GENERAL SERVICES (GOV)	0	28.7%	121.2%
141	0.348	361.43	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	LIGHT INDUSTRY	0	19.7%	39.0%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
142	0.216	361.87	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	LIGHT INDUSTRY	0	6.7%	6.4%
144	0.365	372.45	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	MEDICAL OFFICE	0	13.2%	78.5%
145	0.050	372.59	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	RETAIL TRADE	0	2.3%	5.9%
146	0.120	372.46	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	RETAIL TRADE	0	4.1%	11.4%
149	0.565	370.46	PARKS & OPEN SPACE	DUPLEX	2	41.7%	49.7%
150	0.382	372.75	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	GENERAL SERVICES (GOV)	0	11.8%	95.4%
151	0.570	371.98	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	TEMPORARY LODGING	0	8.7%	34.0%
152	0.395	372.03	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	TEMPORARY LODGING	0	7.6%	29.4%
153	0.450	372.44	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	TEMPORARY LODGING	0	8.0%	30.8%
155	0.055	369.73	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	15.2%	14.1%
163	0.038	369.16	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	15.1%	13.5%
165	0.366	369.13	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	35.8%	43.8%
172	0.053	367.61	RESIDENTIAL - MEDIUM DENSITY	MULTI-DWELLINGS, 5-9	6	15.2%	14.1%
179	0.134	368.19	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	15.4%	17.3%
180	0.009	368.49	RESIDENTIAL - MEDIUM DENSITY	TRIPLEX/QUAD	4	15.0%	12.3%
182	0.053	368.47	RESIDENTIAL - MEDIUM DENSITY	TRIPLEX/QUAD	4	15.2%	14.1%
185	0.154	368.64	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	15.5%	18.1%
186	0.053	368.98	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	15.2%	14.1%
188	0.752	366.09	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	38.4%	41.9%
189	0.140	369.08	RESIDENTIAL - MEDIUM DENSITY	RETAIL TRADE	0	4.7%	13.0%
190	0.207	370.38	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	20.4%	17.4%
191	0.441	369.81	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	33.2%	35.1%
192	0.460	369.57	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	33.5%	35.6%
195	0.326	369.58	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	31.3%	32.5%
196	0.041	369.40	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
197	0.050	370.55	RESIDENTIAL - HIGH DENSITY	NURSING HOME	75	1.1%	6.2%
198	0.100	385.31	PARKS & OPEN SPACE	RETAIL TRADE	0	3.6%	9.8%
201	0.639	385.83	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	38.3%	41.4%
205	0.494	387.79	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	39.6%	47.6%
206	1.243	387.69	PARKS & OPEN SPACE	TEMPORARY LODGING	0	23.2%	69.4%
208	0.230	387.90	PARKS & OPEN SPACE	TEMPORARY LODGING	0	2.3%	8.3%
209	0.650	377.53	PARKS & OPEN SPACE	RETAIL TRADE	0	22.3%	99.8%
210	0.335	344.45	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	31.5%	32.7%
211	0.145	344.08	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	TRIPLEX/QUAD	4	15.5%	17.7%
212	0.324	343.82	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	31.3%	32.4%
214	0.415	343.87	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	32.8%	34.5%
215	0.708	343.45	PARKS & OPEN SPACE	SINGLE FAMILY DWELLING	1	39.0%	42.3%
216	0.684	343.52	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	38.7%	42.0%
219	0.325	344.10	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	31.3%	32.5%
222	0.393	343.84	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	32.4%	34.0%
223	0.604	343.64	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	35.9%	38.9%
226	0.321	343.81	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	31.3%	32.4%
227	0.464	343.71	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	33.6%	35.7%
228	0.411	343.89	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	32.7%	34.4%
229	0.210	344.04	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	20.4%	17.4%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
230	0.671	343.69	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	38.6%	41.8%
231	0.697	343.52	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	38.9%	42.1%
234	0.669	343.54	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	38.6%	41.8%
235	0.600	343.66	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	35.8%	38.8%
239	0.723	343.61	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	39.1%	42.5%
240	0.942	342.97	PARKS & OPEN SPACE	SINGLE FAMILY DWELLING	1	59.4%	53.4%
242	1.004	343.08	PARKS & OPEN SPACE	SINGLE FAMILY DWELLING	1	60.5%	54.2%
247	0.600	343.85	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	35.8%	38.8%
250	0.508	343.62	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	34.3%	36.7%
252	0.521	343.81	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	34.6%	37.0%
253	0.776	343.62	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	39.6%	43.2%
257	0.183	344.54	PARKS & OPEN SPACE	SINGLE FAMILY DWELLING	1	20.2%	17.2%
258	0.504	343.84	PARKS & OPEN SPACE	SINGLE FAMILY DWELLING	1	34.3%	36.6%
259	0.301	344.03	PARKS & OPEN SPACE	SINGLE FAMILY DWELLING	1	21.0%	18.0%
260	0.436	343.98	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	33.1%	35.0%
261	0.054	344.33	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	19.4%	16.4%
263	0.077	344.38	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	19.5%	16.5%
265	0.113	344.36	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	19.7%	16.7%
266	0.041	344.11	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.1%	13.6%
267	0.055	345.06	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.2%	14.2%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
268	0.583	343.75	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	35.6%	38.4%
269	0.531	343.75	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	40.7%	48.7%
272	0.120	344.17	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.4%	16.7%
273	0.146	344.05	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.5%	17.7%
274	0.194	343.97	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.6%	19.6%
275	0.239	343.84	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.8%	21.4%
314	0.367	347.35	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	32.0%	33.4%
318	0.250	347.47	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	38.0%	22.7%
319	0.023	347.80	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	13.5%	4.8%
320	0.245	347.59	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.6%	17.6%
321	0.198	347.38	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	32.4%	18.6%
323	0.198	347.64	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	32.5%	18.6%
324	0.050	347.61	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	16.4%	6.9%
326	0.106	347.52	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	22.5%	11.4%
327	0.102	347.62	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	22.0%	11.0%
334	0.070	347.94	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	18.6%	8.5%
341	0.207	347.96	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33.4%	19.3%
342	0.184	347.74	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	30.9%	17.5%
343	0.113	347.81	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.2%	11.9%
349	0.174	347.81	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	29.9%	16.7%
352	0.429	347.62	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	89.7%	80.0%
353	0.737	347.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	107.2%	115.3%
354	0.851	347.17	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	110.9%	120.9%
355	0.512	347.79	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	94.9%	85.9%
357	0.595	347.53	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	100.1%	92.0%
360	0.853	347.41	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	111.0%	121.0%
361	0.113	347.71	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23.2%	11.9%
362	0.269	347.49	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	40.1%	24.2%
363	0.097	347.82	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	21.5%	10.6%
365	0.158	347.67	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	28.1%	15.4%
366	0.295	347.57	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	43.0%	26.3%
367	0.318	347.44	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82.8%	71.9%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
368	0.392	347.44	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.4%	77.3%
373	0.397	347.47	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.7%	77.6%
375	0.352	347.57	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85.0%	74.4%
378	0.313	347.63	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82.5%	71.6%
380	0.498	347.56	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	94.1%	85.0%
382	0.365	347.35	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85.8%	75.3%
384	0.396	347.46	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.7%	77.6%
387	0.498	347.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	94.1%	85.0%
391	0.251	347.42	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	38.2%	22.8%
392	0.394	347.34	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.5%	77.4%
395	0.276	347.39	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	40.9%	24.8%
396	0.680	346.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	105.3%	112.4%
397	0.607	347.04	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	100.8%	92.8%
398	0.649	346.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	104.3%	110.9%
401	0.636	347.22	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	103.9%	110.3%
402	0.630	347.60	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	103.7%	110.0%
403	0.631	347.04	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	103.7%	110.1%
406	0.546	347.22	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	97.0%	88.4%
411	0.351	347.27	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	84.9%	74.4%
412	0.430	347.25	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	89.8%	80.0%
413	0.023	347.04	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.2%	16.2%
414	0.110	347.24	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.7%	16.7%
416	0.080	347.05	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.5%	16.5%
419	0.151	346.92	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.0%	17.0%
422	0.237	347.08	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.6%	17.6%
423	0.248	346.98	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.6%	17.6%
427	0.279	346.66	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.8%	17.8%
435	0.116	346.88	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.8%	16.8%
437	0.108	346.49	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.7%	16.7%
443	0.263	346.17	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.7%	17.7%
445	0.249	346.16	RESIDENTIAL - LOW DENSITY	CHURCH	0	8.2%	63.1%
447	0.304	345.85	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	21.0%	18.0%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
448	0.167	346.01	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.1%	17.1%
449	0.237	346.01	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.6%	17.6%
458	0.202	347.25	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.3%	17.3%
459	0.206	347.12	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.4%	17.4%
460	0.169	347.21	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.1%	17.1%
461	0.136	347.19	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.9%	16.9%
462	0.220	347.00	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	20.4%	17.4%
470	0.047	347.40	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
471	0.167	347.29	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.1%	17.1%
472	0.273	347.15	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.8%	17.8%
473	0.258	347.10	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.7%	17.7%
482	0.097	347.59	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.6%	16.6%
483	0.234	347.40	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.5%	17.5%
484	0.235	347.34	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.5%	17.5%
485	0.198	347.36	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.3%	17.3%
486	0.099	347.36	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.6%	16.6%
488	0.635	347.49	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	103.8%	110.3%
491	0.429	347.72	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	89.7%	79.9%
495	0.084	348.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	20.1%	9.6%
499	0.082	348.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	19.9%	9.5%
510	0.487	347.54	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	34.0%	36.2%
512	0.134	353.41	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	25.5%	13.5%
513	0.387	353.09	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.1%	77.0%
514	0.372	352.89	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	86.2%	75.8%
515	0.392	352.94	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.4%	77.3%
516	0.404	352.95	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	88.2%	78.1%
