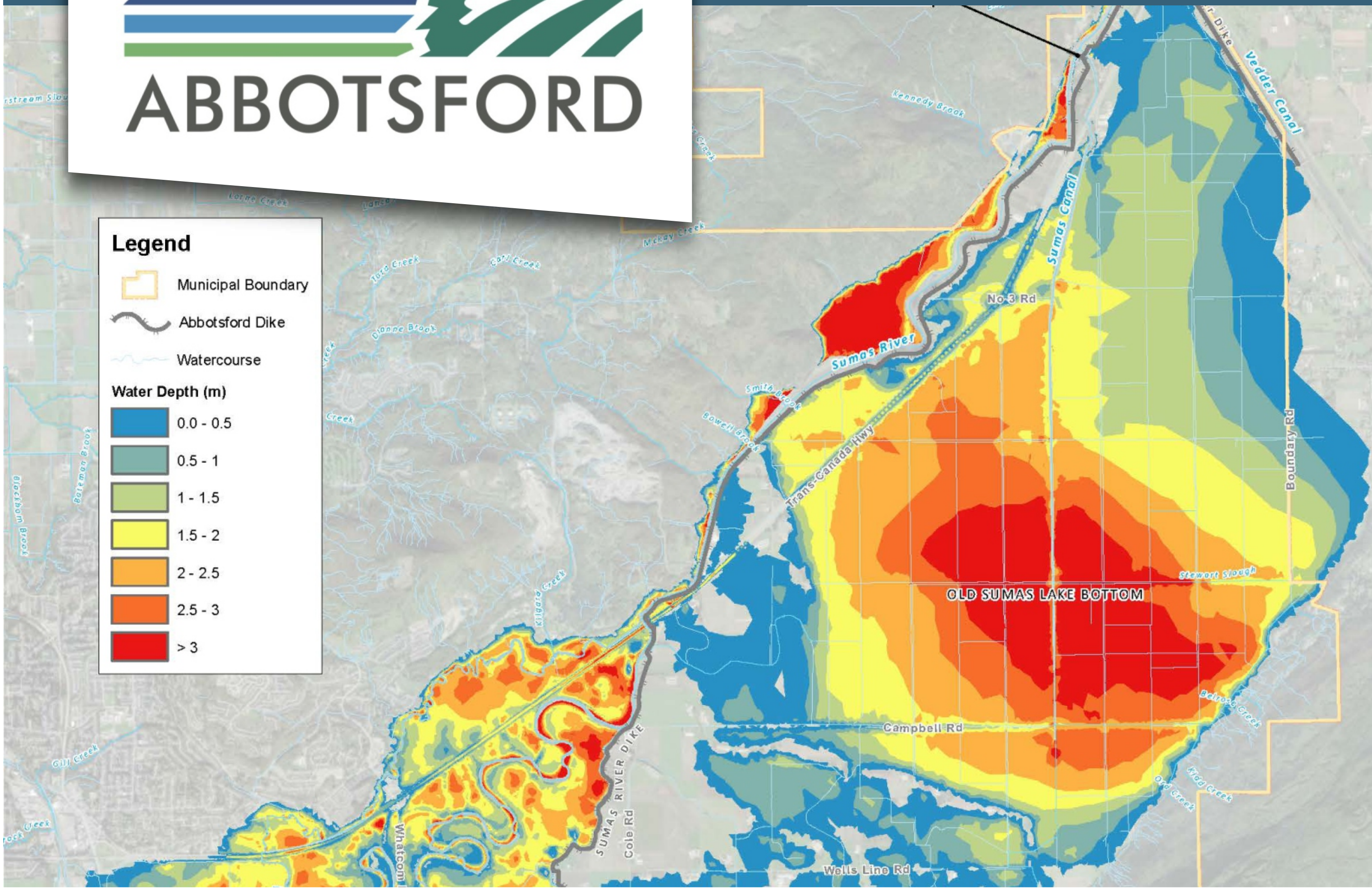

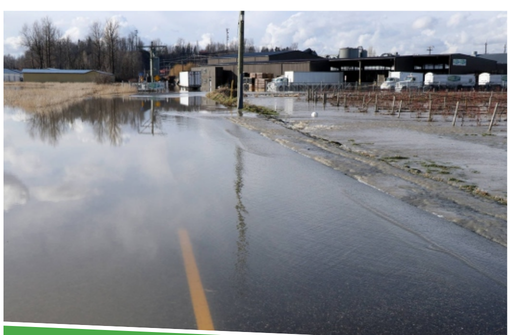

Final Report - Revised

Nooksack River Overflow Flood Mitigation Plan

November 30, 2020
KWL File No. 510.184-300

Submitted by:

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Executive Summary

This report presents the work and results for modelling, flood damage assessment, flood mitigation analysis and benefit-cost analysis associated with flooding in the Sumas Prairie completed by Kerr Wood Leidal Associates Ltd. (KWL) as part of the work for the Nooksack River Overflow Flood Mitigation Plan for the City of Abbotsford (City). This work has been completed with support and funding from the National Disaster Mitigation Program (NDMP), jointly funded from the Province of BC and Federal Government. The work stems from a key strategy of the Nooksack River International Task Force (NRITF) to develop a comprehensive Flood Damage Reduction Plan for flooding in the United States (US) and Canada caused by Nooksack River overflows. As the US has been working to refine a benefit-cost analysis model for use in ongoing integrated planning efforts being led by Whatcom County, the work presented in this report aims to develop a similar model to determine the extent of flood damages in the Sumas Prairie on the Canadian side of the border, which primarily consists of a major agricultural region within the City of Abbotsford. The ultimate goal of this project is to provide sufficient data and background information for Canadian officials to have discussions with Washington State officials to consider economic strategies on the Nooksack River, and develop a mitigation plan to address the flooding issue.

Flooding in the Sumas Prairie is caused by a combination of high flows in the Sumas River watershed and flows from the Nooksack River that overtop its right bank near Everson, Washington and are then conveyed along Johnson Creek and the Sumas River to the Canadian border. Floodwaters cross the Canadian border as overland flows toward low-lying areas referred to as the Marshall Creek sump, Saar Creek sump and Arnold Slough sump. During extreme flood events, floodwaters in the Sumas Prairie have the potential to overtop and breach the dike system protecting the Old Sumas Lake Bottom, a low-lying agricultural area that was formerly a lake and provided additional storage during flood events. All flows ultimately drain to the Barrowtown Dam, which consists of a flood box and pump system to convey flows from the Sumas River and the Old Sumas Lake Bottom into the lower reach of the Sumas River that joins the Vedder River and discharges into the Fraser River. Water levels along this lower reach of the Sumas River are therefore impacted by backflows from the Vedder River and the Fraser River.

A calibrated 2D MIKE FLOOD model was previously developed in 2014 for the Sumas Prairie in Canada based on the 35-year Nooksack River overflow flood event that occurred in November 1990, and three variations of the 100-year flood scenarios were simulated. The MIKE FLOOD model was used in this study to (1) simulate a 200-year flood event, (2) simulate climate change impacts on the three 100-year flood scenarios and the 200-year flood event, and (3) simulate three flood mitigation options selected as part of this study.

Flood damage assessments were completed for the November 1990 flood (based on 2019 building, agricultural, business and traffic conditions), the three 100-year flood scenarios, the 200-year flood event and the flood mitigation scenarios. Damage assessments involved determining the following quantitative and qualitative items:

- Structure and content damages: estimated using a HEC-FIA model based on flooding of residential and non-residential structures.
- Agricultural losses: estimated using the Food and Agriculture Organization of the United Nations Damages and Losses method based on the areas flooded within each agricultural parcel.
- Affected populations: estimated based on flooding of residential structures.
- Transportation and business economic losses: estimated based on highway and railway closure times and flooding of non-agricultural businesses.
- Qualitative impacts: evaluated environmental impacts, lifeline and utility disruption, impacts to First Nations and the potential for a Nooksack River avulsion.

Multiple flood mitigation options for the Sumas Prairie have been suggested and modelled in numerous studies since the November 1990 flood event. These options generally include the following measures:

- Increasing the capacity at Barrowtown Dam through modifications to the floodboxes or pumps;
- River modifications downstream of Barrowtown Dam such as channel improvements or channel separation including tunneling through Sumas Mountain;
- Constructing floodways to relieve Marshall Creek sump or improve conveyance to Saar Creek sump;
- Raising or constructing relief spillways for the dike system protecting the Old Sumas Lake Bottom;
- Raising or reinforcing the Southern Railway;
- Floodproofing individual properties; and,
- Carrying out measures in Washington State such as blocking the Nooksack overflow at Everson.

A thorough review of the above solutions was carried out, and improvements to these solutions were investigated including an alternative floodway configuration along the Sumas River corridor and local area dikes for higher density areas. The three following options were ultimately selected for costing (Class D), modelling, damage assessment and benefit-cost analysis:

- Mitigation Option #1: construct a new floodway from Marshall Creek sump through Whatcom Road in combination with tunneling Sumas River high flows through Sumas Mountain (capital cost: $580 million).
- Mitigation Option #2: Raise dikes protecting the Old Sumas Lake Bottom in combination with floodproofing each building (ring dikes) and constructing area dikes for high-density areas (capital cost: $339 million).
- Mitigation Option #3: construct a structure at Everson to block all overflows from the Nooksack River (capital cost: $29 million)

The three mitigation options were modelled for the 100-year flood under existing climate conditions and the 200-year flood under future climate change conditions. Pre-mitigation damages for these two floods were estimated to total $462 million and $960 million, respectively. Benefit-cost analysis was then carried out for the three options based on their capital costs, annual maintenance costs and the annual damages that they prevent for their assumed 100-year lifespans. Benefit-cost ratios were estimated for the three options to be 0.06, 2.0 and 16.1 at a 2% discount rate and 0.02, 0.6 and 5.1 at an 8% discount rate. A benefit-cost analysis was also carried out for a fourth option consisting of constructing a US/Canada border dike and is provided in Appendix J.

Mitigation Option #1 was found to provide minimal benefit for its cost and is therefore not recommended. While the capital cost of this option is primarily driven by the high costs of the tunnel, this option also provides minimal flood reduction benefits and does not prevent overtopping and failure of the dike system protecting the Old Sumas Lake Bottom during the 200-year climate change flood.

Mitigation Option #2 is recommended from a benefit-cost analysis, although non-monetary factors should be of particular consideration for this option where the cost of mitigation could be similar to the cost of the mitigated damages. This option also completely prevents all forms of flooding within the Old Sumas Lake Bottom and the communities of Huntingdon and Arnold, whereas it increases water levels in the remaining areas of the Sumas Prairie where floodproofing would only be carried out to protect structures. Additional benefit-cost analyses of area dike options for Huntingdon and Arnold as standalone projects are provided in Appendix I.

Mitigation Option #3 provides the highest benefit when looking only at Canada-side damages, as the cost to expand the existing levee system at Everson to block the Nooksack River overflows is significantly lower than the flood damages in the Sumas Prairie that are avoided by preventing the overflow flood. However, additional analysis work is needed on the US side to provide the overall benefit-cost ratio that covers the benefits and costs on both sides of the border, including further damages and mitigation needed along the Nooksack River.

1. Introduction

This report presents the work and results for modelling, flood damage assessment, flood mitigation assessment and benefit-cost analysis associated with flooding in the Sumas Prairie completed as part of the work for the Nooksack River Overflow Flood Mitigation Plan for the City of Abbotsford (City). This work has been completed with support and funding from the National Disaster Mitigation Program (NDMP), jointly funded from the Province of BC and Federal Government.

1.1 Project Background

Abbotsford, BC is one of the most intensively and diversely farmed areas in Canada, supporting a wide range of crop and livestock enterprises. Agriculture is the economic backbone of the City and the vital link between the social health of the community and the sustainability of the City. Abbotsford has the highest total revenue per acre in the Fraser Valley region, and approximately three times per-acre revenue region of the Niagara peninsula in Ontario, which is the next highest region in revenue for agricultural production. Agriculture-related economic activity in the City amounts to about $1.8 billion annually or about 35% of the total gross domestic product generated in the City. The farm gate receipts of the dairy, broiler, turkey, and egg sectors, alone, account for about 52% of the gross farm receipts generated in the municipality.

Major flooding of West Sumas Prairie and the Washington State cities of Everson, Sumas and the unincorporated areas of Whatcom County, occurred in November 1990 when overflow from the Nooksack River flooded north into the Sumas River basin and into Abbotsford. The TransCanada Highway 1 was closed for 26 hours due to flooding and numerous farms in the Sumas Prairie were impacted by the flood. The November 1990 overflow was estimated to have approximately a 35-year return period[1], and observations from the event indicate that there was approximately three feet of freeboard above the level of the flood water to the crest of the Interceptor Dike which protects the Old Sumas Lake Bottom area .

The Nooksack River International Task Force (NRITF) was established in response to the widespread flooding in November 1990. The Task Force is comprised of members from both Canada and the United States (US) from various levels of government. Canadian members include Federal, Provincial and the municipal (City of Abbotsford) staff. The NRITF is co-chaired by the Province of British Columbia and the State of Washington. The focus of the NRITF is on the following four strategies:

1. Improving emergency response to Trans-Boundary flooding.
2. Improving floodplain management.
3. Restoring the early 1970s Nooksack River flow capacity.
4. Developing a comprehensive Flood Damage Reduction Plan.

The recent focus has been on Strategy #4. Discussions at the 2012 NRITF technical committee meeting indicated that there is a need to assess damages stemming from the flood scenarios. The US has been working to refine a food damage assessment model (HEC-FIA) for use in ongoing integrated planning efforts being led by Whatcom County. The Canadian proponents wish to develop a similar model to determine the extent of flood damages that would occur on the Canadian side of the border for a 100-year administrative (a standard return-period event used in the US) flood hydrograph.

The last NRITF meeting was held in 2011, and a meeting was held within the duration of this study on May 15, 2020 to review the study findings. The Technical Committee (TC) of the NRITF also met recently on two occasions: on July 25, 2019 to reaffirm the purpose of the TC, review recent work of the past few years in Washington and in B.C., and to initiate planning for regrouping of the NRITF; and on January 23, 2020 for the presentation of the damage assessment portion of the work completed for the Nooksack River Overflow Flood Mitigation Plan (this project).

A calibrated 2D MIKE FLOOD model was developed in 2014 for the Sumas Prairie in Canada, and three 100-year flood scenarios were run[2]. Model outputs include mapping of flood extents, depths and velocities. In addition, other works that have been completed to date include:

- Creation of a Flood Emergency Response Model for Sumas Prairie covering both Abbotsford and Washington state lowlands (requires further calibration);
- Installation of a gauge at Everson, WA which is the location where the Nooksack overflow would occur; and
- Development of a methodology to estimate potential flooding extents in West Sumas Prairie given recorded water levels at the gauge.

A damage assessment study from 2003[3] indicated that if the Interceptor Dike failed and the Old Sumas Lake Bottom flooded due to an Extreme Flood Event (200-year), it would result in approximately $0.5 billion in direct damages and a further $0.5 billion in indirect damages (2003 dollars). The assessment, however, did not include losses due to shutdown of the TransCanada Highway and other transportation infrastructure, and the cost of repairing damage to utilities.

Modelling results of the 100-year event indicated a reduced flooding impact as compared to a 200-year event; however, the Interceptor Dike and Sumas River Dike would still be overtopped, leading to some flooding in the Old Sumas Lake Bottom area.

The Nooksack River Overflow Flood Mitigation Plan is one of the next steps to address an internal and transboundary issue from the US into Canada. The Plan would generally include estimating flood damage on the Canada side, developing mitigation options, and performing benefit-cost analyses associated with flood mitigation options. For estimating flood damages, software (HEC-FIA or equal) would be used so that outputs for both Canada and US are comparable.

The ultimate goal of this project is to provide sufficient data and background information for the City of Abbotsford, the Province, and other Canadian officials to have discussions with Washington State officials to consider economic strategies on the Nooksack River, and develop a mitigation plan to address the flooding issue.

1.2 Scope

The scope of this work includes the following elements:

- Review of background material, including past reports and minutes from past meetings;
- Collection of data from various local agencies;
- Assessment of flood damages for the following five scenarios under existing hydraulic and climate conditions:
  - Scenario 1 – November 1990 Nooksack Overflow (35-year event)
  - Scenario 2A – 100-year event with Nooksack Overflow (assume dike breach)
  - Scenario 2B – 100-year event with Nooksack Overflow (assume overtopping)
  - Scenario 2C – 100-year event without Nooksack Overflow

  - Scenario 3 – 200-year event with Nooksack Overflow

  All but Scenario 1 were also simulated under climate change conditions.
- Selection of flood mitigation options:
  - Mitigation Option #1 - Marshall Creek Sump Floodway with Sumas Mountain Tunnel
  - Mitigation Option #2 - Dike Raise and Floodproofing
  - Mitigation Option #3 - Eliminate Nooksack Overflows
- Hydraulic modelling of flooding for 3 mitigation options for each of 2 flood events (6 scenarios), including simulating effects of climate change;
- Assessment of flood damages for all 6 modelled mitigation scenarios;
- Cost estimates for construction of the mitigation options, as well as estimation of ongoing operations and maintenance costs for each option;
- Development of benefit-cost ratios for each mitigation option and comparison of options using curves for each option compared to no mitigation and showing damages avoided over the lifespan of the mitigation.