517	0.273	353.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	40.5%	24.5%
518	0.281	353.19	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	41.4%	25.1%
519	0.349	352.93	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	84.7%	74.2%
521	0.397	352.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.7%	77.6%
522	0.413	352.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	88.8%	78.8%
523	0.512	352.96	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	94.9%	86.0%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
524	0.392	352.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87.4%	77.3%
525	0.229	353.32	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	35.8%	21.0%
526	0.262	353.24	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	39.3%	23.6%
527	0.303	353.20	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	43.8%	26.9%
529	0.306	353.19	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82.1%	71.1%
530	0.298	353.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	43.2%	26.5%
531	0.172	353.24	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	29.6%	16.5%
532	0.735	352.29	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	39.2%	42.6%
533	0.300	354.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	43.5%	26.6%
534	0.206	355.21	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33.3%	19.2%
535	0.349	355.02	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	84.8%	74.2%
536	0.311	354.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82.4%	71.5%
538	0.678	357.32	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	37.7%	41.5%
539	0.039	358.44	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
546	0.040	358.68	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
547	0.040	358.50	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
548	0.099	358.36	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.6%	16.6%
549	0.041	358.21	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.3%	16.3%
550	0.279	357.56	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.8%	17.8%
551	0.340	357.05	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	35.0%	43.0%
555	0.074	356.85	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.2%	14.9%
556	0.060	356.79	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.2%	14.3%
557	0.402	355.89	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	36.9%	44.9%
558	0.573	354.99	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	41.9%	49.9%
559	0.559	354.54	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	41.5%	49.5%
561	0.574	354.51	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	42.0%	50.0%
566	0.010	354.81	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.1%	16.1%
567	0.058	355.25	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	19.4%	16.4%
568	0.213	355.31	RESIDENTIAL - LOW DENSITY	SINGLE FAMILY DWELLING	1	20.4%	17.4%
588	0.147	353.32	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	26.9%	14.6%
589	0.122	353.34	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	24.2%	12.6%
597	0.126	354.25	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	24.7%	12.9%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
599	0.251	354.23	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	38.1%	22.7%
600	0.301	354.32	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	43.5%	26.7%
602	0.279	354.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	41.2%	24.9%
604	0.733	354.14	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	107.0%	115.1%
605	0.289	354.51	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	42.3%	25.8%
606	0.050	354.48	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	16.5%	7.0%
614	0.025	355.50	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	13.7%	5.0%
617	0.518	369.11	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	34.5%	36.9%
619	0.090	366.07	RESIDENTIAL - MEDIUM DENSITY	MULTI-DWELLINGS, 5-9	6	15.3%	15.6%
620	0.070	366.10	RESIDENTIAL - MEDIUM DENSITY	MULTI-DWELLINGS, 5-9	6	15.2%	14.7%
626	0.019	367.06	RESIDENTIAL - MEDIUM DENSITY	DUPLEX	2	15.1%	12.8%
630	0.839	362.35	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	LIGHT INDUSTRY	0	28.3%	80.0%
633	0.794	362.64	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	TRIPLEX/QUAD	4	38.8%	42.2%
637	0.462	375.61	PARKS & OPEN SPACE	RETAIL TRADE	0	21.6%	66.2%
638	0.221	377.06	PARKS & OPEN SPACE	SINGLE FAMILY DWELLING	1	20.4%	17.4%
639	0.076	377.11	RESIDENTIAL SMALL LOT - SINGLE & TWO FAMILY DWELLING	SINGLE FAMILY DWELLING	1	19.5%	16.5%
641	0.337	374.94	MIXED USE - HIGH DENSITY COMMERCIAL AND RESIDENTIAL	RETAIL TRADE	0	19.5%	59.7%
642	0.780	374.04	RESIDENTIAL - HIGH DENSITY	TEMPORARY LODGING	0	9.6%	46.4%
643	1.050	373.97	RESIDENTIAL - HIGH DENSITY	MULTI-DWELLINGS, 50 +	56	34.4%	47.9%
646	0.344	365.63	RESIDENTIAL - MEDIUM DENSITY	TRIPLEX/QUAD	4	35.2%	43.2%
647	0.209	365.86	RESIDENTIAL - MEDIUM DENSITY	TRIPLEX/QUAD	4	15.7%	20.2%
650	0.420	366.06	RESIDENTIAL - MEDIUM DENSITY	MULTI-DWELLINGS, 20 - 49	27	37.4%	45.4%
654	0.251	367.16	RESIDENTIAL - MEDIUM DENSITY	SINGLE FAMILY DWELLING	1	20.6%	17.6%
656	0.681	373.96	MIXED USE - HIGH DENSITY COMMERCIAL AND RESIDENTIAL	RETAIL TRADE	0	22.5%	101.3%
658	0.853	361.08	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	GENERAL SERVICES (GOV)	0	32.0%	131.0%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
660	0.318	361.67	LIGHT INDUSTRIAL / SERVICE COMMERCIAL	LIGHT INDUSTRY	0	19.2%	37.6%
666	0.071	358.18	RESIDENTIAL - LOW DENSITY	TRIPLEX/QUAD	4	15.2%	14.8%
670	0.267	347.84	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	39.9%	24.0%
672	0.203	347.38	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	32.9%	19.0%
677	0.572	343.81	MIXED USE - MEDIUM DENSITY COMMERCIAL AND RESIDENTIAL	SINGLE FAMILY DWELLING	1	35.4%	38.1%
678	0.760	360.14	PUBLIC & INSTITUTIONAL	INSTITUTIONAL	0	28.0%	118.4%
Priest's Valley 6							
685	0.04071	344.63	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	15%	6%
687	0.022095	344.59	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	13%	5%
688	0.345367	344.11	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85%	74%
689	0.196899	344.21	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	32%	19%
690	0.345398	344.08	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85%	74%
691	0.454742	343.95	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	91%	82%
692	0.454742	343.90	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	91%	82%
693	0.37735	344.08	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87%	76%
694	0.556305	343.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	98%	89%
695	0.44696	343.90	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	91%	81%
696	0.392242	343.93	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87%	77%
697	0.423462	343.95	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	89%	80%
698	0.306335	344.08	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82%	71%
699	0.321899	344.17	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	83%	72%
700	0.29071	344.23	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	42%	26%
701	0.056305	344.40	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	17%	7%
705	0.071838	344.32	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	19%	9%
706	0.126373	344.30	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	25%	13%
707	0.001404	344.38	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	11%	3%
711	0.350342	344.10	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85%	74%
712	0.352997	344.13	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85%	74%
713	0.546967	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	97%	88%
714	0.145477	344.33	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	27%	14%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
715	0.209351	344.29	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	34%	19%
717	0.458618	343.90	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	92%	82%
718	0.740173	343.76	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	107%	115%
719	0.489624	343.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	94%	84%
720	0.478271	343.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	93%	84%
722	0.875824	343.56	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	112%	122%
725	0.375977	344.12	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	86%	76%
726	1.19519	343.49	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	108%	106%
727	0.547211	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	97%	88%
728	0.389954	343.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87%	77%
729	0.388916	343.91	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87%	77%
730	0.388	344.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87%	77%
731	0.441467	344.00	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	91%	81%
732	0.479248	343.88	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	93%	84%
733	0.408203	343.82	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	88%	78%
734	0.508759	343.82	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	95%	86%
735	0.414551	343.89	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	89%	79%
736	0.36676	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	86%	75%
737	0.389465	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	87%	77%
738	0.57428	343.76	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	99%	90%
739	0.465698	343.85	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	92%	83%
740	0.502075	344.00	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	94%	85%
741	0.612152	343.70	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	103%	109%
742	0.447266	343.89	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	91%	81%
743	0.485779	343.89	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	93%	84%
744	0.603607	343.72	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	101%	93%
745	0.63443	343.71	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	104%	110%
746	0.649597	343.73	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	104%	111%
747	0.547699	343.73	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	97%	89%
748	0.407074	343.92	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	88%	78%
749	0.532166	343.84	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	96%	87%
750	1.082611	343.42	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	106%	103%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
751	0.966553	343.37	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	104%	101%
752	1.111145	343.48	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	106%	104%
753	1.101837	343.42	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	106%	104%
754	0.976685	343.43	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	104%	101%
755	0.874268	343.73	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	112%	122%
756	0.732849	343.82	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	107%	115%
757	0.443787	343.94	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	91%	81%
758	0.990479	343.72	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	104%	101%
759	0.523712	343.94	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	96%	87%
760	0.202576	344.09	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33%	19%
761	0.288391	344.13	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	42%	26%
762	0.40567	344.12	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	88%	78%
763	0.555115	344.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	98%	89%
764	0.461365	343.97	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	92%	82%
765	0.514984	343.93	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	95%	86%
766	0.492615	344.07	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	94%	85%
767	0.312988	344.10	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	83%	72%
768	0.305298	344.01	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82%	71%
769	0.297546	344.05	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	43%	26%
770	0.165405	344.13	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	29%	16%
771	0.220947	344.18	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	35%	20%
772	0.205383	344.10	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33%	19%
773	0.175354	344.15	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	30%	17%
774	0.161224	344.15	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	28%	16%
775	0.107056	344.20	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23%	11%
778	0.16864	344.12	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	29%	16%
779	0.296356	344.17	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	43%	26%
780	0.062714	344.33	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	18%	8%
781	0.106445	344.30	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23%	11%
785	0.187927	344.19	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	31%	18%
786	0.031677	344.33	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	14%	5%
789	0.109741	344.29	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	23%	12%