1.3 General Description of Sumas Prairie Flooding

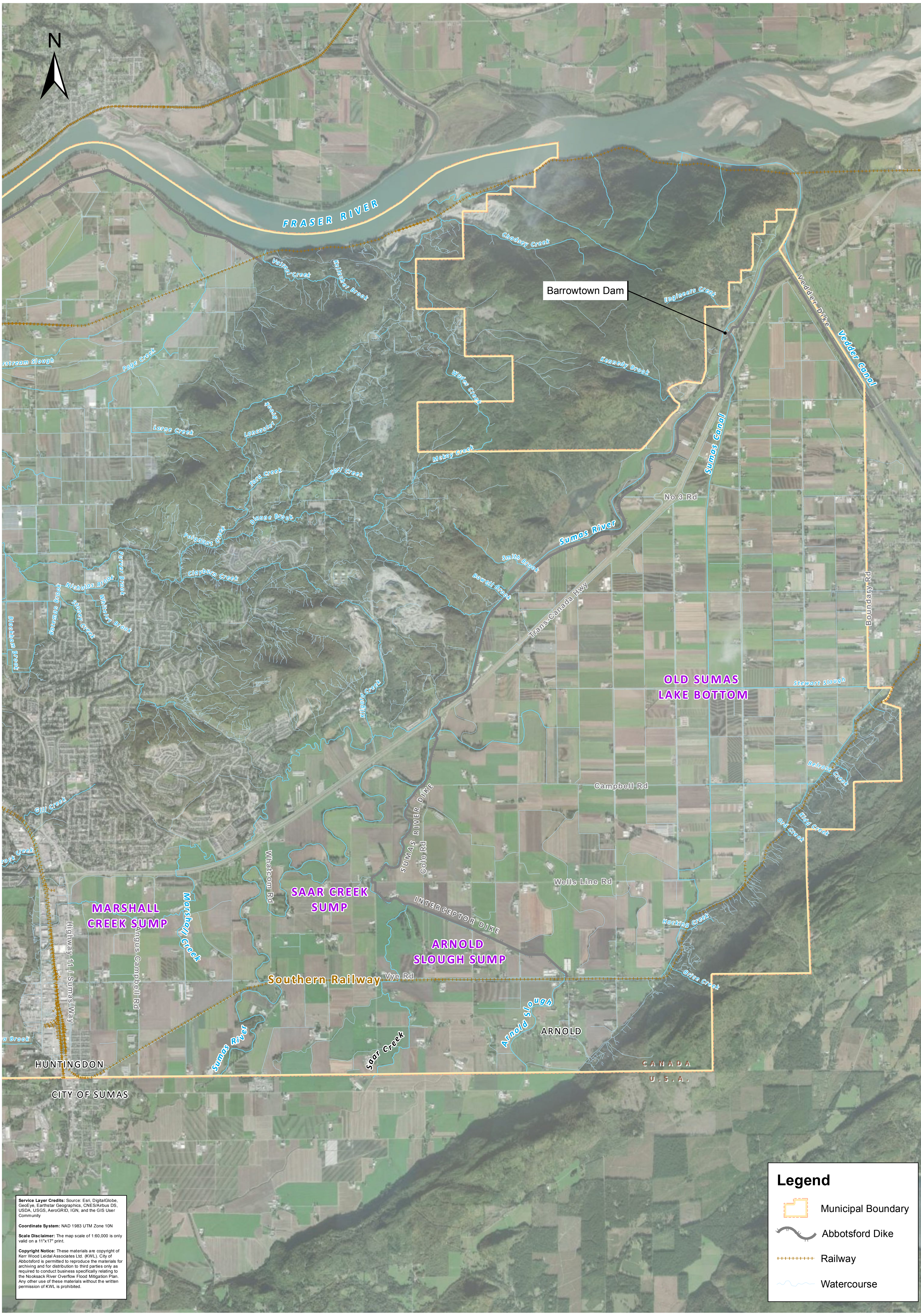
The Nooksack River overtops its right bank near Everson, Washington at approximately a 5-year to 10-year return period[1]. Overflows from the Nooksack River are then conveyed along Johnson Creek from Everson to the City of Sumas where Johnson Creek discharges into the Sumas River. Overflows from the Nooksack River typically overwhelm the capacity of Johnson Creek and the Sumas River, resulting in overland flows that cross over the Canadian border into the Sumas Prairie.

A map of the Sumas Prairie study area is provided in Figure 1-1. Flooding of the Sumas Prairie originates from a combination of left bank and right bank overland cross-border flows. Left bank overland flows originate from overtopping at Boundary Road near the City of Sumas when the capacity of Johnson Creek and the Sumas River are exceeded, and floodwaters proceed north towards the Marshall Creek sump, overtopping the Southern Railway and Vye Road. The community of Huntingdon and the border crossing are also at risk of being flooded by the left bank overland flows. Right bank overland flows originate from the east side of Whatcom Road and proceed towards the Saar Creek sump and Arnold Slough sump, which are lower than the Marshall Creek sump and are therefore also impacted by floodwater volumes ultimately draining from the Marshall Creek sump.

City of Abbotsford

Nooksack River Overflow Flood Mitigation Plan

KERR WOOD LEIDAL
consulting engineers



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:60,000 is only valid on a 11"x17" print.

Project No. 510.184

Date May 2020

Scale 1:60,000 — 0 250 500 1,000 (m)

Map of Study Area

Figure 1-1

The Old Sumas Lake Bottom is a low area protected by a dike located along the right banks of the Sumas River, Saar Creek and Arnold Slough. This dike is named the “Interceptor Dike” along Saar Creek and Arnold Slough and the “Sumas River Dike” along the Sumas River. This dike was not overtopped during the 1990 flood event. As the Old Sumas Lake Bottom was originally a lake that would have provided additional storage during flood events, the dikes protecting the former lake area contribute to higher water levels on the unprotected side (the West Sumas Prairie). Elevations in the Old Sumas Lake Bottom are several metres lower than the surrounding land and are drained through the Sumas Lake Canal via the Barrowtown Dam pump station into the Sumas River downstream of the Barrowtown Dam.

The Barrowtown Dam consists of four floodboxes designed to a combined flow rate of 225 m^3/s to convey the Sumas River flow and a pump station containing four pumps with a total pumping capacity of 40 m^3/s to mainly pump the Old Sumas Lake Bottom. Downstream of the dam, discharged water flows along the Sumas River to its confluence with the Vedder Canal and ultimately drains into the Fraser River. The Barrowtown Dam floodboxes are intended to close and prevent backflows into the Sumas River when water levels downstream of the dam are higher than upstream of the dam as a result of high flows in the Fraser River and/or Vedder River. During these high flow periods, water levels typically rise in the Fraser River as water levels drop in the Vedder River. Sumas River flow can also be diverted to two of the pumps so that they may pump the Sumas River instead of the Lake Bottom. This pump diversion is typically carried out during Fraser River freshets when water levels in the Fraser River are higher than water levels upstream of Barrowtown Dam in the Sumas River.

1.4 Background Studies

The following background studies and reports in Table 1-1 were provided by the City and reviewed by KWL as part of this project

Table 1-1: Background Studies and Reports

Study or Report Title	Year	Prepared By	Prepared For
Flooding of West Sumas Prairie Nov. 9-12, 1990	1991	Klohn Leonoff	BC Environment
Nooksack River Trans-Boundary Flooding	1991	Nooksack River International Task Force	BC Environment, Environment Canada, District of Abbotsford, Washington State, Whatcom County, Seattle District, FEMA Region 10
Nooksack River Trans-Boundary Flooding - Status Report #1	1992	Nooksack River International Task Force	BC/Washington Environmental Cooperation Council, Washington State, BC Environment
Nooksack River Avulsion Study	1993	Klohn Leonoff	BC Environment
Lower Nooksack River Comprehensive Flood Hazard Management Plan- Program for Flood Forecasting, Monitoring, and Warning Precipitation Spotter Network	1994	KCM	Whatcom County

Study or Report Title	Year	Prepared By	Prepared For
Nooksack River Trans-Boundary Flooding - Status Report #2	1994	Nooksack River International Task Force	BC/Washington Environmental Cooperation Council, Washington State, BC Environment
Lower Nooksack River Comprehensive Flood Hazard Management Plan - Sediment Supply and Transport	1995	KCM	Whatcom County
The Sumas River Flood Routing Study - Interim Report (Vol 1)	1998	Wilson Hydrotechnical	City of Abbotsford, BC Environment
The Sumas River Flood Routing Study - Interim Report (Vol 2)	1998	Wilson Hydrotechnical	City of Abbotsford, BC Environment
The Sumas River Flood Routing Study - Interim Report (Vol 3)	1998	Wilson Hydrotechnical	City of Abbotsford, BC Environment
Lower Nooksack River Comprehensive Flood Hazard Management Plan	1999	Whatcom County, KCM	Whatcom County
Lower Nooksack River Comprehensive Flood Hazard Management Plan - Developing a Long-Term Plan to Address Flood Problems	1999	Whatcom County, KCM	Whatcom County
Sumas River Flood Study – Farm Survey Report	2001	UMA Engineering	City of Abbotsford
Sumas Prairie Flood Hazard Investigation Interim Report 2003	2003	UMA Engineering	City of Abbotsford
Lower Nooksack River Unsteady-Flow Model and Analysis of Initial Scenarios Near Everson	2004	Linsley Kraeger Associates	Whatcom County
Sumas Prairie Flood Hazard Investigation, 1990 Flood Calibration (2005)	2005	UMA Engineering	City of Abbotsford
Flood Frequency Analysis at Deming, Ferndale and Everson	2005	Linsley Kraeger Associates	Whatcom County
Review of the 100-Year Demining and cross-border Flows Provided by US in January 2007	2007	UMA Engineering	City of Abbotsford
Deming Gage Analysis and Development of a 100-Year Design Hydrograph	2008	Whatcom County	Whatcom County

Study or Report Title	Year	Prepared By	Prepared For
Flood Emergency Model Preparation for Sumas Prairie	2012	Kerr Wood Leidal	City of Abbotsford
Sumas Prairie Design Flood Simulation and Impact Mitigation (Phase 1 Project Summary)	2014	Kerr Wood Leidal	City of Abbotsford
City of Abbotsford Drainage Master Plan	2018	Kerr Wood Leidal	City of Abbotsford

1.5 Acknowledgements

Kerr Wood Leidal would like to acknowledge contributions and input from many people during the process of completing this work:

- City of Abbotsford Staff, especially Stella Chiu, Rob Isaac, and Tyler Bowie
- Inspector of Dykes for British Columbia, Mitchell Hahn
- Province of BC staff, including Queenie Yip, Cher King-Scobie, and Junyung Qu
- Whatcom County, Washington River and Flood Division staff Paula Harris and Deborah Johnson
- Washington State Department of Ecology staff Douglas Allen and David Radabough
- Philip Davies of Davies Transportation Consulting Inc., who provided analysis of and estimates for transportation and business impacts of flooding.

2. Flood Analysis for Existing Climate Conditions

The scope of this project involved analysing flood risks for the following five (5) flood scenarios under existing climate conditions:

- **Scenario 1**: November 1990 flood (includes embankment breaching that occurred during the event)
- **Scenario 2A**: 100-year Sumas flood with Nooksack overflow (includes embankment breaching as in November 1990 flood)
- **Scenario 2B**: 100-year Sumas flood with Nooksack overflow (assumes no embankment or dike breaching)
- **Scenario 2C**: 100-year Sumas flood without Nooksack overflow (assumes no embankment or dike breaching)
- **Scenario 3**: 200-year Sumas flood with Nooksack overflow (includes embankment breaching as in November 1990 flood and breaching of the Sumas River dike)

The embankment breaching referred to in the descriptions above consists of two breaches that occurred during the November 1990 flood event. The first breach was along the Southern Railway near Kenny Road and the second breach was along Whatcom Road near Highway 1. These embankments are not flood protection dikes and thus the breaching is an assumption and not a function of flood probability.

The Sumas River Dike breach referred to in the descriptions above consist of a hypothetical breach in the Sumas River Dike at the low point in the dike alignment located approximate 1.3 km downstream of its intersection with Lakemount Road and McDermott Road. Previous studies[3,4] have noted that the dike is prone to breaching because it was constructed without controlled spillways and inadequate structural protection.

2.1 MIKE FLOOD Modelling

All five flood scenarios (1, 2A, 2B, 2C and 3) were simulated using the MIKE FLOOD model that was previously developed by KWL for the 2014 Sumas Prairie flood study[2]. Four of these scenarios (1, 2A, 2B and 2C) were previously simulated using the MIKE FLOOD model for the 2014 study. For the 200-year flood (Scenario 3), the following inflows and downstream boundary conditions data were input into the model:

- Cross-border 200-year bank overflow hydrographs from the 2003 UMA study[3] (referred to as C1, C2, C3 and C6), which were received from Whatcom County in 2002;
- Sumas River catchment 200-year flow hydrographs (excluding Nooksack River overflows) from the UBC Watershed model (Dr. Michael Quick, 1997);
- Vedder / Chilliwack River 200-year flow hydrograph based on the shape developed for 2003 UMA ONE-D model[3] but scaled up to current 200-year Chilliwack River flow estimate (1,545 m^3/s); and
- Downstream 200-year water level boundary, based on the shape developed for UMA 2003 ONE-D model[3] but scaled up to match the existing Fraser River 200-year winter peak water level at the mouth of the Sumas River (6.19 m CGVD28 as per 2014 NHC model[5]).

The 200-year flood event simulated in the 2003 UMA study was labelled in the report as an "Extreme Flood Event" rather than a "200-year flood", as the Deming flow gauge data that was used to generate this flood event in the Whatcom County FEQ model of the Nooksack River was found to be unreliable. An investigation by Whatcom County found that the Deming gauge issues were a result of bed instability and scour during flood events[6]. Thus, the 200-year bank overflow hydrographs used for Scenario 3 in the current study are based on older and less reliable data compared to the updated 100-year hydrographs that were received from Whatcom County in 2011. Updated 200-year hydrographs were requested but were not available for this study and further work would need to be carried out in the US to update the 200-year flood hydrographs. Furthermore, it has been observed that the Nooksack River has been aggrading in certain locations including near Everson at the overflow location. It appears that the overflows are occurring at lower Nooksack River flow rates as evidenced by the recent February 2020 overflow event. Given this change, it would be prudent to update the US-side models, obtain up-to-date cross-border flows, and update the Canada-side modelling on a regular basis as the overflows may become larger than previously modelled for the same return period flood.

Scenario 3 assumed that the road and railway embankments breach in the same manner and location as the 1990 flood, as simulated in Scenario 1 and 2A. The logic behind this assumption is that the hydraulic loads on the embankments during the 200-year flood would be greater than they were in 1990, leading to a higher risk of breaching. Embankment breaching was modelled for all relevant scenarios as per the conditions used in the 2014 KWL model[2], which assumes that breaching occurs when the embankments are overtopped by a depth of 0.15 m. This overtopping depth is equivalent to elevations of 9.55 m CGVD28 for Southern Railway and 7.85 m CGVD28 for Whatcom Road.

Breaching of the Sumas River Dike was also assumed for Scenario 3, as peak water levels at the low point in the dike alignment were found to be approximately 0.5 m above the dike crest elevation and the 2003 UMA study[3] noted that breaching would occur if the dike is overtopped by a depth of 0.2 m. The dike breach was modelled following the same assumptions as the 2003 UMA model where a two-stage breach occurs when water levels reach 0.2 m above the dike crest, or 6.67 m CGVD28. In the first stage, the breach grows over a 15-minute period to a 60 m wide gap with near vertical side slopes and an invert elevation of 2.45 m CGVD28. In the second stage which occurs over the next 2.5 hours, the breach widens to 110 m total bottom width with 1.5H:1V side slopes and an invert elevation of 2.45 m CGVD28. The intent of the updated modelling (Scenario 3 model) was to replicate the previous UMA 200-year model and therefore alternate breach grown patterns were not investigated.