Buildings Inundated by Design Flood							
Object ID	Maximum Flood Depth (m)	Ground Floor Elevation (m)	OCP Designation	Damage Curve	Dwelling Units (#)	Structure Damage (%)	Contents Damage (%)
790	0.141022	344.31	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	26%	14%
793	0.207703	344.17	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33%	19%
794	0.207672	344.20	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33%	19%
795	0.04425	344.29	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	16%	6%
796	0.309326	344.08	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	82%	71%
797	0.246857	344.17	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	38%	22%
798	0.152832	344.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	28%	15%
799	0.043427	344.21	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	16%	6%
800	0.098206	344.22	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	22%	11%
802	0.002106	344.37	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	11%	3%
803	0.056152	344.44	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	17%	7%
804	0.125702	344.42	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	25%	13%
805	0.187958	344.31	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	31%	18%
806	0.047302	344.44	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	16%	7%
807	0.19574	344.14	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	32%	18%
808	0.35199	344.26	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	85%	74%
813	0.19574	344.24	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	32%	18%
814	0.203552	344.29	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33%	19%
818	0.054047	344.36	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	17%	7%
821	0.164459	344.22	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	29%	16%
822	0.148865	344.21	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	27%	15%
823	0.32074	344.34	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	83%	72%
825	0.086304	344.25	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	20%	10%
827	0.148865	344.32	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	27%	15%
828	0.25824	344.14	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	39%	23%
829	0.203552	344.08	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33%	19%
830	0.203552	344.11	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	33%	19%
831	0.016052	344.28	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	13%	4%
832	0.054077	344.41	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	17%	7%
833	0.210297	344.21	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	34%	20%
834	0.055115	344.35	RESIDENTIAL - LOW DENSITY	MANUFACTURED HOUSING	1	17%	7%