As this project involves modelling of new flood scenarios (the 200-year event, climate change events and flood mitigation events) that were run using a newer hardware and software environment relative to the previous work completed in 2014[2], all flood scenarios for this project including those that were previously run for the 2014 study (1, 2A, 2B and 2C) were simulated using the same environment (2017 MIKE software[7]) to ensure consistency between the scenarios.

A summary of the model components for each flood scenario is presented in Table 2-1. The total cross-border peak flows listed in the table refer to the combined river and overland flow crossing the US/Canada border.

With the exception of the November 1990 flood scenario that used recorded data downstream of Barrowtown Dam, the remaining 100-year and 200-year flood scenarios used design flow hydrographs for the Vedder River and design water levels for the Fraser River.

Table 2-1: Summary of Existing Climate Flood Scenario Model Components

Scenario ID	Sumas & Vedder Hydrograph Inputs	Nooksack Overflow Hydrograph Inputs	Total Cross-Border Peak Flow (m^3/s)	Peak Fraser River Water Level (m CGVD28)	Road & Railway Embankment Breaches	Sumas River Dike Breach
1	[1]Nov 1990	Nov 1990	238	[1]N/A	yes	no
2A	100-year	100-year	413	[2]5.80	yes	no
2B	100-year	100-year	413	[2]5.80	no	no
2C	100-year	(none)	61	[2]5.80	no	no
3	200-year	200-year	566	[2]6.19	yes	yes

[1] Recorded water levels downstream of Barrowtown Dam were used for the downstream boundary condition for the November 1990 event in lieu of a Vedder River flow hydrograph and Fraser River water level hydrograph inputs.

[2] Peak Fraser River water levels used for the 100-year and 200-year scenarios match the winter peak (non-freshet) Fraser River water levels at the mouth of the Sumas River for existing sea level conditions reported in the 2014 NHC modelling study[8].

2.2 Flooding Impacts for Existing Climate Conditions

Following the MIKE FLOOD model simulations of the five flood scenarios, peak water depths were exported from the model and interpolated into a gridded flood depth raster for each of the five scenarios to be used for the flood damage assessments. The flood depth rasters were generated at a 5 m resolution, which was selected to best represent the water level surface within the model and to best reproduce the flood results reported in the 2014 KWL study[2]. Flood depth mapping for the five scenarios are presented in Figures A-1 to A-6 in Appendix A.

As shown in the figures, the November 1990 Nooksack overflow flood (having an estimated 35-year return period) resulted in the least amount of flooding, even less than the 100-year flood without Nooksack overflow scenario (Scenario 2C). While higher peak flows were associated with the November 1990 flood than Scenario 2C, less overall flooding occurred during the November 1990 flood due to differences in flood volumes, timing, and water levels downstream of Barrowtown Dam. More flooding occurred in the Marshall Creek sump area during the November 1990 flood due to the railway breaching.

The Lake Bottom experiences relatively minor flooding in all scenarios except the 200-year flood which is expected to breach the Sumas River Dike. This dike and the Interceptor Dike are overtopped in the 100-year return period with Nooksack overflow scenarios (Scenarios 2A and 2B), but not in the November 1990 flood or the 100-year flood without Nooksack overflows. Comparing Scenarios 2A and 2B, there are some differences in the flooding pattern where in Scenario 2B the Marshall Creek sump floods less at the expense of the Saar Creek sump area that sees larger flows due to the Southern Railway embankment staying intact.

3. Flood Analysis for Future Climate Change Conditions

The scope of this project involved analysing flood risks for the following four (4) climate change flood scenarios:

1. **Scenario CC-2A**: 100-year Sumas flood with Nooksack overflow under climate change conditions (includes embankment breaching as in November 1990 flood and breaching of the Sumas River dike)
2. **Scenario CC-2B**: 100-year Sumas flood with Nooksack overflow under climate change conditions (assumes no embankment or dike breaching)
3. **Scenario CC-2C**: 100-year Sumas flood without Nooksack overflow under climate change conditions (assumes no embankment or dike breaching)
4. **Scenario CC-3**: 200-year Sumas flood with Nooksack overflow (includes embankment breaching as in November 1990 flood and breaching of the Sumas River dike).

The above climate change scenarios consist of the four previously analysed 100-year and 200-year design flood scenarios (2A, 2B, 2C and 3) simulated under future climate change conditions. The November 1990 flood (Scenario 1) was not included in the climate change analysis.

3.1 Impacts of Climate Change on Extreme Flows

Climate change hydrographs for the 100-year and 200-year floods were developed by analysing all relevant climate change information for extreme flows in the Nooksack River, Sumas River and Vedder River. The following four (4) relevant data sources on climate change were identified for this project:

1. **University of Washington Climate Impacts Group Research on Columbia River Basin and Adjacent Coastal Watersheds**[9,10,11,12]: provides climate change projections for the 100-year flow in the Nooksack River at Ferndale using a Variable Infiltration Capacity (VIC) model for Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) scenarios A1B and B1.
2. **Western Washington University Research on Nooksack River**[13,14,15]: provides climate change projections for daily flows in the Nooksack River at North Cedarville using a Distributed Hydrology-Soil-Vegetation Model (DHSVM) coupled with a dynamic glacier model (GLACIER) for IPCC Fifth Assessment Report (AR5) Representative Concentration Pathways (RCPs) 4.5 and 8.5.
3. **Pacific Climate Impacts Consortium (PCIC) Climate Explorer Tool**[16]: provides climate change projections for extreme precipitation amounts using RCP 8.5 and multiple GCMs for gridded locations within British Columbia.
4. **Western University IDF_CC Tool**[17]: provides climate change projections for extreme precipitation amounts using multiple IPCC AR5 RCPs for gridded locations and climate stations within Canada.

The following sections summarize the findings of each of the above four data sources.

University of Washington Research

For climate change flows in the Nooksack River, Whatcom County recommends the use of research carried out by the Climate Impacts Group from the College of the Environment at the University of Washington[9,10,11,12]. This research uses a large-scale hydrologic model of the Columbia River Basin and adjacent coastal watersheds, as shown in Figure 3-1. The hydrologic model used for the study was the Variable Infiltration Capacity (VIC), which is a spatially distributed water balance model that includes vegetation and soil layers for infiltration and evapotranspiration processes. The model was calibrated to eleven river gauging stations in the Columbia Basin based on a monthly timestep, and therefore did not include any calibration along the Nooksack River.

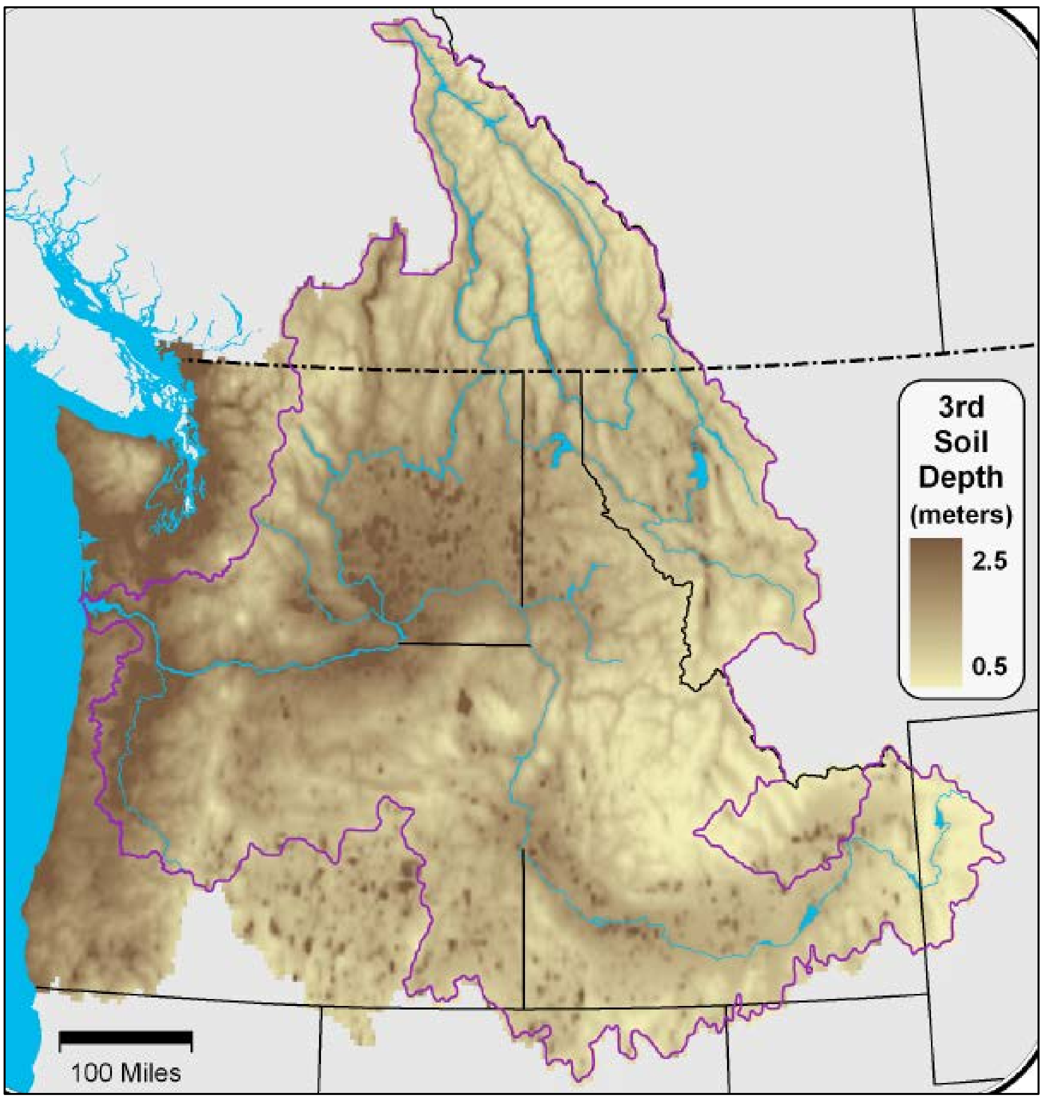


Figure 3-1: VIC Model Extents (shaded) and Columbia River watershed delineation (purple outline) (Source: 2010 University of Washington Report[9])

The VIC model was used to simulate climate change flows throughout the 21st century at 297 river gauging stations, including Nooksack River at Ferndale, using 10 statistically downscaled Global Climate Models (GCMs). The climate change scenarios selected for these simulations were A1B and B1 from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios issued in 2000. A1B is a medium emissions scenario associated with increasing greenhouse gas emissions throughout the century, whereas B1 is a low emissions scenario associated with implementing significant greenhouse gas mitigation measures throughout the century. These climate change scenarios were historically used for the IPCC Third Assessment Report (AR3) issued in 2001 and the Fourth Assessment Report (AR4) issued in 2007, and have since been superseded by the Representative Concentration Pathways (RCPs) published in the Fifth Assessment Report (AR5) issued in 2014. The RCPs include scenarios with much larger climate change impact predictions than those predicted by A1B and B1. Results published by The University of Washington research are therefore based on climate change information that is not up to date and is no longer used in the scientific community. Nevertheless, the results from this study are discussed below such that they can be compared with other works that use the more recent IPCC AR5 scenarios.

Extreme flows were generated from the VIC model results by carrying out a flood frequency analysis with the Generalized Extreme Value (GEV) distribution using the L-moments method. Results provided by the University of Washington study for the Nooksack River are summarized in Table 3-1 for Scenario A1B and Table 3-2 for Scenario B1. Increases in flow are based on a historical period spanning from 1970 to 1999. As shown in Table 3-1, an average increase of 30% was predicted for the 100-year flow for the 2070 to 2099 period based on Scenario A1B, and this value was recommended for use by Whatcom County.

It should be noted that increases in flow rates in the Nooksack River do not necessarily correspond to similar increases in overflow rates at Everson and into the Sumas Prairie, as this relationship would need to be modelled. Moreover, climate change impacts associated with the Sumas River would likely differ from climate change impacts associated with the Nooksack River. For these reasons, climate change predictions for the Nooksack River can only be assumed to approximately represent those for the Sumas Prairie.

Table 3-1: Percent Increases in Extreme Flows in Nooksack River for Scenario A1B[12]

Climate Model	Increase in Flow for 2030 to 2059 Period (%)			Increase in Flow for 2070 to 2099 Period (%)		
	20-year	50-year	100-year	20-year	50-year	100-year
ccsm3	15	14	14	14	11	8
cgcm3.1_t47	36	33	30	41	39	38
cnrm_cm3	17	18	19	35	31	29
echam5	9	8	8	24	23	22
echo_g	9	10	12	18	16	15
hadcm	14	11	9	12	12	13
hadgem1	2	3	4	31	39	46
ipsl_cm4	21	17	14	38	34	32

Climate Model	Increase in Flow for 2030 to 2059 Period (%)			Increase in Flow for 2070 to 2099 Period (%)		
	20-year	50-year	100-year	20-year	50-year	100-year
miroc_3.2	50	48	47	70	68	67
pcm1	16	20	23	31	32	32
Average	19	18	18	31	31	30
Median	16	16	14	31	32	31

Table 3-2: Percent Increases in Extreme Flows in Nooksack River for Scenario B1[12]

Climate Model	Increase in Flow for 2030 to 2059 Period (%)			Increase in Flow for 2070 to 2099 Period (%)		
	20-year	50-year	100-year	20-year	50-year	100-year
ccsm3	13	14	15	5	2	0
cgcm3.1_t47	24	23	23	32	33	35
cnrm_cm3	14	15	17	24	24	24
echam5	8	7	5	25	25	25
echo_g	-18	-18	-18	10	9	8
hadcm	0	0	1	20	20	20
hadgem1	-	-	-	-	-	-
ipsl_cm4	18	16	15	38	35	33
miroc_3.2	39	38	37	53	51	49
pcm1	11	12	12	34	38	41
Average	12	12	12	27	26	26
Median	13	14	15	25	25	25

Western Washington University Research

Multiple research projects on climate change flows along the Nooksack River have been carried out at Western Washington University under the supervision of Dr. Robert Mitchell. The following three master's theses have been published on the subject and their relevant information is summarized in Table 3-3:

1. Susan E. Dickerson (2010): "Modeling the effects of climate change forecasts on streamflow in the Nooksack River Basin"[13].
2. Ryan D. Murphy (2016): "Modeling the effects of forecasted climate change and glacier recession on late summer streamflow in the Upper Nooksack River Basin"[14].
3. Stephanie E. Truitt (2018): "Modeling the effects of climate change on stream temperature in the Nooksack River Basin"[15].

Table 3-3: Summary of Nooksack River Studies at Western Washington University

Thesis	Hydrologic Model	IPCC Climate Change Scenario	Number of Simulated GCMs	Format of Reported Flow Results	Location along Nooksack River	Relevant Figures and Tables
Dickerson (2010)[13]	DHSVM	A2, B1	3	Annual peak, monthly median, CDFs of annual peak, CDFs of spring peak	North Cedarville	Figures 26, 27, 30, 31, 32
Murphy (2016)[14]	DHSVM-GLACIER	RCP 4.5, RCP 8.5	10	Daily median, monthly median	North Cedarville, South/Middle/ North Forks	Figure 18, Table 9
Truitt (2018)[15]	DHSVM-GLACIER	RCP 4.5, RCP 8.5	10	Daily mean	South/Middle/ North Forks	Figures 8, 9, 10

All three studies use the Distributed Hydrology-Soil-Vegetation Model (DHSVM), which is a spatially distributed water balance model developed at the University of Washington and the Pacific Northwest National Laboratory. While several similarities exist between DHSVM and the VIC model, the DHSVM is applicable for much higher resolution analyses than the large-scale VIC model, and it allows for surface and subsurface water exchanges between model cells. Murphy (2016) and Truitt (2018) used the DHSVM model coupled with a dynamic glacier model (DHSVM-GLACIER).

Dickerson (2010) and Murphy (2016) provided results at the North Cedarville flow gauging station along the Nooksack River, which is downstream of the Deming station and upstream of Everson. However, Truitt (2018) only focused on the upper watershed along the three forks of the Nooksack River and therefore does not provide any results in the lower area of the watershed near Deming, Everson or Ferndale. For this reason, the results presented by Truitt (2018) are not considered to be as relevant as the results presented in the previous two studies. Moreover, all three of the above studies only evaluate flows in the Nooksack River, excluding impacts on overflow rates at Everson and climate change impacts on the Sumas River.