APPENDIX E

DETAILED SUMMARY OF UNDERSIZED CROSSINGS

Crossing ID	Station	Reach	Type	Location	Undersized	Overtopping	Causing Overbank Flooding Upstream
57	2288	Lower BX Creek	CULV	34 st north of 43 Ave	Yes	No	No
59	2159	Lower BX Creek	BRIDGE	32 St south of 43 Ave	Yes	Yes, partial	Yes, minor.
61	2138	Lower BX Creek	CULV	Below Blue Stream Motel, 32 St. Hwy 97	Yes	No	Yes, impacts buildings.
63.25	1951	Lower BX Creek	CULV	Below Vernon Lodge	Yes	No	No
63.6	1865	Lower BX Creek	CULV	Under Vernon Lodge parking	Yes	No	No
71	1322	Lower BX Creek	CULV	35 Ave / 34 St	Yes	Yes	Yes, impacts buildings.
73	1248	Lower BX Creek	CULV	34 Ave btwn 34 St & 35 St	Yes	No	Yes, impacts buildings.
75	1129	Lower BX Creek	BRIDGE	33rd Ave off of 35th Street	Yes	No	Yes
77	1045	Lower BX Creek	CULV	32 Ave btwn 34 St & 35 St	Yes	Yes	Yes
81	830	Lower BX Creek	CULV	30 Ave near 35 St - Behind Safeway	Yes	No	Yes
83	739	Lower BX Creek	CULV	Lane south 30 Ave west 35 St	Yes	No	Yes, impacts buildings and laneway.
84.2	693	Lower BX Creek	CULV	Along 35 St	Yes	Yes	Yes, minor.
84.6	585	Lower BX Creek	BRIDGE	N of 27 St, West of 35 St	Yes	Yes	Yes.
85	497	Lower BX Creek	CULV	27 Ave	Yes	No	Yes, impacts building and property.
88.199997	355	Lower BX Creek	CULV	25 Ave (South side)	Yes	No	No
90	228	Lower BX Creek	CULV	24 Ave East 35 St	Yes	Yes	Yes
92	140	Lower BX Creek	CULV	36 St South 24 Ave	Yes	Yes	Yes, impacts buldings, property and 36 St.
95	4617	Upper Vernon Creek	CULV	Westkal Rd. Kalamalka Lake Outlet	Yes	No	No
96.400002	4578	Upper Vernon Creek	BRIDGE	Cafe, N of Westkal Rd	Yes	No	No
100	4273	Upper Vernon Creek	CULV	College Way, DSCF3828	Yes	No	Yes.
102	4158	Upper Vernon Creek	BRIDGE	Campground, Kalamalka Lk Rd.	Yes	Yes, At Crest	Yes, impacts buildings, property and parking.
103.1	4094	Upper Vernon Creek	BRIDGE	Campground, Kalamalka Lk Rd.	Yes	Yes	Yes, impacts buildings, property and parking.
104	3836	Upper Vernon Creek	CULV	Kalamalka Lake Rd north of lake	Yes	No	Yes, impacts buildings and property.
108	3423	Upper Vernon Creek	BRIDGE	Adjacent Browne Rd. Housing Subdivision	Yes	No	No
109.1	3384	Upper Vernon Creek	BRIDGE	Adjacent Browne Rd. Housing subdivision	Yes	No	No
110	3316	Upper Vernon Creek	BRIDGE	Adjacent Browne Rd. Cul-de-sack	Yes	Yes	Yes, impacts property.
112	3196	Upper Vernon Creek	CULV	Browne Rd	Yes	Yes	Yes, impacts buildings and property.
114	2994	Upper Vernon Creek	BRIDGE	Vernon Golf and Country Club	Yes	No	Yes, impacts buildings and property.
116	2762	Upper Vernon Creek	BRIDGE	Vernon Golf and Country Club	Yes	Yes	Yes, impacts golf course and building.
122	2280	Upper Vernon Creek	BRIDGE	Adjacent Polson Dr. on Vernon Golf Club	Yes	No	Yes, impacts golf course.
124	2205	Upper Vernon Creek	BRIDGE	South of Golf Course, Rail bridge	Yes	No	Yes
127	1466	Upper Vernon Creek	BRIDGE	Polson Park	Yes	No	Yes, impacts Polson Park.
128.1	1354	Upper Vernon Creek	BRIDGE	Polson Park	Yes	No	Yes, impacts Polson Park.
129.3	1022	Upper Vernon Creek	BRIDGE	Polson Park	Yes	No	Yes, impacts Polson Park.
130	990	Upper Vernon Creek	BRIDGE	Polson Park, east of 32nd St	Yes	Yes	Yes, impacts Polson Park.
132	921	Upper Vernon Creek	BRIDGE	Upstream of Hwy 97 Crossing, Polson Park	Yes	Yes	Yes, impacts Polson Park.
134	894	Upper Vernon Creek	CULV	32 St south of 25 Ave	Yes	No	Yes, impacts Polson Park.
136	711	Upper Vernon Creek	BRIDGE	34 St south of 25 Ave	Yes	No	Yes, impacts buildings, parking lots, 25 Ave.
138	605	Upper Vernon Creek	CULV	24 Ave btwn 34 St & 34A St	Yes	No	Yes, impacts buildings, property , 34a St. and 25 Ave.
145	5979	Lower Vernon Creek	CULV	39 St, South of 24th Ave	Yes	No	Yes, impacts buildings and 24 Ave.
148	5477	Lower Vernon Creek	BRIDGE	Behind storage yard at 24th St	Yes	Yes	Yes
150	5187	Lower Vernon Creek	CULV	43 St	Yes	No	Yes, impacts industrial buildings, parking areas, 43 St, large residential area
155.3	4849	Lower Vernon Creek	BRIDGE	Southest of 25 Ave	Yes	Yes	No
156	4669	Lower Vernon Creek	BRIDGE	West of 25th Ave	Yes	No	Yes, impacts buildings, parking areas, 44 St
169	2D Model	Lower Vernon Creek	CULV	Okanagan Landing Rd	Yes	No	Yes, impacts large residential areas, Okanagan Landing Rd.
175	2D Model	Lower Vernon Creek	CULV	Lakeshore Rd	Yes	No	Yes, impacts large residential areas, Lakeshore Rd.

Notes to Users:

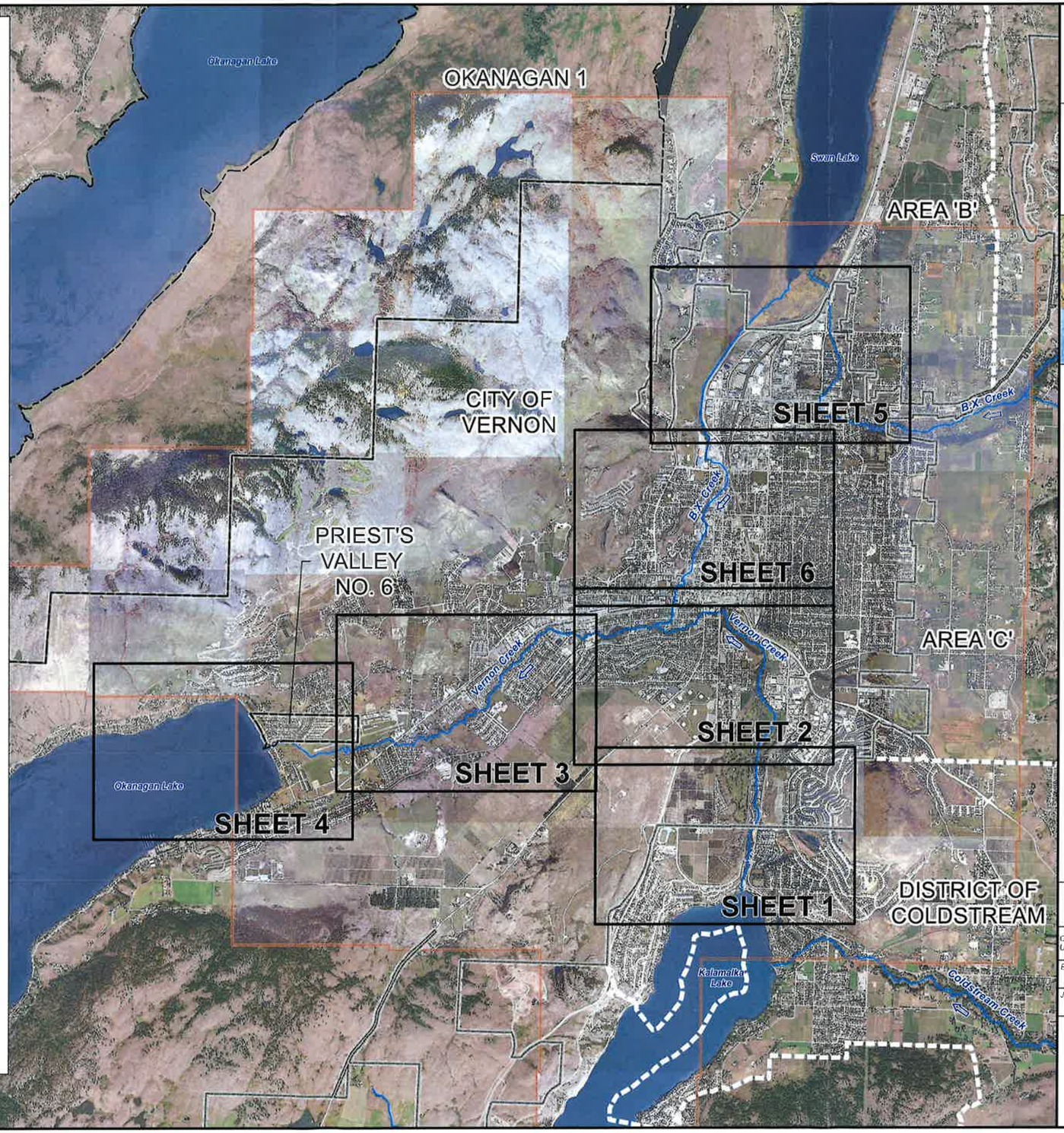
1. Please refer to **Disclaimer** below.
2. Please review the associated project report before using the floodplain and hazard maps:
   a. Northwest Hydraulic Consultants Ltd. (NHC), 2020, 'City of Vernon Detailed Flood Mapping, Risk Analysis and Mitigation Part 1 - Upper B.X. Creek', Report prepared for the City of Vernon (CoV), 2020 August 25, NHC project number 3005032.
   b. Northwest Hydraulic Consultants Ltd. (NHC). 2021, 'City of Vernon Detailed Flood Mapping, Risk Analysis and Mitigation Part 2 - Lower B.X. Creek and Vernon Creek', Report prepared for the City of Vernon (CoV), 2021 August 06, NHC project number 3005032.
3. Map sheet layout shown on this map applies to 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, data, and analysis.
   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, flood fringe, and setbacks. Floodway is considered the primary flow path during a flood event. Flood fringe is considered part of the floodplain that does not contribute substantially to conveyance and where depth and velocity are generally low (< 1 m and < 1 m/s). Setbacks are provided as a recommended no-build zones to maintain flood conveyance and limit risk to development from channel hazards (e.g., high velocity flow, erosion, scour, channel migration, etc.).
6. Hazard maps depict the simulated flood depths and velocities during the design event. No freeboard has been added to flood depths. Hazard maps show modelled flood depths and velocities for both 1D and 2D areas. Low velocity zones are indicted on the hazard maps with the smallest arrow. Areas where velocity arrows are not shown, are indicative of areas where velocity has not been calculated (i.e., overbank areas simulated using 1D model).
   a. Flood depths include a generalized description of the potential consequence. These descriptions are not based on assessment of exposure or vulnerability within the study area, and therefore may not be accurate.
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 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 those indicated on the maps.
8. The calculated water level has been extended perpendicular to flow across the floodplain, thus mapping inundation of isolated areas regardless of likelihood of inundation. Isolated areas may become inundated due to dike failure, seepage, or local inflows. Site specific judgement by a Qualified Professional is required to determine validity of isolated inundation.
9. Filtering was used to remove isolated inundation areas smaller than 100 m^2 as well as isolated "islands" in the inundation extent less than 100 m^2. Isolated inundation areas larger than 100 m^2 within 40 m of adjacent inundation are mapped as inundated areas.
10. 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.
11. 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, Lower B.X. Creek and Vernon Creek watersheds. The design flood event for B.X. Creek 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 design flood event for Vernon Creek is the instantaneous 200-year end of century flood event. The two downstream boundary conditions include, the Swan Lake 500-year flood elevation of 390.08 m, and the Okanagan Lake 2017 flood of record event adjusted for mid-century climate change (comparable to an instantaneous 500-year mid-century flood event).
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. The hydraulic model was calibrated to the 2020 flood event.
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 & 2019) 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 **B.X. Creek and Vernon 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.
Except as required by law, this document and the information and data contained herein are to be treated as confidential and may be used and relied upon only by **City of Vernon**, its officers and employees. **Northwest Hydraulic Consultants Ltd.** denies any liability whatsoever to **other parties** who may obtain access to **this document** 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