While none of the studies explicitly evaluated impacts on 100-year and 200-year extreme flow events, Dickerson (2010) developed cumulative distribution functions (CDFs) on annual peak and spring peak flows that could give a sense of how climate change will impact larger flow events (Figure 3-2). The CDFs show that flows with return periods of approximately 10-year to 50-year could increase by as much as 50% to 100% for Scenario A2. However, the study notes that model calibration was focused on the timing of peaks rather than the magnitude. Moreover, like the VIC modelling work completed at the University of Washington, Dickerson (2010) used IPCC climate change scenarios from the Special Report on Emissions Scenarios (2000) that have now been superseded by RCPs in the IPCC Fifth Assessment Report (2014). For this reason, the modelling results from Murphy (2016) that are based on RCPs supersede the work completed by Dickerson (2010). Murphy (2016) also coupled the previous DHSVM from Dickerson (2010) with a dynamic glacier model and expanded the number of relevant GCMs from 3 to 10, further improving the model.

Murphy (2016) provides daily median flow model output for each day of the year under historical and future climate change conditions (Figure 3-3). From these results, annual maximum flows in the Nooksack River can be estimated to increase by approximately 30% by the end of the century. While the modelling work carried out by Murphy (2016) improves upon the modelling work previously carried out by Dickerson (2010), extreme flows were not evaluated as part of the Murphy (2016) study. The model output from Murphy (2016) would therefore need to be obtained from Western Washington University and further analysed using flood frequency analysis methods to predict increases in extreme flows. However, Murphy (2016) notes that peak flows were generally under-estimated by the model, indicating that a flood frequency analysis on the model results may not provide accurate predictions.

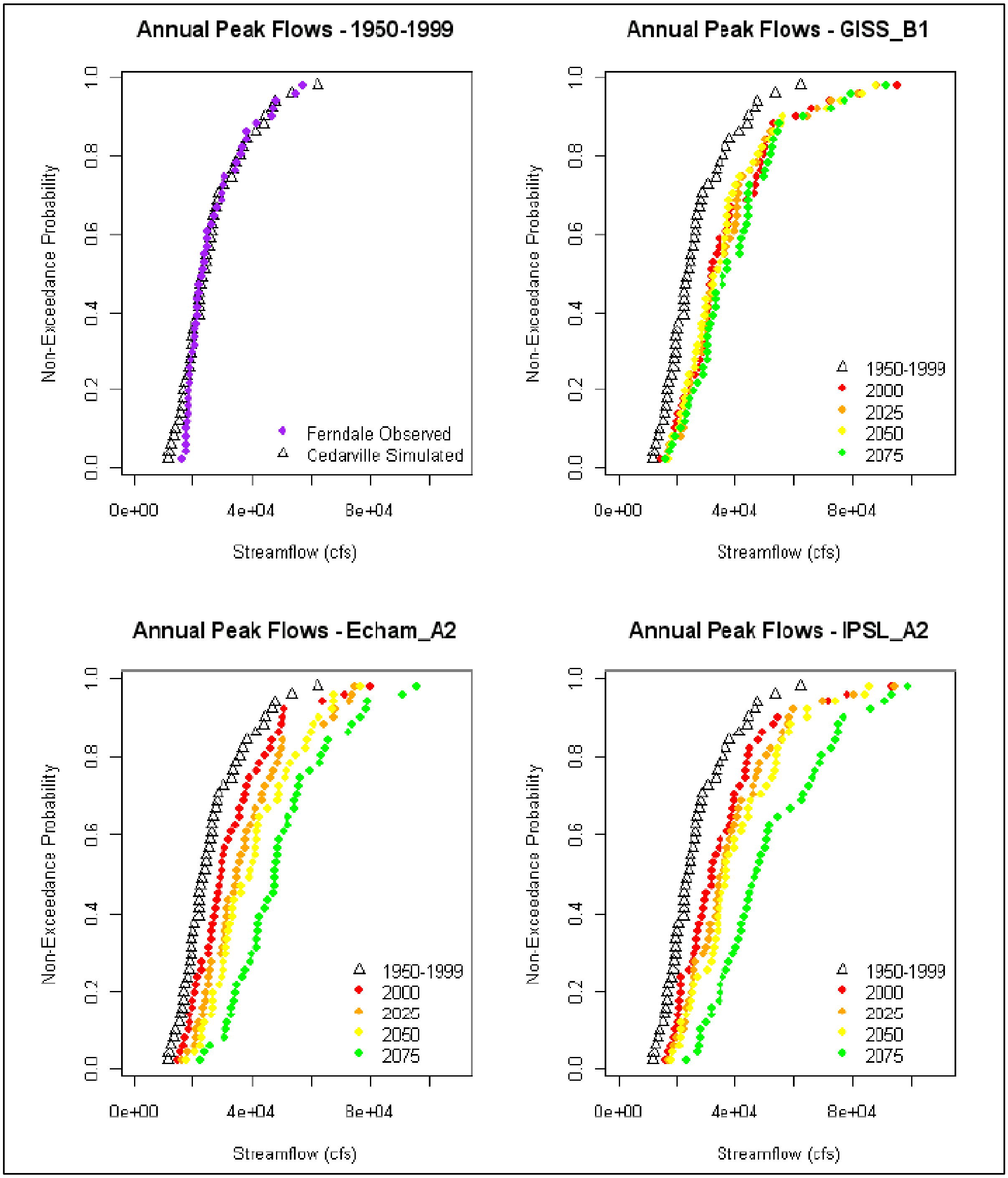


Figure 3-2: Cumulative Distribution Functions of Historical and Predicted Annual Peak Flows at Ferndale (source: Dickerson 2010[13])

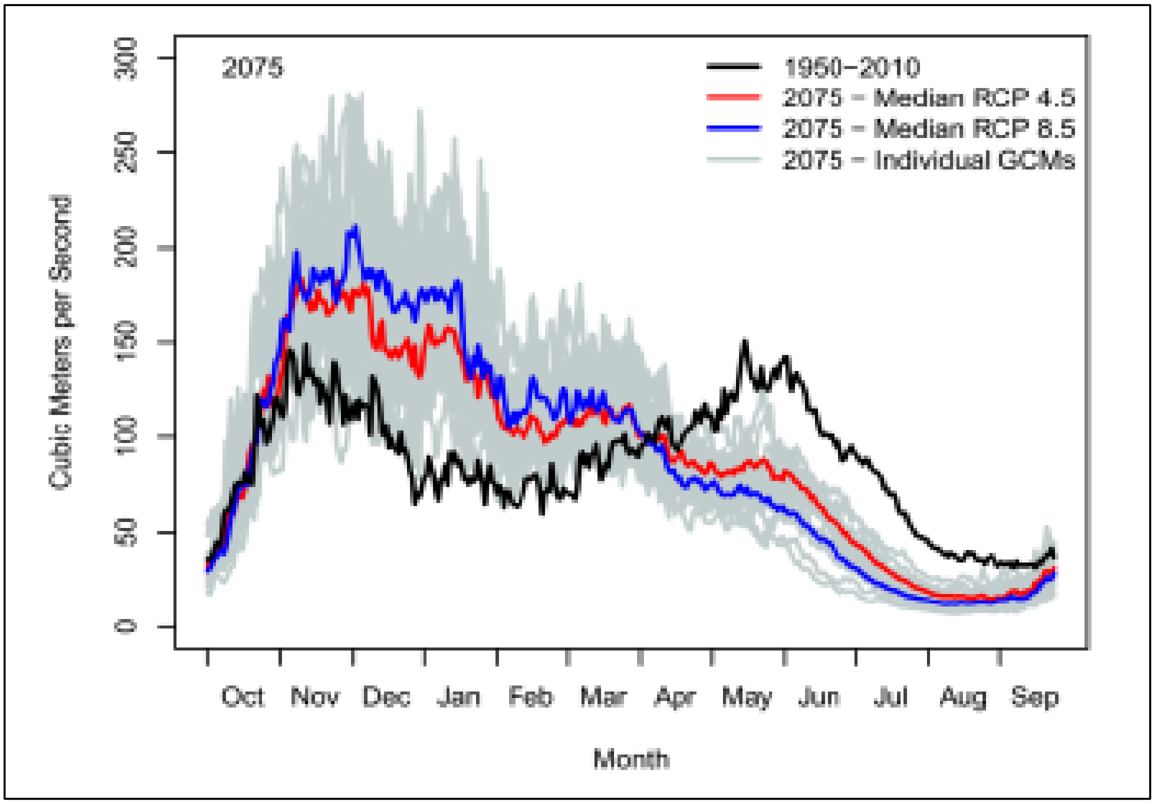


Figure 3-3: Historical and predicted daily median streamflow at North Cedarville (Source: Murphy 2016[14])

Pacific Climate Impacts Consortium Climate Explorer Tool (PCEX)

PCIC provides gridded statistically downscaled precipitation data using the BCCAQ v2 and climate change projections for RCP 8.5 using multiple GCMs. For extreme precipitation events, PCIC also provides 5-year, 20-year and 50-year estimations using a GEV distribution. Extreme precipitation events are calculated for the 1971 to 2000 historical period and for the 2011 to 2040, 2041 to 2070 and 2071 to 2100 future climate change periods. These predictions are available from PCIC's Climate Explorer (PCEX) tool[16] for four climate models.

Predicted increases in extreme 24-hour precipitation amounts were obtained from PCEX for the 50-year return period for the portion of the Sumas Prairie watershed area located within Canada and are presented in Table 3-4. As shown in the table, predictions were highly variable between the four climate models. However, three of the four models predicted that precipitation could increase by as much as 28% or 29% during one of the three future climate change periods that were evaluated.

Table 3-4: Percent Increases in Extreme Precipitation for Scenario RCP 8.5 (PCIC)

Climate Model	Increase in 50-Year 24-Hour Precipitation (%)			
	2011-2040	2041-2070	2071-2100	Maximum
CanESM2	2	12	28	28
CNRM-CM5	29	0	6	29
MIROC5	-11	-13	-3	-3
inmcm4	28	-3	13	28
Average	12	-1	11	20
Median	15	-1	9	28

While increases in extreme precipitation do not necessarily result in the same increases in extreme flows, changes in precipitation amounts will generally correspond to changes in flow rates. Further climate change analyses should, however, be carried out directly on extreme flows in the Nooksack River and Sumas River to provide a better estimate of future flows. Another limitation of the PCIC predictions is that the grid area is limited to British Columbia and does not include the Nooksack River watershed. The use of PCIC predictions for the Sumas Prairie would therefore assume similar climate change impacts for the Nooksack River watershed and the portion of the Sumas River watershed located within the US.

Western University IDF Climate Change Tool

Western University has developed an IDF Climate Change (IDF_CC) Tool[17] for predicting increases in extreme precipitation amounts in Canada both at individual climate stations and through gridded interpolation. The current version of the tool includes 24 bias-corrected climate models produced by PCIC using the BCCAQ v2. Extreme precipitation amounts are estimated using a GEV distribution.

An analysis was carried out for the former Huntingdon Vye Road Environment Canada climate station, which is the closest Environment Canada climate station to the study area. The climate station has thirteen years of data collected from 1961 to 1976. For this period, the 24-hour 100-year precipitation amount was estimated by the IDF_CC Tool to be 129 mm. For the 2071 to 2100 period, the 24-hour 100-year precipitation amount was estimated to be 166 mm based on the median of all 24 BCCAQ v2 models. This corresponds to a predicted increase in precipitation of 28%. Other climate change periods and RCPs were also examined but were found to predict lower amounts of extreme precipitation.

Similar to the PCIC data, the IDF_CC Tool only predicts extreme precipitation and can therefore only be used as a general indicator of extreme flow predictions. Moreover, the tool can only be used to evaluate single point locations within Canada, and predictions for the Sumas Prairie may not be representative of the entire Nooksack River and Sumas River watersheds, particularly in the upper mountainous areas.

Selected Climate Change Factor for Hydrograph Inputs

While no climate change factors have been explicitly estimated for extreme flows in the Sumas Prairie, the research and tools discussed above can be used to make an approximate estimation of future extreme flows for the purposes of this project. The University of Washington research estimates a 30% increase in 100-year flows in the Nooksack River based on a medium emissions scenario from the now outdated IPCC AR4. Considering how the Western Washington University research on the Nooksack River estimates a similar increase in annual peak flows based on RCP 8.5 from IPCC AR5, and both PCEX and the IDF_CC Tool estimate increases in extreme precipitation within the Sumas Prairie to also approach 30% based on RCP 8.5, the use of +30% for increases to 100-year and 200-year peak flows in the Sumas Prairie is a reasonable estimate.

For these reasons, a climate change factor of 1.3 was selected for this project. All inflow hydrographs in the MIKE FLOOD model were therefore be scaled by 1.3 to simulate climate change conditions for the 100-year and 200-year floods.

3.2 Climate Change MIKE FLOOD Modelling

A summary of the model components for each of the four climate change flood scenarios (CC-2A, CC-2B, CC-2C and CC-3) is presented in Table 3-5. In addition to climate change impacts on flows, downstream water level boundary conditions in the Fraser River were increased to 6.16 m CGVD28 for the 100-year and 6.51 CGVD28 for the 200-year to account for a 1 m rise in sea level, as per the 2014 NHC Fraser River model results for winter peak water levels[5].

Table 3-5: Summary of Climate Change Flood Scenario Model Components

Scenario ID	Sumas & Vedder Hydrograph Inputs	Nooksack Overflow Hydrograph Inputs	Total Cross-Border Peak Flow (m^3/s)	[1]Peak Fraser River Water Level (m CGVD28)	Road & Railway Embankment Breach	Sumas River Dike Breach
CC-2A	100-year (CC)	100-year (CC)	537	6.16	yes	yes
CC-2B	100-year (CC)	100-year (CC)	537	6.16	no	no
CC-2C	100-year (CC)	(none)	80	6.16	no	no
CC-3	200-year (CC)	200-year (CC)	735	6.51	yes	yes

[1] Peak Fraser River water levels used for the 100-year and 200-year scenarios match the winter peak (non-freshet) Fraser River water levels at the mouth of the Sumas River for 1 m sea level rise conditions reported in the 2014 NHC modelling study[18].

While breaching of the Sumas River dike was found to be unlikely during the 100-year flood under existing climate conditions (Scenario 2A), the higher water levels that occur during the 100-year flood under climate change conditions (Scenario CC-2A) were found to cause breaching. Thus, breaching of the Sumas River Dike was assumed for Scenario CC-2A, whereas the dike was assumed not to breach for Scenario CC-2B to compare the impacts on flooding between the two assumptions. No other modifications were made to the embankment and dike breach assumptions for the climate change versions of the 100-year and 200-year flood scenarios.

3.3 Flooding Impacts for Climate Change Conditions

Gridded flood depth raster files at 5 m resolution were generated for the four climate change scenarios from the MIKE FLOOD results following the same GIS procedure as for the existing climate flood scenario results. Flood depth mapping for the four climate change scenarios are presented in Figures B-1 to B-4 in Appendix B.

The figures show, as expected, that the 100-year without Nooksack overflow scenario (Scenario CC-2C) resulted in the least amount of flooding. The Lake Bottom experiences relatively minor flooding in the scenarios where the Sumas River Dike is not breached (Scenarios CC-2B and CC-2C). This dike and the Interceptor Dike are overtopped in Scenarios CC-2B and CC-2C. Comparing Scenarios CC-2A and CC-2B, in addition to the minor differences in the flooding pattern in the Marshall and Saar Sumps, the Lake Bottom flooding is much greater when the Sumas River Dike breaches (Scenario CC-2A). In Scenario CC-2B where the Sumas River Dike was not allowed to breach, the water level in the river rises 0.6m above the current crest of the low spot in the dike and therefore a breach is the appropriate assumption in a 100-year with climate change and Nooksack overflow scenario.

4. Flood Damage Assessment

Flood damage assessment for this study for unmitigated conditions was performed for the five existing climate conditions flood scenarios (1, 2A, 2B, 2C and 3). The flood damage assessment described herein includes an assessment of the following:

- **Structure and Content Damages**: estimated using a HEC-FIA model based on flooding of residential and non-residential structures.
- **Agricultural Losses**: estimated based on the areas flooded within each agricultural parcel.
- **Affected Populations**: estimated based on flooding of residential structures.
- **Transportation and Business Economic Losses**: estimated based on highway and railway closure times and flooding of non-agricultural businesses.
- **Qualitative Impacts**: evaluated environmental impacts, lifeline and utility disruption, impacts to First Nations and the potential for a Nooksack River avulsion.

A discussion of the methodology and results for the above types of impacts is provided in each section.

4.1 Structure and Content Damages (HEC-FIA)

Structure and content damages were quantified using HEC-FIA version 3.0.1[19]. The modelling software allows for building footprints (GIS polygons) or building locations (GIS points) to be input with corresponding depth-damage curves for structure and content damages. Simulations are then carried out by overlaying a gridded flood depth raster to estimate flood depths at each structure and multiplying the estimated flood depths by the input depth-damage curves.