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- CITY OF VERNON
- FIRST NATIONS RESERVE
- REGIONAL DISTRICT OF NORTH OKANAGAN SUB-AREA BOUNDARY
- 2019 ORTHOPHOTO EXTENT
- FLOW DIRECTION
- STREAM

SCALE - 1:25,000
0 0.5 1 1.5 KM
N

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

Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	13-Oct-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK SHEET INDEX

SHEET 2 ↑

A setback of 30 m from the top of bank should be applied to the left bank and right bank along this reach.
CITY OF VERNON
DISTRICT OF COLDSTREAM
LIMIT OF MAPPING - City of Vernon boundary
Vernon Creek
Kalamalka Lake
COLLEGE WAY
RESERVOIR RD
COUNTRY ESTATE CRT
KELOWNA PENTICTON RAILWAY
MT BURNABY RD
MT GRADY CRT
MT GRADY CLOSE
MT GRADY DRIVE
MT GRADY PL
MT GREEN CRT
MT GREEN DR
MT GREEN PL
MT GREEN WAY
MT HOLMES CRT
MT HOLMES PL
MT HOLMES RD
MT HOLMES WAY
MT HORSTMAN CRT
MT HORSTMAN PL
MT HORSTMAN RD
MT HORSTMAN WAY
MT LEMAN CRT
MT LEMAN PL
MT LEMAN RD
MT LEMAN WAY
MT MACKIE CRT
MT MACKIE PL
MT MACKIE RD
MT MACKIE WAY
MT MACKIE WAY
MT MACKIE WAY

SHEET 6 ↑

SHEET 3 ↑

SHEET 1 ↓

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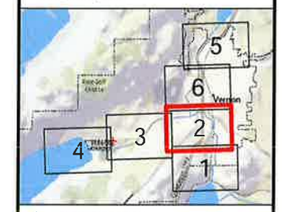

- FLOW DIRECTION
- CITY OF VERNON
- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL *Labelled with elevation in metres*
- MINOR CONTOUR AT 1 METRE
- 2019 ORTHOPHOTO EXTENT
- RAILWAY LINE
- ROAD
- STREAM
- 123.4 (123.4) **FLOOD CONSTRUCTION LEVEL (FCL)** *Labelled with FCL in metres CGVD2013 (FCL in CGVD28)*
- LIMIT OF MAPPING

INUNDATION EXTENT - 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*
- FLOODWAY *30 m top of bank setback*
- FLOOD FRINGE
- OKANAGAN LAKE SHORELINE ZONE *Due to wave effects an FCL of 345.5 m CGVD2013(or 345.2 m CGVD28) should be applied to this area*

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
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 2 OF 6

SHEET 4 ↑

PRIEST'S VALLEY NO.6

SHEET 2 ↓

CITY OF VERNON

VERNON WATER RECLAMATION CENTER

VERNON REGIONAL AIRPORT

Vernon Creek

OKANAGAN LANDING RD

TRONSON RD

CAPT BACEY WAY

OSPREY RD

QUAIL RD

CHUKAR RD

SILVERA DR

SCOTT RD

RELLA VISTA RD

PALMER RD

HYATT RD

WESTSIDE RD

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 and right bank along this reach.

LIMIT OF MAPPING - Further information can be found in mapping report, NHC (2021). See map note details for full report title

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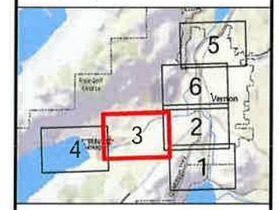

FLOW DIRECTION
CITY OF VERNON
FIRST NATIONS RESERVE
BRIDGE
CULVERT
MAJOR CONTOUR AT 5 METRE INTERVAL
Labelled with elevation in metres
MINOR CONTOUR AT 1 METRE
2019 ORTHOPHOTO EXTENT
RAILWAY LINE
ROAD
STREAM
123.4 (123.4) FLOOD CONSTRUCTION LEVEL (FCL)
Labelled with FCL in metres CGVD2013 (FCL in CGVD28)
LIMIT OF MAPPING

INUNDATION EXTENT - 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

FLOODWAY
30 m top of bank setback

FLOOD FRINGE

OKANAGAN LAKE SHORELINE ZONE
Due to wave effects an FCL of 345.5 m CGVD2013(or 345.2 m CGVD28) should be applied to this area

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
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 3 OF 6

CITY OF VERNON

PRIEST'S VALLEY NO.6

Okanagan Lake

Vernon Creek

LIMIT OF MAPPING =
Further Okanagan Lake flood **extent and flood construction level information outside of the limit** of mapping boundary can be found in: Northwest Hydraulic Consultants Ltd. (NHC). 2020. 'Okanagan Mainstem Floodplain Mapping Project'. **Report** prepared for the Okanagan Basin Water Board (OBWB). 2020 March 31. **NHC project number** 3004430.