Building Locations and Elevations

Buildings were assumed to be point structures located at the centroid of each land parcel, as neither building footprints nor building locations were available in the City of Abbotsford GIS database. This assumption was made following an assessment of building locations based on aerial photography where buildings located on riverfront properties were typically found to be at higher ground or near adjacent roadways, whereas buildings located on other properties were typically found to be near the roadways or distributed throughout the parcel. If building flooding was instead assumed to commence once flooding occurs on its corresponding land parcel, this would highly overestimate flooding depths, particularly for properties located adjacent to the river. The centroid of the land parcel was therefore estimated to provide a best approximation of building locations for flood depth estimation purposes in the absence of building footprint GIS data.

The ground elevation at the centroid of each parcel was assumed for first-floor building elevations. Building foundations and foundation walls were therefore assumed to be fully buried below the ground. This assumption of the first floor being at ground elevation was observed to hold true for many of the residential houses based on available public online imagery accessible in Google StreetView, particularly for the single-family dwellings located within the higher density residential area of Huntingdon.

Depth-Damage Curves

Structure and content depth-damages curves used in the HEC-FIA model were obtained from the 2015 Alberta Provincial Flood Damage Assessment Study[20], which had a Calgary area focus. While depth-damage curves are currently in development for the Lower Mainland Flood Risk Assessment study by Fraser Basin Council as part of the Lower Mainland Flood Management Strategy, these curves are not yet available by the time this study concluded. Moreover, depth-damage curves from the 2003 UMA study[3] were not used, as the 2015 Alberta curves were more rigorously developed and are more current.

The depth-damage curves from the 2015 Alberta study provide damages value in units of "2014 dollars per square metre of floor area". These dollar damage values were converted to percentages of total damages such that BC Assessment values and content-to-structure value ratios could be used in lieu of the direct monetary estimates. This conversion was carried out because building floor areas are needed to apply the Alberta curves, and floor areas were not available for non-residential structures. The damage value associated with maximum depth on the Alberta curves (ceiling of the first floor) was assumed to be the damage value associated with 100% damage to the structure or contents.

The following residential depth-damage curves were obtained from the 2015 Alberta study and used in the HEC-FIA model:

- **Residential structure and content depth-damage curve names**
  - A1: large high-end house (one-storey)
  - A2: large high-end home (two-storey)
  - B1: medium-size average quality house (one-storey)
  - B2: medium-size average quality house (two-storey)
  - C1: small-size lower quality house (one-storey)
  - C2: small-size lower quality house (two-storey)
  - D1: mobile home
  - MW1: walk-up apartment (less than five storeys)
- **Non-residential structure depth-damage curve names**
  - S1: Office/Retail
  - S2: Industrial/Warehouse
  - S3: Hotel/Motel
  - S5: Institutional
- **Non-residential content depth-damage curve names**
  - A1: General Office
  - C6: Misc. Retail (retail that is not specific to other retail categories listed in 2015 Alberta study)
  - C7: General Retail (uncategorized retail – includes all retail categories)
  - G1: Auto
  - H1: Hotels
  - I1: Restaurants
  - L1: Warehouse/Industrial
  - N1: Other/Institutional

Building Categorization for Depth-Damage Curves

Building categories were developed for the various residential and non-residential buildings located within the study area (MIKE FLOOD model extents) such that the above 2015 Alberta study depth-damage curves could be applied. The building categories were developed by first grouping together all non-vacant land use categories from the Abbotsford parcel GIS database (the "USE_DESC" attribute) that were expected to have similar depth-damage relationships based on the 2015 Alberta study curves. A summary of the building categorization is presented in Table 4-1. As shown in the table, non-vacant agricultural parcels were initially assumed to contain both residential and non-residential building types, as these properties typically contain a mix of single-family dwellings and agricultural buildings (verified using aerial photography). However, non-vacant agricultural parcels with no corresponding residential first floor area data from BC Assessment were assumed to contain agricultural buildings only. This assumption was verified by checking the corresponding BC Assessment land use description, which often listed these parcels as barns, stables and other types of outbuildings.

Table 4-1: Building Categorization

Land Use Category ("USE_DESC" Attribute)	Residential Building Category	Non-Residential Building Category	Percent of Study Area
(blank)	-	-	3.0%
2 Acres or More (Outbuilding)	-	Warehouse	0.1%
[1]2 Acres or More (Seasonal Dwelling)	-	Warehouse	0.1%
2 Acres or More (Single Family Dwelling, Duplex)	Single-Family-Dwelling	-	2.2%
2 Acres or More (Vacant)	-	-	1.4%
Auto. Paint Shop Garages Etc.	-	Auto Garage	0.1%
Beef	Single-Family-Dwelling	Agriculture	0.7%
Big Box	-	Retail Warehouse	0.1%
Chemical & Chem.Prod. Indust.	-	Chemical Warehouse	< 0.1%
Churches & Bible Schools	-	Church	< 0.1%
Civic Institute & Rec.-Vacant	-	-	1.5%
Convenience Store/Service Stn.	-	Convenience Store	< 0.1%
Dairy	Single-Family-Dwelling	Agriculture	20.1%
Dairy - Vacant	-	-	5.6%
Elect. Power Systems (Non. Uti)	-	Electrical Substation	< 0.1%
Fast Food Restaurants	-	Restaurant	< 0.1%
Food Market	-	Retail	< 0.1%

Land Use Category ("USE_DESC" Attribute)	Residential Building Category	Non-Residential Building Category	Percent of Study Area
Gas Distribution Systems	-	Gas Distribution Facility	< 0.1%
Golf Courses (Public & Private	-	Clubhouse	0.3%
Gov. Bldgs. (Fire Post Police	-	Government Building	< 0.1%
Gov. Research (Fish Nurseries)	-	Animal Research Facility	< 0.1%
Grain & Forge	Single-Family-Dwelling	Agriculture	6.7%
Grain & Forge - Vacant	-	-	3.8%
[2]Group Home	-	-	< 0.1%
Hall(Community Lodge Club)	-	Clubhouse	< 0.1%
Hotel	-	Hotel	< 0.1%
[3]Industrial - Vacant	-	Warehouse	0.1%
Lmbr. Remanuf-Sep From Sawmill	-	Lumber Remanufacturing Facility	0.1%
Lumber Yard or Bldg. Supplies	-	Lumber Yard	0.1%
Mf - Apartment Block	Apartment Building	-	< 0.1%
Misc. & (Industrial Other)	-	Warehouse	< 0.1%
Misc. (Petroleum Industry)	-	Gas Distribution Facility	< 0.1%
Mixed	Single-Family-Dwelling	Agriculture	1.3%
Mixed - Vacant	-	-	0.2%
Mobile Home (Not in Mh Park)	Mobile Home	-	< 0.1%
Mobile Home (Within Mh Park)	Mobile Home	-	< 0.1%
Nursing Home	Nursing Home	-	< 0.1%
Office Building (Primary Use)	-	Office	< 0.1%
Oil Gas Pumping & Compressor Stn	-	Gas Distribution Facility	0.1%
Oil Gas Transport. Pipelines	-	-	< 0.1%
Other	Single-Family-Dwelling	Agriculture	14.9%
Other - Vacant	-	-	9.3%
Parks and Playing Fields	-	Recreational Facility	0.1%
Petroleum Bulk Plants	-	Gas Station	< 0.1%

Land Use Category (“USE_DESC” Attribute)	Residential Building Category	Non-Residential Building Category	Percent of Study Area
Poultry	Single-Family-Dwelling	Agriculture	3.9%
Railway	-	Warehouse	0.1%
Recreational & Cultural Bldgs.	-	Recreational Facility	0.2%
Recreational Clubs Ski Hills	-	Recreational Facility	0.1%
Sand & Gravel(Vacant & Improv)	-	-	< 0.1%
Schools Univ College Techn.	-	School	< 0.1%
Sfd With Basement Suite	Single-Family-Dwelling	-	0.1%
Shopping Centre (Community)	-	Retail	0.1%
Shopping Centre (Neighbourhood)	-	Retail	0.1%
Single Family Dwelling	Single-Family-Dwelling	-	0.4%
Small Fruits	Single-Family-Dwelling	Agriculture	7.7%
Small Fruits-Vacant	-	-	2.2%
Storage & Warehousing-Closed	-	Warehouse	0.6%
Storage & Warehousing-Cold	-	Warehouse	0.1%
Storage & Warehousing-Open	-	Warehouse	0.1%
Store(S) And Offices	-	Retail	< 0.1%
Telephone	-	-	< 0.1%
Triplex	Single-Family-Dwelling	-	< 0.1%
Vacant	-	-	< 0.1%
[4]Vacant Res. Less Than 2 Acres	-	Warehouse	< 0.1%
Veg & Truck	Single-Family-Dwelling	Agriculture	9.2%
Veg & Truck - Vacant	-	-	3.0%

[1]The “2 Acres or More (Seasonal Dwelling)” land use consisted of a single property (PID 013-075-888) that, according to BC Assessment, contains an outbuilding with a corresponding building value.

[2]The “Group Home” land use consisted of a single property (PID 013-394-193) with no BC Assessment data or building value and was therefore assumed to be vacant as per 2019 conditions.

[3]One property within the “INDUSTRIAL - VACANT" land use (PID 018-221-092) had an assessed building value and was therefore assumed to be non-vacant.

[4]One property within the “VACANT RES. LESS THAN 2 ACRES” land use (PID 000-793-795) had an assessed building value and was therefore assumed to be non-vacant. A “Warehouse” building category was assigned to this property because the property was described by BC Assessment as “Improvement Unclassified” with a building value of $1000.

Structure and content depth-damage curves from the 2015 Alberta study were applied to each residential building category as per Table 4-2. As shown in the table, the "single-family dwelling" building category was further sub-categorized based on the first-floor area and the number of storeys to be consistent with the single-family dwelling categories and corresponding depth-damage curves from the 2015 Alberta study. First, second, and third-floor areas were obtained from BC Assessment to estimate first floor areas and the number of storeys. Houses with more than two storeys were assumed to follow depth-damage relationships for two-storey houses, as depth-damage curves were not developed from the 2015 Alberta study for houses with more than two storeys. Further refinement was then made to distinguish between houses with and without basements using basement area data obtained from BC Assessment. For houses without a basement, the depth-damage curves were modified to not include basement damages. For non-residential buildings, individual structure and content depth-damage curves from the 2015 Alberta study were best selected for each building category as per Table 4-3. Depth-damage curve values are provided in Appendix D.

Table 4-2: Residential Building Categorization

Building Category	First Floor Area (ft^2)	Storeys	Basement?	[1]Depth-Damage Curves from 2015 Alberta Study
Single-Family Dwelling (A1-B)	2,400 to 3,999	One	Yes	A1
Single-Family Dwelling (A1-NB)	2,400 to 3,999	One	No	[2]A1
Single-Family Dwelling (A2-B)	2,400 to 3,999	Two	Yes	A2
Single-Family Dwelling (A2-NB)	2,400 to 3,999	Two	No	[2]A2
Single-Family Dwelling (B1-B)	1,200 to 2,399	One	Yes	B1
Single-Family Dwelling (B1-NB)	1,200 to 2,399	One	No	[2]B1
Single-Family Dwelling (B2-B)	1,200 to 2,399	Two	Yes	B2
Single-Family Dwelling (B2-NB)	1,200 to 2,399	Two	No	[2]B2
Single-Family Dwelling (C1-B)	< 1,200	One	Yes	C1
Single-Family Dwelling (C1-NB)	< 1,200	One	No	[2]C1
Single-Family Dwelling (C2-B)	< 1,200	Two	Yes	C2
Single-Family Dwelling (C2-NB)	< 1,200	Two	No	[2]C2
Mobile Home	-	-	-	D1
Apartment Building	-	-	-	MW1
Nursing Home	-	-	-	MW1

[1]Structure and content depth-damage curves (two separate curves for each building category).
[2]Depth-damage curves were modified to not include basement damages for houses without basements.

Table 4-3: Non-Residential Building Categorization

Building Category	Depth-Damage Curve from 2015 Alberta Study		Building Type
	Structure	Contents	
Warehouse	Industrial/Warehouse (S2)	Warehouse/Industrial (L1)	Industrial
Auto Garage	Industrial/Warehouse (S2)	Auto (G1)	Commercial
Agriculture	Industrial/Warehouse (S2)	Warehouse/Industrial (L1)	Agriculture
Retail Warehouse	Industrial/Warehouse (S2)	General Retail (C7)	Commercial
Chemical Warehouse	Industrial/Warehouse (S2)	Warehouse/Industrial (L1)	Industrial
Church	Institutional (S5)	Other/Institutional (N1)	Institutional
Convenience Store	Office/Retail (S1)	Misc. Retail (C6)	Commercial
Electrical Substation	Industrial/Warehouse (S2)	Warehouse/Industrial (L1)	Industrial
Restaurant	Office/Retail (S1)	Restaurants (I1)	Commercial
Retail	Office/Retail (S1)	General Retail (A1)	Commercial
Gas Distribution Facility	Industrial/Warehouse (S2)	Warehouse/Industrial (L1)	Industrial
Government Building	Institutional (S3)	Other/Institutional (N1)	Institutional
Animal Research Facility	Industrial/Warehouse (S2)	Warehouse/Industrial (L1)	Industrial
Clubhouse	Office/Retail (S1)	Other/Institutional (N1)	Commercial
Hotel	Hotel/Motel (S3)	Hotels (H1)	Commercial
Lumber Remanufacturing Facility	Industrial/Warehouse (S2)	Warehouse/Industrial (L1)	Industrial
Lumber Yard	Industrial/Warehouse (S2)	Warehouse/Industrial (L1)	Industrial
Office	Office/Retail (S1)	General Office (A1)	Commercial
Gas Station	Office/Retail (S1)	Misc. Retail (C6)	Commercial
Recreational Facility	Office/Retail (S1)	Misc. Retail (C6)	Commercial
School	Institutional (S5)	Other/Institutional (N1)	Institutional

Structure Values

Building structure values were estimated using 2019 BC Assessment improvement values, as provided in the Abbotsford GIS database. For non-vacant agricultural properties that may contain both residential and non-residential buildings ("USE_DESC" attribute from Abbotsford GIS data equal to BEEF, DAIRY, GRAIN & FORGE, MIXED, OTHER, POULTRY, SMALL FRUITS and VEG & TRUCK), only the total improvement value is reported by BC Assessment. As previously noted, these properties typically contain a combination of single-family dwellings and agricultural buildings. To distinguish between the house values and agricultural building values on non-vacant agricultural properties, the following procedure was carried out:

1. Properties that contain single-family dwellings only (see Table 4-1) and that are located within the MIKE FLOOD model extents outside of high-density urban areas were identified. A total of 111 one-storey houses and 17 two-storey houses were identified from this process.
2. The average improvement value of the 111 one-storey houses and the 17 two-storey houses was calculated to be $140,000 and $370,000, respectively.
3. For the non-vacant agricultural properties, house values were assumed to be 90% of the total improvement value up to a maximum of $140,000 for one-storey houses and $370,000 for two-storey houses. The remaining 10% of the improvement values or the remaining improvement values in excess of $140,000 for one-storey houses and $370,000 for two-storey houses was then assumed for the non-residential building values.

Content Values

Building content values were assumed to be represented as percentages of the building structure values, as shown in Table 4-4. The content-to-structure value ratios selected for this study were estimated based on those that are used in the Hazus-MH model[21]. Crop damages, livestock damages and non-fixed agricultural equipment and machinery are not included in the agricultural value estimate, as these items are included in the agricultural loss analysis. A breakdown of the building types for each non-residential building category is presented in Table 4-3.

Table 4-4: Content-to-Structure Value Assumptions

Building Type	Content Value (Percentage of Structure Value)
Residential	50%
Agriculture	100%
Commercial	100%
Institutional	100%
Industrial	150%

Replacement Factor

Building replacement values were estimated by assuming that the improvement values listed by BC Assessment were 70% of full replacement values. This assumption was based on results from the recent flood damage risk assessment for Squamish River completed by KWL[22] that concluded that depreciated values were approximately 70% of full replacement values for structures in the Squamish River floodplain, based on differences between BC Assessment values and adjusted full replacement costs from Natural Resources Canada's version of the Hazus-MH model.

HEC-FIA Model Development

The HEC-FIA model for the Sumas Prairie was developed using the residential and non-residential buildings (parcel centroid points) with their associated structure values, content values, structure depth-damage curves and content depth-damage curves. The resulting structure and content damages predicted by the model were then multiplied by the replacement factor to convert the damages based on building improvement values to estimated damages in terms of replacement costs.