A setback of 30 m from the top of bank should be applied to the left bank and right bank along this reach.

SHEET 3 →

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- MINOR CONTOUR AT 1 METRE
- 2019 ORTHOPHOTO EXTENT
- **RAILWAY LINE**
- ROAD
- STREAM
- 123.4 (123.4) FLOOD CONSTRUCTION LEVEL (FCL) *Labelled with FCL in metres CGVD2013 (FCL in CGVD28)*
- LIMIT OF MAPPING

INUNDATION EXTENT - 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*
- FLOODWAY *30 m top of bank setback*
- FLOOD FRINGE
- OKANAGAN LAKE SHORELINE ZONE *Due to wave effects an FCL of 345.5 m CGVD2013(or 345.2 m CGVD28) should be applied to this area*

PLEASE REFER TO NOTES ON SHEET INDEX

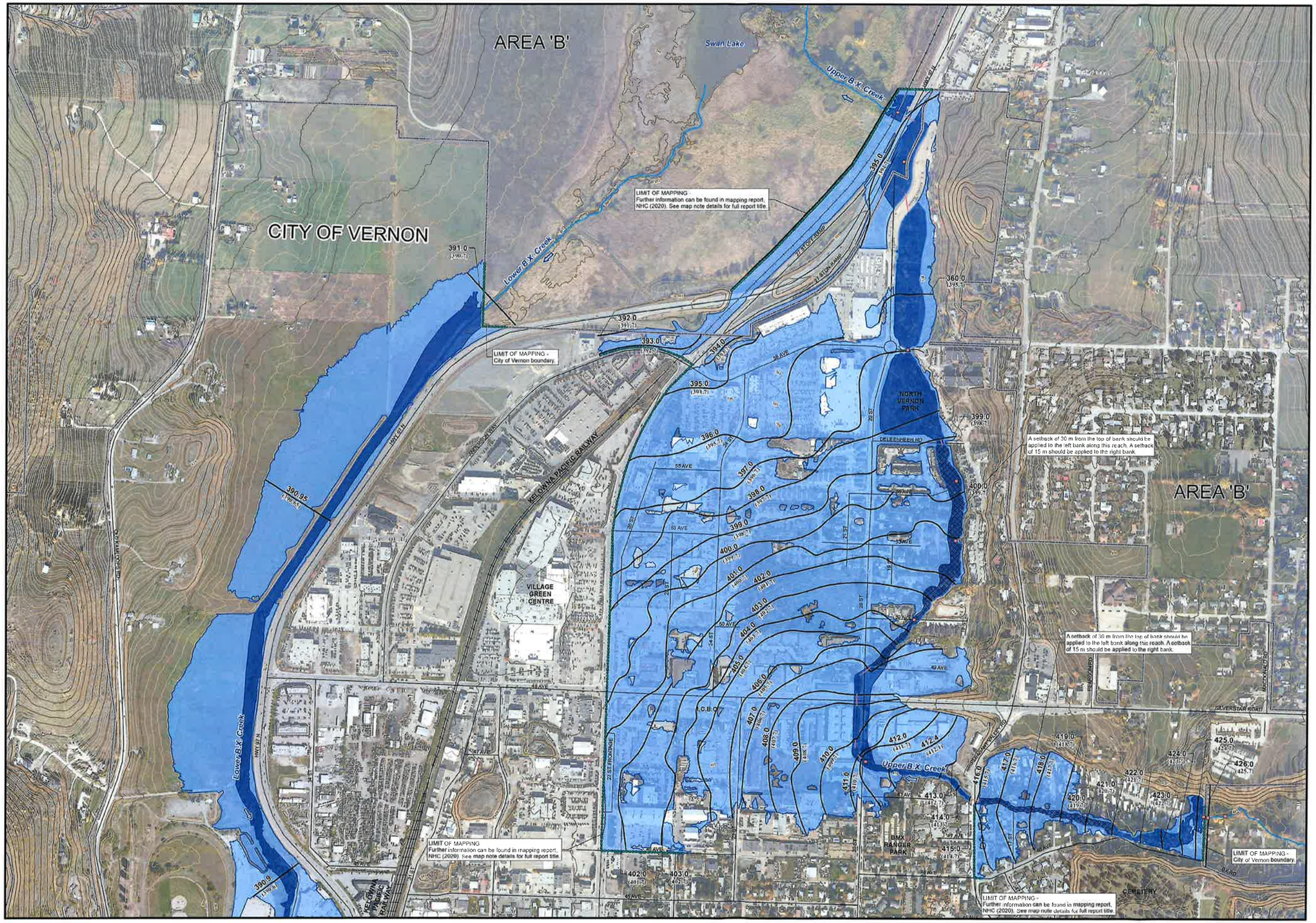
SCALE - 1:4,000
0 100 200 M
N

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

Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 4 OF 6



SHEET 6 ↓

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northwest hydraulic consultants

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Canada
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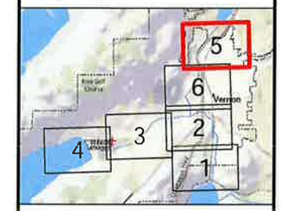
Fax: 604.980.9264
www.nhcweb.com



- FLOW DIRECTION
- CITY OF VERNON
- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL *Labelled with elevation in metres*
- MINOR CONTOUR AT 1 METRE
- 2019 ORTHOPHOTO EXTENT
- RAILWAY LINE
- ROAD
- STREAM
- 123.4 (123.4) **FLOOD CONSTRUCTION LEVEL (FCL)** ***Labelled with FCL in metres CGVD2013 (FCL in CGVD28)***
- LIMIT OF MAPPING

INUNDATION EXTENT - 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*
- FLOODWAY *30 m top of bank setback*
- FLOOD FRINGE
- OKANAGAN LAKE SHORELINE ZONE *Due to wave effects an FCL of 345.5 m CGVD2013(or 345.2 m CGVD28) should be applied to this area*

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
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 5 OF 6

SHEET 5 ↑

SHEET 2 ↓

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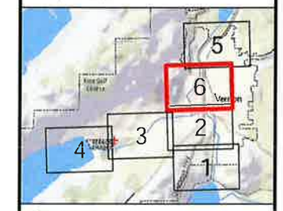

- FLOW DIRECTION
- CITY OF VERNON
- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL
  Labelled with elevation in metres
- MINOR CONTOUR AT 1 METRE
- 2019 ORTHOPHOTO EXTENT
- RAILWAY LINE
- ROAD
- STREAM
- 123.4 (123.4) FLOOD CONSTRUCTION LEVEL (FCL)
  Labelled with FCL in metres CGVD2013 (FCL in CGVD28)
- LIMIT OF MAPPING

INUNDATION EXTENT - 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
- FLOODWAY
  30 m top of bank setback
- FLOOD FRINGE
- OKANAGAN LAKE SHORELINE ZONE
  Due to wave effects an FCL of 345.5 m CGVD2013(or 345.2 m CGVD28) should be applied to this area

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
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	12-OCT-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK FLOODPLAIN SHEET 6 OF 6

SHEET 2 ↑

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- FLOW DIRECTION
- CITY OF VERNON
- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL *Labelled with elevation in metres*
- MINOR CONTOUR AT 1 METRE INTERVAL
- 2019 ORTHOPHOTO EXTENT
- RAILWAY LINE
- ROAD
- STREAM
- LIMIT OF MAPPING