Structure and Content Flood Damage Results

A summary of the structure and content flood damages calculated from the HEC-FIA simulation is provided in Table 4-5. All damages presented in the table are associated with the estimated replacement costs. It should be noted that properties located within the Sumas First Nation reservation lands (Upper Sumas 6) were not included in this assessment because their structures have not been assessed. However, the location of individual buildings within the reserve lands were identified based on aerial photography, and almost all buildings were found to be located north of the flood extents of the simulated 100-year and 200-year flood scenarios, whereas a few buildings were found to be just within the flood extents where flood depths are relatively low. Minimal structure and content flood damages are therefore expected for Upper Sumas 6.

Table 4-5: Flood Damage Results for Structures and Contents

Scenario	Residential Buildings			Non-Residential Buildings			Total Damages ($ million)	Percentage of 200-Year Damages
	Number of Buildings	Damages ($ million)		Number of Buildings	Damages ($ million)			
		Structures	Contents		Structures	Contents		
1	247	$42	$20	76	$23	$20	**$105**	19%
2A	523	$106	$54	323	$82	$73	**$316**	57%
2B	523	$106	$54	523	$77	$71	**$307**	56%
2C	175	$34	$18	257	$36	$35	**$123**	22%
3	804	$167	$85	780	$148	$151	**$551**	100%

The estimated flood damages can be broken down to estimate the potential magnitude of the impact of these floods on the provincial Disaster Financial Assistance (DFA) program through Emergency Management BC. The DFA program allows those affected by a major disaster to claim disaster assistance from the Province of up to $300,000 in damages per claim. The estimated damages that qualify for the DFA program are shown below in Table 4-6. As many agricultural properties contain both residential and non-residential buildings, the total damages to both building types were assumed to be covered under a single claim. Claims for residential buildings alone (excluding non-residential buildings) are also provided in the table as additional information.

Table 4-6: Estimated Damages That Qualify for DFA Funding

Scenario	Residential Buildings Only		Residential and Non-Residential Buildings Combined	
	Number of Potential Claims	Total Structure and Content Damages ($ million)	Number of Potential Claims	Total Structure and Content Damages ($ million)
1	247	$52	259	$56
2A	523	$121	563	$133
2B	523	$120	561	$131
2C	175	$37	191	$43
3	804	$189	878	$209

4.2 Agricultural Losses

The Food and Agriculture Organization of the United Nations (FAO) Damages and Losses method was selected to assess the economic agricultural impact. The primary reason this approach was selected was due to the ability to take a higher-level economic analysis approach (i.e., the economic disruption caused by the disaster), rather than a detailed crop-by-crop level analysis (used by the HEC-FIA model). A detailed description of the economic agricultural impact methodology using the FAO method that was carried out for this project is provided in Appendix E.

In summary, the following agricultural data sources were available for the agricultural loss analysis:

- City of Abbotsford GIS: parcel data;
- Statistics Canada: online 2016 census data for the Abbotsford Consolidated census subdivision and custom data request (received November 29, 2019);
- Ministry of Agriculture, including the Production Insurance Office; and
- Online literature.

Statistics Canada's Census Data for 2016 include a detailed breakdown of the agricultural activities in Abbotsford, including the following information:

- North American Industry Classification System (NAICS), Industry Group Code;
- Total number of farms;
- Total farm capital, including farm machinery and equipment, livestock and poultry, land and buildings;
- Total farm area;
- Total gross farm receipts (excluding sales of forest products) in the calendar year prior to the census or for the last complete accounting (fiscal) year prior to the census; and

- Total farm business operating expenses in the calendar year prior to the census or for the last complete accounting (fiscal) year prior to the census.

It should be noted that census data is self-reported by the farm operators, and thus the level of accuracy and whether some values are over or under-reported is unknown. Statistics Canada was also not able to provide more detailed census data (i.e., by dissemination blocks) due to privacy reasons, therefore data was only available for Abbotsford as a whole.

FAO identifies three types of agricultural impacts:

1. Production Loss (PL) – Value of lost production and is measured by the difference in expected (i.e., pre-disaster) and actual value (i.e., post-disaster) of production and post-disaster maintenance costs.
2. Production Damage (PD) – Value of damaged/destroyed stored inputs (e.g., seeds), stored production (e.g., harvested products in storage), and replacement costs of lost perennial trees and livestock.
3. Asset Damage (AD) – Replacement cost of fully destroyed assets, and repair/rehabilitation costs of partially damaged assets, such as machinery, equipment and tools.

The sum of the above damages represents the financial impact to agriculture from a disaster, as follows:

$$Impact\ to\ Agriculture = PL + PD + AD$$

This study was generally challenged by the need to distribute the Statistics Canada census data to the City of Abbotsford parcels. The City of Abbotsford parcel data uses the BC Land Use Code numbering system, whereas the Statistics Canada census data uses the North American Industry Classification System (NAICS) Industry Group numbering system. Though similar, the two numbering systems are not identical. Thus, the first step in the agricultural loss assessment was to reassign NAICS codes to BC Land Use codes.

In order to relate the NAICS and BC Land Use Codes, NAICS code descriptions were matched to similar land use descriptions in the BC Use Code. As there were more BC Use Codes than NAICS codes and all NAICS codes had to be accounted for, assumptions were made regarding the grouping of different classifications:

- BC Use Codes for Grain & Forge (110 and 111), Beef (150 and 151), and Dairy (160 and 161) were combined and associated with a combined NAICS group for Oilseed and Grain (11100), and Cattle (112100). This grouping was created, under the assumption that most grain and forage farming is for the purpose of cattle/dairy farming, and therefore many of the NAICS codes were under cattle farming. It was determined that this combination is likely suitable as oilseed/grain farming and cattle ranching have similar sales per acre. Oilseed and grain farming also only accounts for 0.9% of the total farm area and 0.3% of the total farm sales.
- NAICS codes that were not mentioned in the BC Use Code (Greenhouse, nursery, floriculture, hog and pig farming, sheep and goat farming, other crop farming) were combined into the Other category. When combined, the area percentages were similar between the BC Use Code and NAICS code.

Table 4-7 outlines the NAICS assignments to each BC Land Use Code, and the comparison of the codes. Using this new grouping, the 2016 census data was distributed to each farm parcel in Abbotsford. Results are presented in Table 4-8.

Table 4-7: BC Use Code and NAICS Assignments for Abbotsford

BC Use Code	BC Use Code Description	NAICS Code	NAICS Description	BC Use Code Percentage (Area)	NAICS Percentage (Area)	Percentage Difference (Area)
120	Veg & Truck	111200	Vegetable & Melon	11.6%	7.7%	3.9%
121	Veg & Truck - Vacant					
180	Mixed					
181	Mixed - Vacant					
130	Tree Fruits	111300	Fruit & Tree Nut	23.0%	20.6%	2.4%
140	Small Fruits					
141	Small Fruits-Vacant					
110	Grain & Forge	111100 and 112100	Oilseed, Grain, & Cattle	35.8%	34.4%	1.4%
111	Grain & Forge - Vacant					
150	Beef					
151	Beef - Vacant					
160	Dairy					
161	Dairy - Vacant					
170	Poultry	112300	Poultry & Egg	6.8%	14.0%	-7.2%
190	Other	112900,111400, 111900, 112200, and 112400	Greenhouse, Nursery, Floriculture, Hog & Pig, Sheep & Goat, Other crop and animal production	22.7%	23.3%	-0.6%
191	Other - Vacant					

Table 4-8: Combined Parcel Data, NAICS Assignments and Farm Receipts and Expenses

City of Abbotsford Parcel Data				NAICS Assignments		Statistics Canada Data (2016) For Abbotsford		Unit Rates ($/Ha)	
Use Code	Use Code Description	Total Area (Ha)	Total Area (Ha)	NAICS Code	NAICS Description	Total Gross Farm Receipts	Total Farm Business Operating Expenses	Gross Farm Receipts Per Area	Farm Business Operating Expenses Per Area
120	VEG & TRUCK	1,186	2,501	111200	Vegetable & Melon	$30,607,729	$26,307,753	$12,238	$10,519
121	VEG & TRUCK - VACANT	341							
180	MIXED	944							
181	MIXED - VACANT	30							
130	Tree Fruits	30	4,942	111300	Fruit & Tree Nut	$77,302,963	$61,408,057	$15,641	$12,425
140	SMALL FRUITS	4,345							
141	SMALL FRUITS-VACANT	567							
110	GRAIN & FORGE	1,831	7,670	111100_ 112100	Oilseed, Grain, & Cattle	$132,182,811	$103,049,125	$17,233	$13,435
111	GRAIN & FORGE - VACANT	515							
150	BEEF	1,022							
151	BEEF - VACANT	19							
160	DAIRY	3,469							
161	DAIRY - VACANT	815							
170	POULTRY	1,467	1,467	112300	Poultry & Egg	$417,560,410	$361,639,549	$284,718	$246,588
190	OTHER	3,742	4,856	112900_ 111400_ 111900_ 112200_ 112400	Greenhouse, Nursery, Floriculture, Hog & Pig, Sheep & Goat, Other Crop and Animal Production	$195,416,863	$168,859,494	$40,239	$34,770
191	OTHER - VACANT	1,115							

The farm capital values were further broken down as per Table 4-9.

Table 4-9: Breakdown of Farm Capital (Statistics Canada 2016 Census Data)

<table>
<tr><th>Farm Capital</th><th>Market Value of Total Farm Capital</th><th>Proportion of Total Capital (Without Livestock)</th><th>Proportion of Total Capital (With Livestock)</th></tr>
<tr><td>Value of land and buildings, owned</td><td>$3,471,377,797</td><td>76.51%</td><td>74.39%</td></tr>
<tr><td>Value of land and buildings, rented or leased from others</td><td>$868,740,725</td><td>19.15%</td><td>18.62%</td></tr>
<tr><td>Tractors under 60 hp</td><td>$27,695,080</td><td rowspan="10">4.34%</td><td rowspan="10">4.22%</td></tr>
<tr><td>Tractors from 60 to 149 hp</td><td>$30,433,030</td></tr>
<tr><td>Tractors over 149 hp</td><td>$18,907,968</td></tr>
<tr><td>Pick-ups, cargo vans, cars and other passenger vehicles used in the farm business</td><td>$28,442,198</td></tr>
<tr><td>Grain combines and swathers</td><td>$1,970,000</td></tr>
<tr><td>Forage harvesters, balers, mower-conditioners, etc.</td><td>$13,254,450</td></tr>
<tr><td>Tillage, cultivation, seeding and planting equipment</td><td>$10,238,650</td></tr>
<tr><td>Irrigation equipment</td><td>$13,851,291</td></tr>
<tr><td>All other farm machinery and equipment</td><td>$52,081,126</td></tr>
<tr><td>Value of livestock and poultry</td><td>$129,767,481</td><td>0.00%</td><td>2.78%</td></tr>
<tr><td>Total Farm Capital</td><td>$4,666,759,796</td><td>100.00%</td><td>100.00%</td></tr>
</table>

The above percentages were then applied to the unit farm capital values ($/hectare) developed for each NAICS code to determine the portion of the capital assets that fall under equipment (i.e., farm capital excluding buildings, land and livestock) and livestock.

Production Loss

To find the difference between the expected and actual value of production post-disaster, each unit value of annual revenue was multiplied by the flooded area and percent destroyed to find the total production loss for each plot of land. The flood depth had to be greater than a minimum threshold for damage of the livestock or crop to occur. It was assumed that 100% of annual crops and livestock above the threshold were destroyed. The percentage of perennials destroyed is based on a flood duration relationship.

The average age of animals at slaughter varies by animal, but also by their use (e.g., dairy cattle vs beef cattle, boilers vs laying hens).

The following average age at the flooding event is used for this analysis:

- Poultry: 8 weeks
- Cattle: 1.5 years
- Others: 1 year

Annual revenue of animal production was multiplied by the age of animal to represent the loss of production of animals with different life spans. It was also assumed that post-disaster maintenance costs account for 10% of the gross farm receipts.

Production Damage

For the purpose of this assessment, destroyed stored inputs were represented by 60% of one month of farm business operating expenses (i.e., assumed that 60% of annual expenses were for stored inputs, and only 1 month of stored inputs were stored on site at any given time). It was also assumed that annual crops do not have stored inputs (as they would likely have been expended prior to harvest). As it is unlikely for a farm in Abbotsford to store a substantial amount of product in the floodplain, stored production was not accounted for in this assessment. The perennial replacement cost (including loss in revenue in subsequent years until fully established) of $7,905 per hectare was used in the production damage cost.

Asset Damage

The distribution of market value for capital assets into smaller categories was applied to the total farm capital for each NAICS code, excluding livestock, which was only assigned to NAICS codes that had livestock. It was assumed that each NAICS code has the same distribution of farm capital. As this section is focused on agricultural assessment, the evaluation of land and building damage due to flooding was not included.

Agricultural Results

The financial impact analysis results for agriculture is presented in Table 4-10.

Table 4-10: Agricultural Damage Assessment Results for All Scenarios

Scenario	Scenario Name	Damage ($ million)	Percentage of 200-Year Damages
1	1990 Flood	**$41**	15%
2A	100-Year Flood	**$136**	50%
2B	100-Year Flood (no dike breaching)	**$144**	53%
2C	100-Year Flood (no Nooksack overflows)	**$84**	31%
3	200-Year Flood	**$271**	100%

4.3 Transportation and Business Economic Losses

Davies Transportation Consulting Inc. completed a report providing estimates of transportation and business economic losses. The information provided in this section is excerpted from this report, which is provided in Appendix F.

Highway Closure Economic Impacts

Closure of the TransCanada Highway would result in $2,504,000 in traveller costs per day, and closure of Highway 11 and the Sumas border crossing together would result in $47,000 in traveller costs per day. A summary of the highway closure durations for each of the five flood scenarios based on the hydraulic modelling results is presented in Table 4-11. For comparison, the recent Nooksack River overflow flood event that occurred in February 2020 resulted in a closure of the Sumas Border of approximately one day but no closure of Highway 1.

Table 4-11: Highway Closure Durations

Scenario	Scenario Name	Highway 1 Closure Duration (days)	Sumas Border Closure Duration (days)
1	November 1990 Flood	1.1	0.9
2A	100-Year Flood	3.5	1.5
2B	100-Year Flood (no embankment breaching)	3.6	1.5
2C	100-Year Flood (no Nooksack overflows)	2.3	0
3	200-Year Flood	4.8	1.6

Railway Economic Losses

Economic losses resulting from flooding of the Southern Railway would be minimal, as traffic on this railway is minimal and the local customers that use the railway could use alternative interchanges with CNR during floods. Delays resulting from closure of the Southern Railway border crossing are also not expected to have large economic impacts, as railcars are frequently held along this line until they accumulate sufficient traffic.

Repair costs for a breach of the Southern Railway similar to the breach that occurred during the 1990 flood were estimated to be approximately $290,000. This repair would be expected for all flood scenarios except Scenarios 2B and 2C which are 100-year events when the railway embankment is assumed to not breach.

Non-Agricultural Business Losses

Business disruption impacts were estimated for each flood scenario based on the number of businesses that are impacted by flooding and the expected closure durations (see Table 4-12). A total of 44 businesses were identified as vulnerable to business losses within the 200-year flood extents. Businesses were assumed to be closed for each day that Highway 1 is closed.

Table 4-12: Highway Closure Economic Impacts

Scenario	Scenario Name	Business Disruption Impacts ($/day)	Business Closure Duration (days)
1	November 1990 Flood	$300,000	2
2A	100-Year Flood	$330,000	4
2B	100-Year Flood (no embankment breaching)	$330,000	4
2C	100-Year Flood (no Nooksack overflows)	$300,000	3
3	200-Year Flood	$350,000	5

Summary of Transportation and Business Economic Losses

A summary of the transportation and business economic impacts associated with highway closures, border closures, railway damages and business disruptions is provided in Table 4-13.

Table 4-13: Business and Transportation Economic Impacts

Scenario	Highway 1 Closure Impacts	Sumas Border Closure Impacts	Southern Railway Repair Costs	Business Disruption Impacts	Total Damages ($ million)
1	$2,754,000	$43,000	$290,000	$600,000	**$4**
2A	$8,764,000	$71,000	$290,000	$1,320,000	**$10**
2B	$9,014,000	$71,000	$0	$1,320,000	**$10**
2C	$5,759,000	$0	$0	$900,000	**$7**
3	$12,019,000	$76,000	$290,000	$1,750,000	**$14**

4.4 Affected Populations

The number of residents that are potentially exposed to flooding was estimated by overlaying the flood extents of each flood scenario on residential buildings and assigning population estimates to each building based on the 2016 Census Dissemination Block (CDB) data. Since census population data is not publicly available at the property level, dissemination block populations were distributed among the residential properties contained within each block.

The scope of this study does not include an explicit calculation of loss-of-life. Quantifying loss-of-life risks that could be investigated as part of future work.