VELOCITY AND DEPTH - DESIGN EVENT WITHOUT FREEBOARD

VELOCITY (m/s)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1.5
- 1.5 - 2.5

*Areas where velocity arrows are not **shown are indicative of areas where** velocity has not been calculated.*

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; River — ***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
VCCM	RLM	JWT/DPM

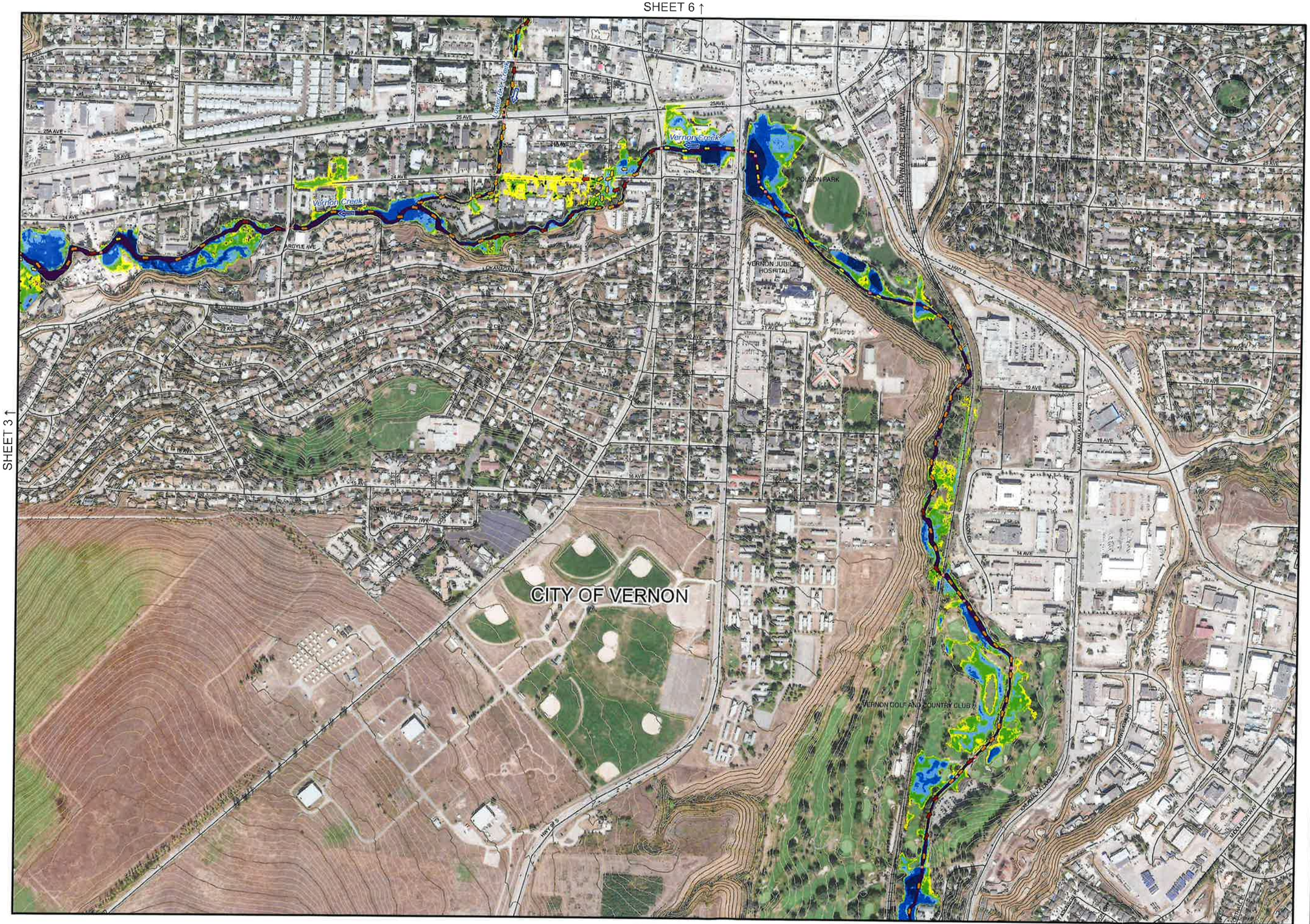
Job Number	Date
3005032	13-OCT-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK

HAZARD MAP SHEET 1 OF 6

SHEET 6 ↑

SHEET 3 ↑



SHEET 1 ↓

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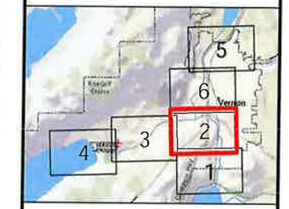

FLOW DIRECTION
CITY OF VERNON
FIRST NATIONS RESERVE
BRIDGE
CULVERT
MAJOR CONTOUR AT 5 METRE INTERVAL
Labelled with elevation in metres
MINOR CONTOUR AT 1 METRE INTERVAL
2019 ORTHOPHOTO EXTENT
RAILWAY LINE — ROAD
STREAM
LIMIT OF MAPPING

VELOCITY AND DEPTH - DESIGN EVENT
WITHOUT FREEBOARD

VELOCITY (m/s)

< 0.1	
0.1 - 0.5	*Areas where velocity arrows are not shown are indicative of areas where velocity has not been calculated.*
0.5 - 1.5	
1.5 - 2.5	

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*
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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; River	*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

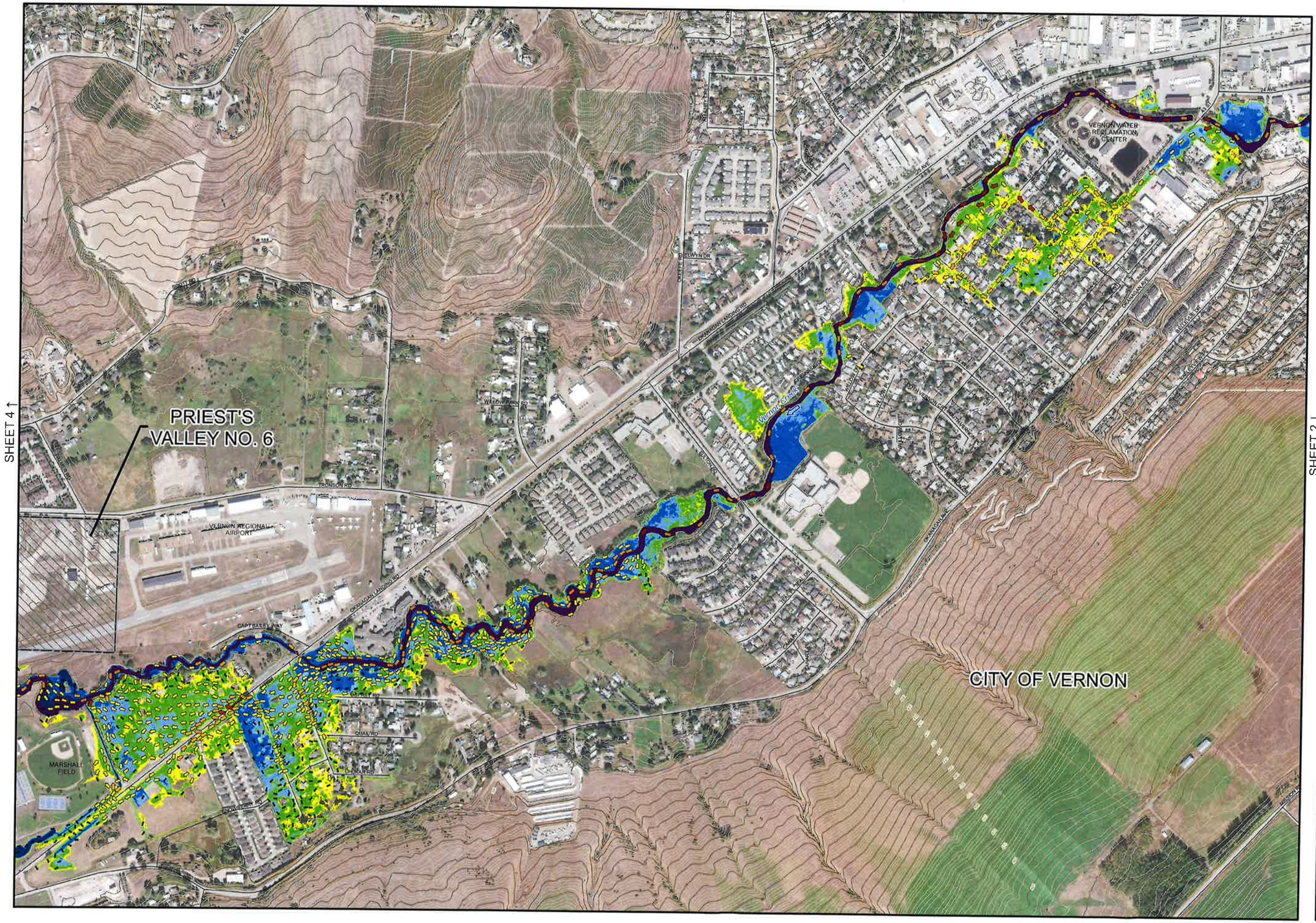
Coordinate System: NAD 1983 CSRS UTM ZONE 11N
Units: METRES; Vertical Datum: CGVD2013

Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK

HAZARD MAP SHEET 2 OF 6



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- FLOW DIRECTION
- CITY OF VERNON
- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
- MAJOR CONTOUR AT 5 METRE INTERVAL *Labelled with elevation in metres*
- MINOR CONTOUR AT 1 METRE INTERVAL
- 2019 ORTHOPHOTO EXTENT
- RAILWAY LINE
- ROAD
- STREAM
- LIMIT OF MAPPING

VELOCITY AND DEPTH - DESIGN EVENT WITHOUT FREEBOARD

VELOCITY (m/s)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1.5
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- 1.0 - 2.0 — *ground floor flooded; residents and workers evacuate*
- > 2.0; River — *first floor and often higher levels covered by water; residents and workers evacuate*

PLEASE REFER TO NOTES ON SHEET INDEX

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Engineer	GIS	Reviewer
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Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK

HAZARD MAP SHEET 3 OF 6

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Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK

HAZARD MAP SHEET 4 OF 6

SHEET 6 ↓

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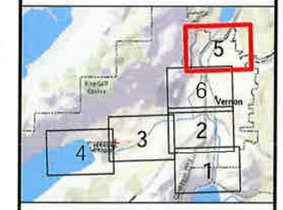

- FLOW DIRECTION
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- FIRST NATIONS RESERVE
- BRIDGE
- CULVERT
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- MINOR CONTOUR AT 1 METRE INTERVAL
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- RAILWAY LINE
- ROAD
- STREAM
- LIMIT OF MAPPING

VELOCITY AND DEPTH - DESIGN EVENT WITHOUT FREEBOARD

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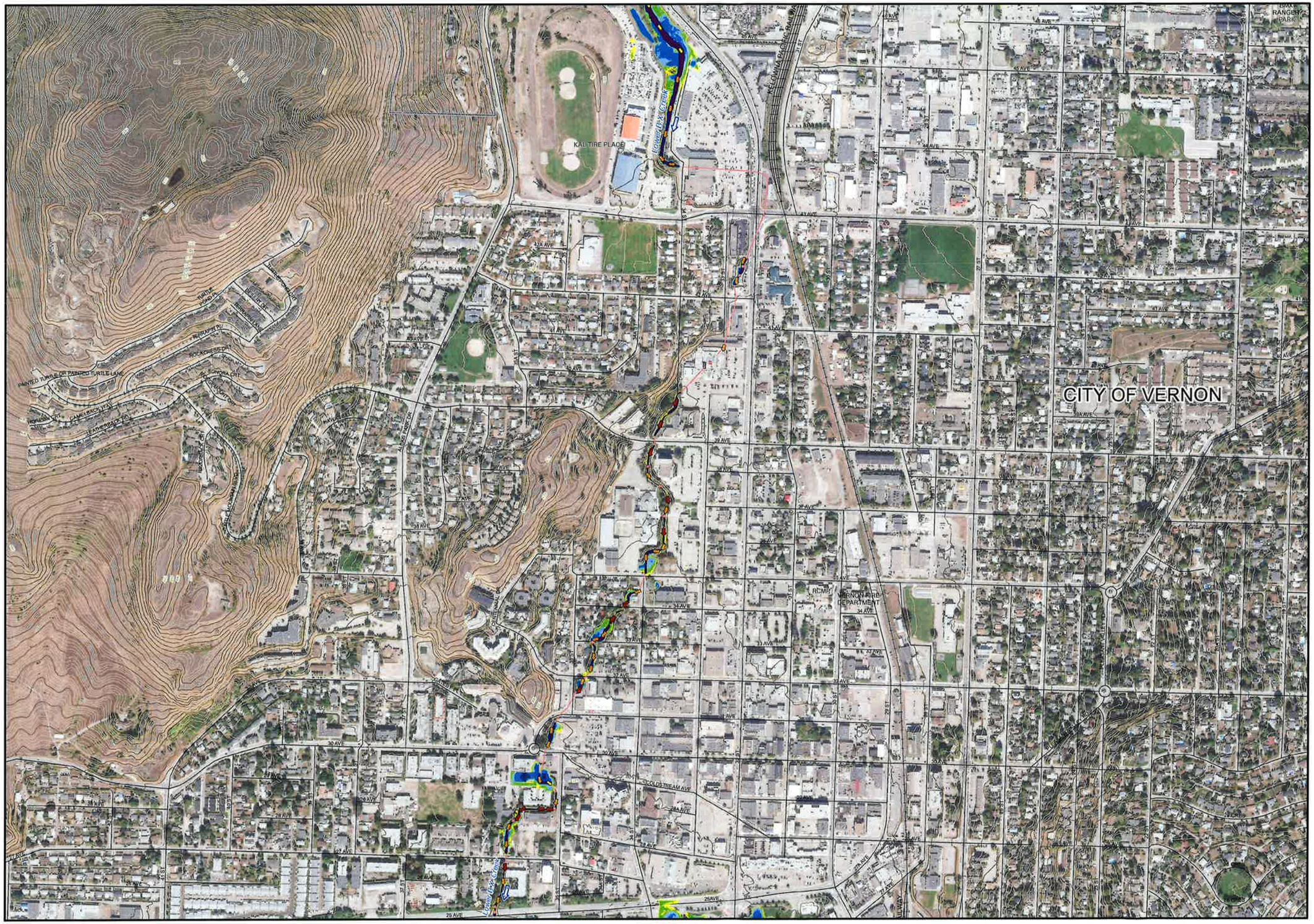
Engineer	GIS	Reviewer
VCCM	RLM	JWT/DPM

Job Number	Date
3005032	18-AUG-2021

CITY OF VERNON FLOOD MAPPING B.X. CREEK & VERNON CREEK

HAZARD MAP SHEET 5 OF 6

SHEET 5 ↑


KAL TIRE PLACE
Lower B.X. Creek
KELOWNA PACIFIC RAILWAY
RANGEY PARK
CITY OF VERNON
RCMP
VERNON FIRE DEPARTMENT
SCOLDSTREAM AVE
Lower Bx Creek
45 AVE
44 AVE
43 AVE
42 AVE
41 AVE
40 AVE
39 AVE
38 AVE
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