Distribution of Population Data

The Abbotsford Official Community Plan (OCP) model was used to determine population weights for each property. Populations estimated by the Abbotsford OCP are based on assigning a unit population for each residential building category (see Table 4-14) such that the total estimated population of the City matches the 2016 Census. These estimates do not use individual CDB population data, as all units within the City are assumed to have the same population for a given building category. The total population of each CDB (obtained from Statistics Canada) was therefore distributed to each containing property based on the corresponding total population estimated by the Abbotsford OCP.

While properties located within the Sumas First Nation reserve (Upper Sumas 6) were not included in the Abbotsford OCP, these properties were included in the census population estimates. Aerial photography was used to identify residential properties within the Sumas First Nation reservation lands, and all identified residential buildings were assumed to be single-family dwellings.

Table 4-14: Unit Population Assumptions

Residential Building Category	Unit Population
Single-Family Dwelling (or Accessory Unit)	3.3
Townhouse	2.5
Apartment	1.7

Affected Population Results

Total affected populations estimated for each of the five flood scenarios by overlaying the corresponding flood extents are presented in Table 4-15. No depth threshold was selected for this analysis, as the intention was to estimate the population that resides in the areas that are impacted by floodwaters of any depth. For comparison, the total population of residential buildings located within the MIKE FLOOD model extents (flooded and not flooded) was estimated to be 4,474.

Table 4-15: Population Results

Scenario	Scenario Name	Affected Population
1	1990 Flood	**932**
2A	100-Year Flood	**2,039**
2B	100-Year Flood (no dike breaching)	**2,038**
2C	100-Year Flood (no Nooksack overflows)	**666**
3	200-Year Flood	**3,113**

The above population estimates do not include Temporary Foreign Workers (TFWs) who may also reside within the study area. According to Employment and Social Development Canada[23], a total of 4,585 and 4,049 TFW positions on positive Labour Market Impact Assessments (LMIAs) were reported in 2018 and 2019, respectively, for all of Abbotsford. While the number of TFWs residing within the study area could not be estimated, it is expected that several TFWs would hold agricultural positions, and TFWs are often required to live on the properties of their employers. Moreover, TFWs are a vulnerable population that could experience additional impacts related to losing their temporary residence or job while being a visitor to Canada and on a temporary work permit.

4.5 Qualitative Impacts

The following categories of impacts and losses are considered from a qualitative rather than a quantitative perspective and are not included in damage estimates.

Environmental Flood Impacts

Septic Systems and Waste Lagoons

Much of the floodplain area for the Nooksack overflow flood event is rural, containing homes and working farms. Rural homes typically rely on septic systems for sewage treatment and flooding can impact the operation of septic systems, causing them to overflow and release human fecal contamination, and potentially other pathogenic microorganisms such as viruses, into the floodwaters. The biological contamination can then spread through the floodwaters and impact other areas, including homes and farmland.

In addition to septic systems, many of the farms in the floodplain area appear to have liquid waste lagoons for treatment of animal wastes. Figure 4-1 shows one example.

Figure 4-1: Farm with Liquid Waste Lagoons Located in the Sumas Prairie Floodplain Area

Surface liquid waste lagoons may be edged with berms which may provide some protection from flood inundation of the lagoons. However, the primary requirements for waste lagoons do not include any requirement for above grade berms[24]. Some of these lagoons would likely be inundated or the containment breached during a large flood event and there is potential for widespread distribution of animal-source biological contamination from such facilities during a major flood event.

Research carried out in North Carolina in the US[25] indicated that biological contamination from animal waste lagoons can persist in the soil for several years after a major flood event where animal waste lagoons were breached during the event. Vegetable, forage and other crops subsequently grown will need to consider the level of contamination, however, generally, the level of biological contamination will naturally degrade after floodwaters recede. Application of liquid wastewater to farmland for irrigation and fertilizer is a standard practice and guidance exists for the amount of time required before crops are grown in soils following liquid waste application. Similar timeframes would likely be required before crops could be grown in previously flooded soils[26].

Hydrocarbon Sources

One automotive parts recycling business (Empire Abbotsford Recycled Auto and Truck Parts) was identified near the western edge of the inundated area, along Sumas Way. This business has hundreds of vehicles on-site which could contribute hydrocarbons and other contaminants to the floodwaters. The level of risk this site poses is unclear however, as the level or risk would be associated with the amount of hydrocarbons that spill or leak onto the ground during normal operations.

No gas stations were identified within the flood inundation area within the City of Abbotsford, however, at least three gas stations are located near the edges of the inundation area, along Sumas Way and on Whatcom Road North of Highway 1. In addition, it is unclear whether gas stations located in the town of Nooksack, WA may be within the flood inundation area of the overflow event and could contribute hydrocarbons to the floodwater before it crosses the border.

It is likely that at least some of the farms within the flood inundation area have on-site oil or diesel fuel tanks. Above-ground and below-ground tanks can potentially be affected by flooding and have the potential to leak fuel into floodwaters. Fuel tanks can experience buoyancy during a flood event and may pop out from underground or break loose from above-ground supports. If they are attached to piping which ruptures, or if the tank ruptures, fuel would be released.

Hydrocarbon contamination in floodwaters can volatilize as well as transfer to soil and surfaces. Most petroleum hydrocarbons are carcinogenic to people and harmful to plants and animals. Hydrocarbon contamination in soils can be transferred to groundwater and can contaminate drinking water wells.

Asbestos Sediments

Asbestos fibres are naturally occurring in sediments in the Sumas River, with much of the sediment load contributed by Swift Creek in Washington State[27]. The City of Abbotsford has confirmed that asbestos is present in the Sumas River sediments in Canada[28] and it is anticipated that some of those sediments would be entrained in the flow of floodwaters in the Nooksack overflow event. It is expected that the sediments and asbestos fibres would be deposited across the flood inundation area during the flood event.

It is difficult to assess the possible health impacts to people from exposure to naturally occurring asbestos, because the bulk of knowledge on asbestos health effects comes from exposure to specific commercial asbestos products in high-exposure settings[29]. One aspect of the difficulty in assessing the risk is that most asbestos health effects study the longer asbestos fibres common in asbestos products, while the bulk of the asbestos found in the Sumas River sediments are short fibres that do not meet the criteria for harmful fibres in drinking water (in the US[30]).

Drinking-Water Wells and Aquifers

Any major flood event carries some risk of spreading biological contamination to wells. Wells may be susceptible to contamination when[31]:

- wells or aquifers are shallow and/or the overlying soils are permeable (e.g., sand or gravel);
- wells are located in pits or depressions where water can pool;
- wells have rusted, cracked or unsealed casings that do not extend at least 30 centimeters above ground;
- wells are near septic tanks or fields, barns, feed lots or other potential sources of contamination;
- wells are near unsealed abandoned wells, sink holes, quarries or other potential groundwater contamination pathways; and
- wells close by are flooded and may be contaminated.

Individual wells that do become contaminated with biological contaminants can be disinfected with chemical treatments. Non-biological contaminants such as hydrocarbons are more difficult to treat or remove from wells.

There are 89 wells in the provincial registry that are located within the flood inundation area for the 100-year event without Nooksack overflow, 26 of which are designated as water supply wells. There are 325 wells in the provincial registry that are located within the flood inundation area for the 200-year event with Nooksack overflow and dike breach, 102 of which are shown as water supply wells. A map showing the location of the wells within the 100-year and 200-year flood areas is shown in Figure 4-2.

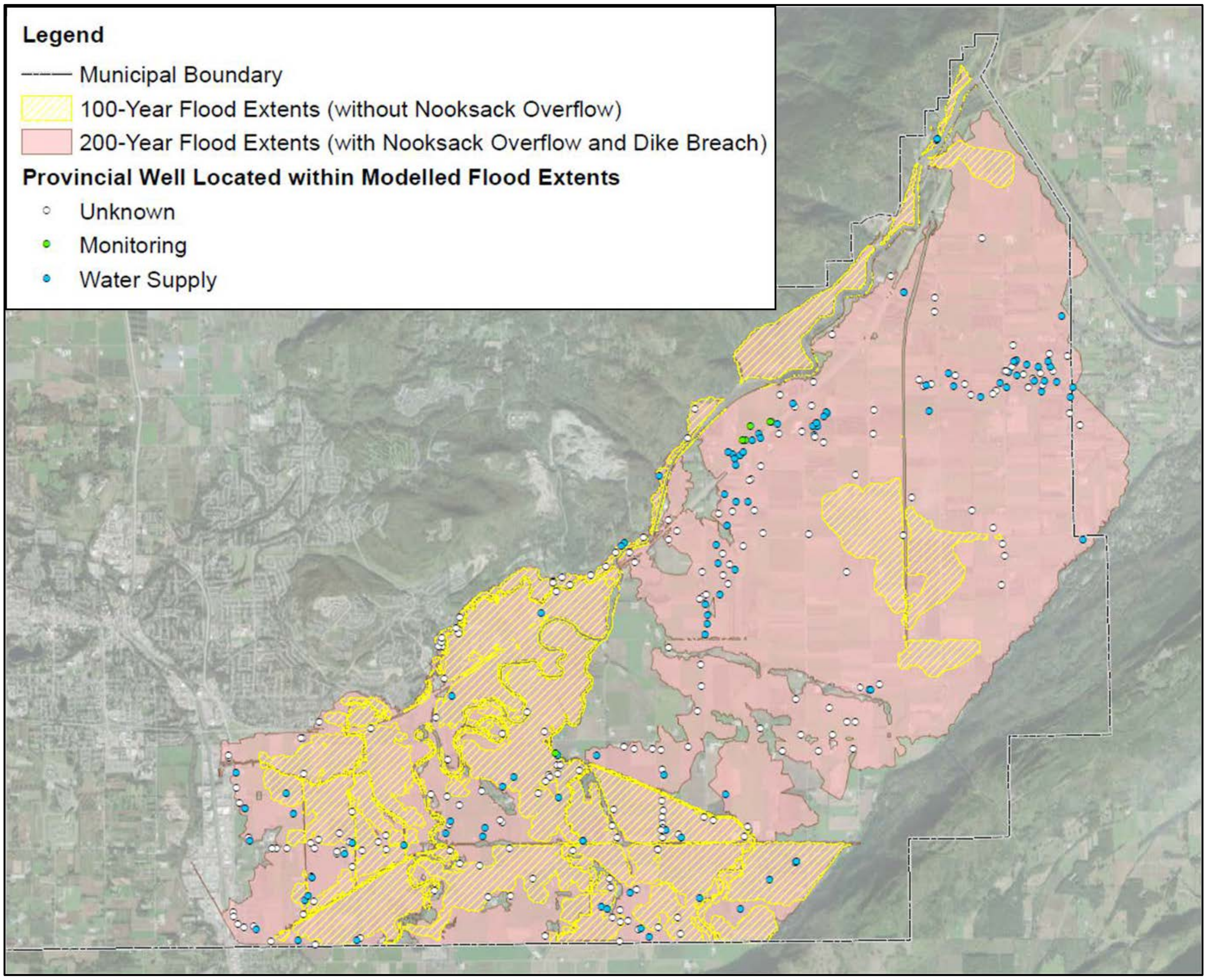


Figure 4-2: Well Locations Within the Flood Inundation Area[32]

A portion of the flood inundation area overlaps with portions of the "Vulnerable Aquifer Recharge Areas" defined by the Province (see screenshot in Figure 4-3) at the eastern and western edges of the flood area.

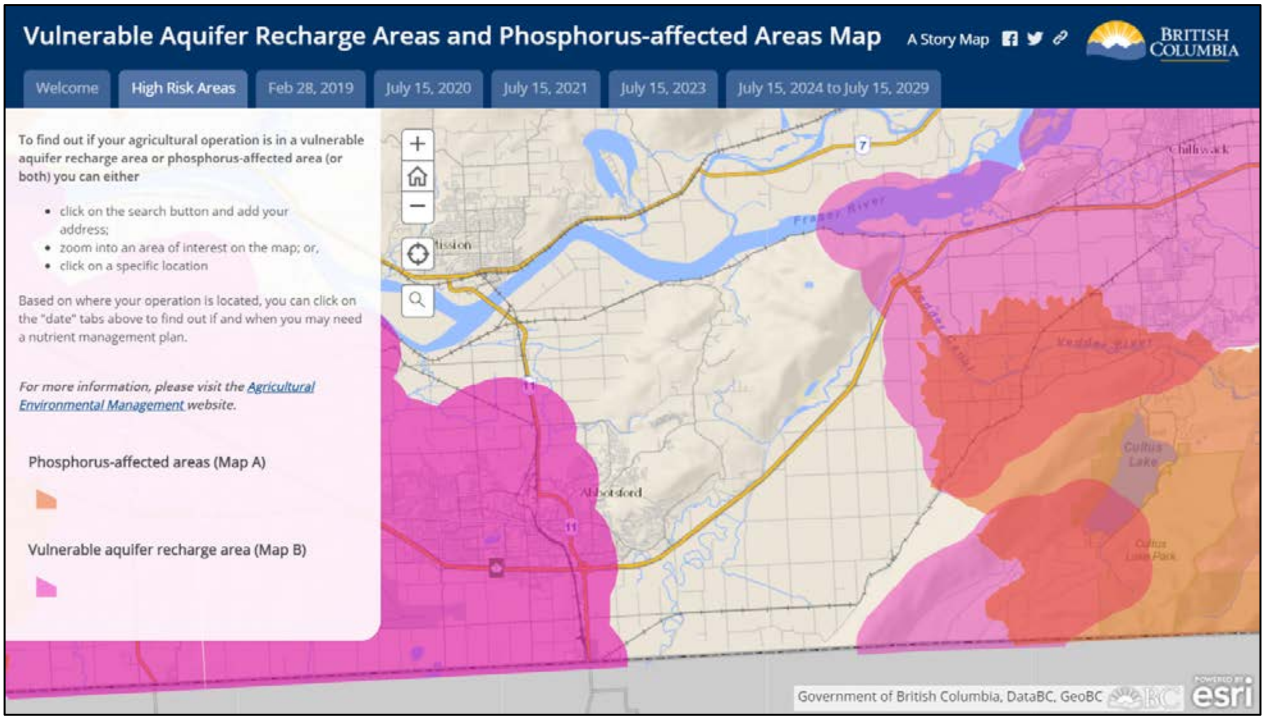


Figure 4-3: Vulnerable Aquifer Recharge Areas that Intersect with the Nooksack Overflow Flood[33]

Floodwaters in these areas could adversely impact the aquifer and put drinking water resources at risk.

Other Environmental Concerns

Other possible flood sources of environmental concern including hazardous waste generating facilities were not identified within the floodplain area for this event.

Lifeline and Utility Disruption

Water Utilities

All properties located within the Sumas Prairie are serviced by the City's water distribution system. Thus, several kilometres of watermains are located within the Sumas Prairie floodplain along with their associated valves, fittings, hydrants and water meters. No impacts to these utilities are expected unless they are exposed from road washouts. No reservoirs, intakes or water treatment plants are located within the Sumas Prairie floodplain.

Wastewater Utilities

While municipal wastewater services are generally not provided to properties located within the Sumas Prairie, multiple private wastewater systems have been installed within the prairie and the serviced areas surrounding the prairie are impacted by prairie floodwaters. No wastewater treatment plants are located within the Sumas Prairie floodplain.

Flooding of wastewater pump stations and manholes were identified as follows:

- A private wastewater pump station located at 852 Whatcom Road, which presumably serves the Upper Sumas Elementary School, is within the 200-year flood extents. The 100 mm diameter forcemain from this pump station is also privately owned and travels west along Vye Road within the floodplain to Sumas Way (Highway 11) where it ties into the municipal system.
- One private pump station servicing 1625 Angus Campbell Road is within the 100-year flood extents (all scenarios). This pump station does not tie into the municipal system.
- Three private wastewater pump stations servicing the dairy complex and residential property at 1356 Sumas Way are within the 100-year flood extents (all scenarios).
- Two wastewater pump stations within the Huntingdon community are within the 100-year flood extents (all scenarios), one private pump station at the recycling depot at 30 2nd Avenue and one municipal pump station at 75 Melan Court. While a third pump station along B Street between 7th Avenue and 8th Avenue is also within the flood extents, this pump station is abandoned. Numerous manholes along the gravity sewer systems in Huntingdon are also within the 100-year flood extents.
- Three wastewater pump stations were identified within the 200-year flood extents on the north side of the TransCanada Highway, including two private pump stations located at 35570 Old Yale Road and behind 35995 North Parallel Road, and one private pump station located at 2061 Whatcom Road. The pump station behind 35995 North Parallel Road is also within the 100-year flood extents (all scenarios). Another municipal pump station located within Upper Sumas 6 at 37350 Kilgard Road was found to be within the 100-year flood extents but not within the 200-year flood extents due to the breaching of the Sumas River Dike during 200-year floods that lowers water levels on the unprotected side of the dike. Numerous manholes along the gravity sewer systems north of Highway 1 are also flooded during extreme events.

Stormwater Utilities

Drainage systems within the Sumas Prairie mostly consist of roadside ditch and culvert systems. Small pockets of municipal and private storm sewer systems exist within the prairie, whereas properties surrounding the prairie receive storm sewer service. Numerous storm sewer inlets, outlets, manholes and stormwater detention systems are impacted by extreme floods in the Sumas Prairie.

Additionally, four irrigation pump stations reside within the Old Sumas Lake Bottom. All four pump stations are within the 200-year flood extents, whereas one is also within the 100-year flood extents. The Old Sumas Lake Bottom also contains numerous weirs and control structures that are impacted by extreme floods.

Electrical Substations

The Sumas Way Substation located on the west side of Highway 11 at 34473 McClary Avenue is the only electrical substation within the study area. No impacts on electrical power distribution systems are expected to result from flooding in the Sumas Prairie, as this substation is located outside of the flood extents. However, power outages and electrical hazards associated with damages to power lines from flood damages to buildings, roads, power poles and trees remain a general concern during flood events.

Natural Gas Pipelines

The Westcoast Pipeline passes through the Sumas Prairie, bringing natural gas from the Western Canadian Sedimentary Basin to the Lower Mainland and to the US. The pipeline enters the Prairie from Chilliwack, crossing the Vedder Canal towards the Yarrow regulator station at 5260 Boundary Road on the Chilliwack side. The pipeline then continues through the Old Sumas Lake Bottom towards a second regulator station in Abbotsford at 1574 McDermott Road. From there, the pipeline travels to the Huntingdon station at the US/Canada border, which is owned by Fortis BC on the Canada side and Williams on the US side. The Huntingdon station is located at 176 Whatcom Road, approximately half a kilometre east of the Sumas River. From the Huntingdon station, the pipeline continues west through the prairie, passing below the Sumas River and then crosses Highway 11 just south of Vye Road. On the US side of the border, the Huntingdon station marks the beginning of the Northwest Pipeline system that distributes natural gas from Canada throughout northwestern US.

The Huntingdon station is at risk of flooding during extreme flood events from Sumas River right bank overflows, and both the Yarrow and McDermott regulator stations are at risk of flooding during extreme flood events if the Interceptor Dike or Sumas River Dike are overtopped or breached as both stations are located in the Sumas Lake Bottom area. While flooding on the US side has not been evaluated as part of this study, it is expected that the portion of the Huntingdon station owned by Williams on the US side of the border would be at similar flood risk. The pipeline itself may also be at risk of damage resulting from erosion and washout during extreme flood events. Damages to the Huntingdon station on either side of the border, the regulator stations or the connecting pipelines could result in high environmental impacts, public safety issues, transmission interruptions and economical losses. Existing floodproofing and failure prevention efforts for these facilities or the pipeline have not been investigated as part of this study.

Oil Pipelines

The Trans Mountain Pipeline, which carries refined and crude oil from Alberta, passes through the Old Sumas Lake Bottom from Chilliwack towards the Sumas Pump Station located at 3434 McDermott Road just south of the TransCanada Highway. From this pump station, the pipeline then crosses the Sumas River and travels up Sumas Mountain to its terminus in Burnaby. The pump station also diverts oil to a branch pipeline that runs Southwest to cross the border and connect to the Puget Sound Pipeline in the US, which distributes Canadian oil towards Anacortes, Cherry Point and Ferndale. An oil distribution facility is located at the US/Canada border at 102 Whatcom Road, which is immediately to the west of the Fortis BC natural gas Huntingdon station.

The Sumas Pump Station is located at the fringe of the estimated 200-year flood extents, assuming that the Sumas River Dike breaches. The pump station appears to be protected by a ring dike system that prevents the station from flooding during this event. Thus, minimal risk of flooding for the pump station is expected, provided that this ring dike system does not breach. However, the distribution facility located at the border remains at risk, flooding during extreme flood events from Sumas River right bank overflows and cross border overland flows. Similar to the natural gas pipelines and facilities, damages to this distribution facility or washout of the connecting pipelines within the Sumas Prairie could result in high environmental impacts and economical losses. Additionally, the Puget Sound Pipeline was identified in the 1993 Klohn Leonoff study[34] to be at risk of being washed out if an avulsion forms at Everson, which would result in substantial environmental damages within the Sumas Prairie.

Emergency Services Facilities

One fire hall (Abbotsford Fire Hall 2) was identified in the study area located at 35995 North Parallel Road, which is north of the TransCanada Highway. While flooding on the property occurs during the 100-year flood event, the building is outside of the 200-year flood extents. No police stations or hospitals are located within the flooded area.

Schools

Two schools are located within the Sumas Prairie, the Upper Sumas Elementary School (36321 Vye Road) and Barrowtown Elementary School (5137 Tolmie Road). The Upper Sumas Elementary School is within the 100-year flood extents, whereas the Barrowtown Elementary School would only experience flooding during the 200-year flood if the dikes protecting the Old Sumas Lake Bottom breach.

Assisted Living and Rehabilitation Facilities

One assisted living and rehabilitation facility was identified within the Sumas Prairie, located at 5133 Boundary Road within the Old Sumas Lake Bottom (Mountain View Home). This facility was found to be just outside of the 200-year flood extents under dike breaching conditions, although the building could be at risk of flooding during larger events.

Major Roadways

Evacuation and emergency services issues are of large concern in the Sumas Prairie during extreme flood events, as many major roadways outside of the Old Sumas Lake Bottom that provide routes out of the prairie including Boundary Road, Vye Road, Angus Campbell Road, Whatcom Road and Cole Road are at risk of flooding. Moreover, the TransCanada Highway and Highway 11 are also expected to flood during extreme flood events, preventing vehicles from being able to leave or enter the Sumas Prairie and from being able to cross between the US and Canada. If the dikes protecting the Old Sumas Lake Bottom breach from a 200-year flood, all major roads including the TransCanada Highway within the protected area would also be flooded.

Parks and Trails

All parks and trails along the banks of the Sumas River (Hougen Park, Jensen Park, MacDonald Park and McKay Creek Park) are flooded during extreme events and are expected to be flooded during more frequent events as well. Additionally, high water levels in Marshall Creek impact a sports park (Delair Park) and a community garden (Abbotsford Community Garden) during extreme flood events. The entrance to Winfield Park is also at risk of flooding from Marshall Creek, although the trail itself is at higher ground.

The trail running along the top of the Interceptor Dike and Sumas River Dike is at risk of flooding during extreme flood events at locations where the dikes are overtopped. These dikes pose additional safety hazards when overtopped because they were constructed without controlled spillways and therefore have a high potential to breach.

Impacts to First Nations

The following First Nations reserves belonging to the Sumas First Nation (Sema:th) and the Leq'á:mel First Nation were identified along the Sumas River:

1. Upper Sumas 6 (Sumas First Nation) – 216 ha area
2. Aylechootlook 5 (Leq'á:mel First Nation) – 8.0 ha area

3. Sumas Cemetery 12 (Leq'á:mel First Nation) – 2.8 ha area

Both of these First Nations communities are part of the larger Stó:lō Nation.

Upper Sumas 6 (Sumas First Nation)

Upper Sumas 6 is the reserve land designated for Sumas First Nation. While the area of the reserve is currently 216 ha[35], the lands of the Sema:th people traditionally encompassed over 20,000 acres (8,100 ha) and included regions such as Sumas Mountain, the former Sumas Lake (Sema:th Lake) and its connecting waterways. Upper Sumas 6 is the former location of the main village of the Sema:th people, whereas a total of seven villages were historically located throughout their lands. Thus, many areas within the Sumas Prairie outside of Upper Sumas 6 are traditionally connected to the Sema:th people.

A map of the existing land use designations for Upper Sumas 6 obtained from the 2013 Sema:th Land Use Plan[36] is provided in Figure 4-4, and the 200-year flood extents within the reserve are shown in Figure 4-5. Areas of the reserve that were found to be at risk of flooding include a mix of commercial, community and residential land uses. All areas located south of Marshall Creek are at risk of flooding. Based on the available aerial imagery, almost all buildings in Upper Sumas 6 are located outside of the flood extents, whereas a few buildings are located just within the flood extents where flood depths are relatively low. Most reserve homes reside within the residential zoning designation north of Kilgard Road, and houses within this area were not found to be at risk of flooding.

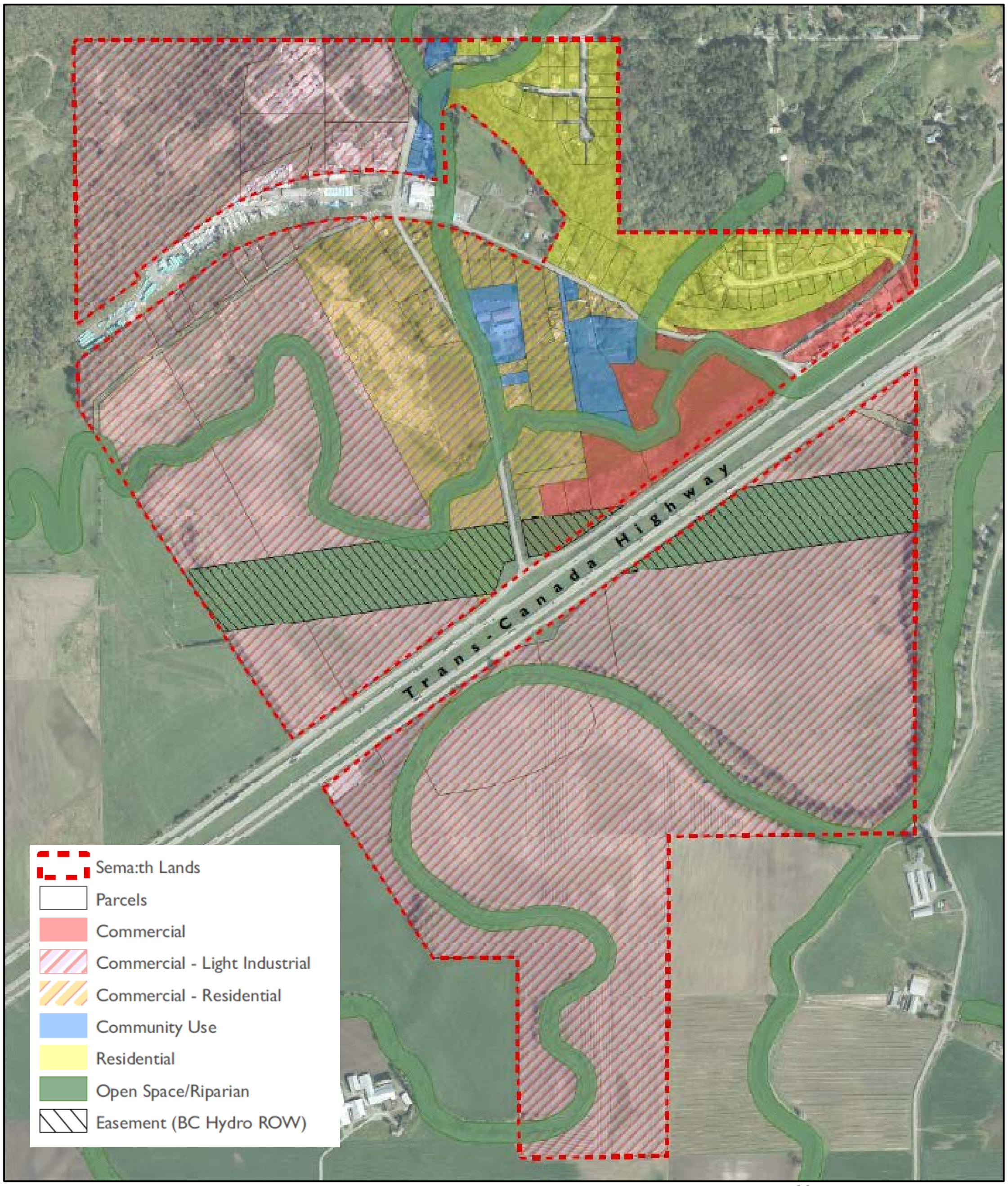


Figure 4-4: Upper Sumas 6 Land Use (source: Sema:th Land Use Plan[36])

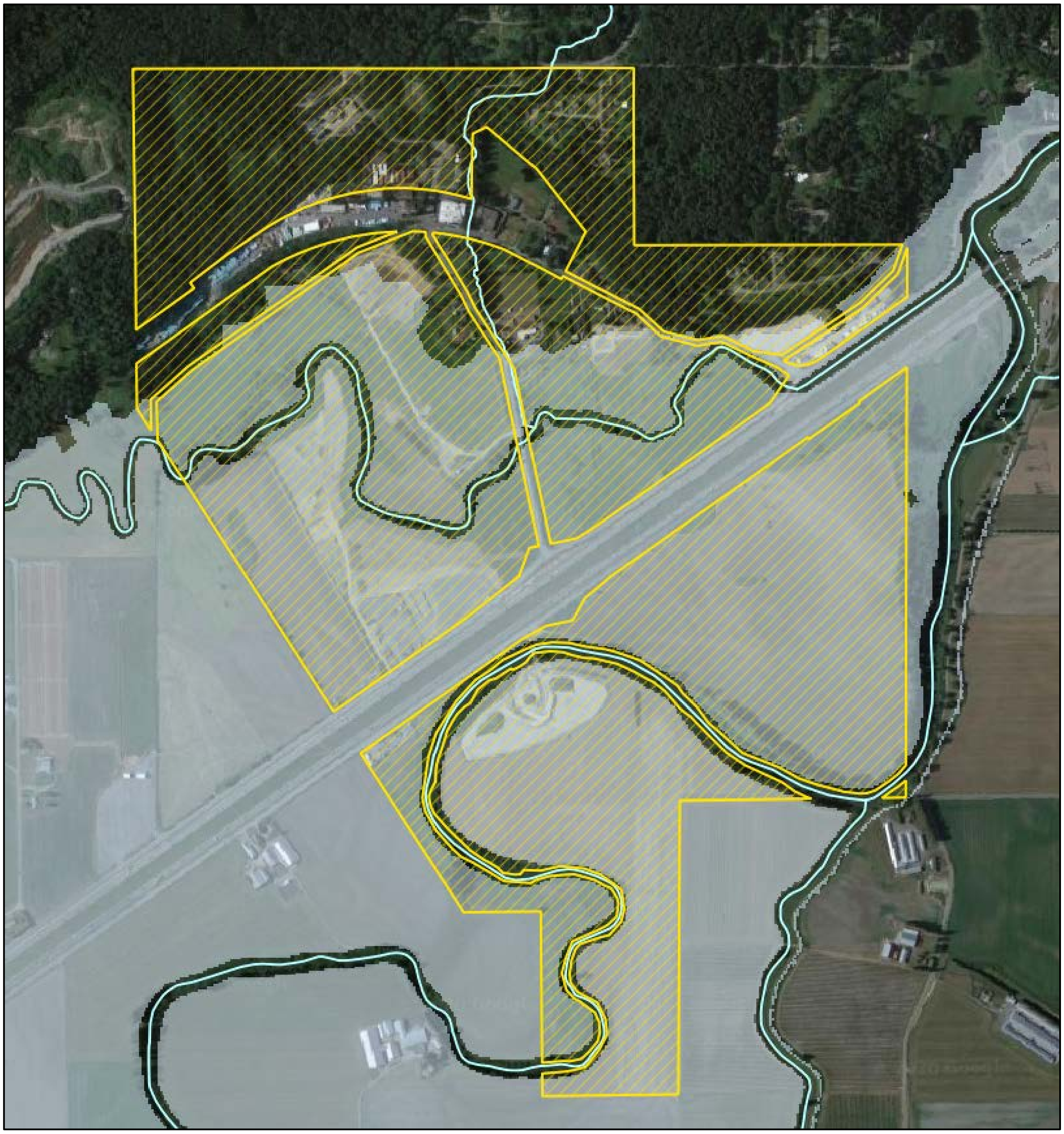


Figure 4-5: Upper Sumas 6 Boundary with 200-Year Flood Extents

Aylechootlook 5 (Leq'á:mel First Nation)

Aylechootlook 5 is an undeveloped reserve area belonging to Leq'á:mel First Nation and is located at the confluence of the Sumas River with the Vedder Canal. According to the 2015 "Leq'á:mel First Nation Land Use Plan" (Dillon Consulting Ltd.), land use on the reserve is designated as commercial recreation, which is intended for outdoor activities, eco-tourism, cultural tourism and preservation of environmental features. Prior to its current land use, the land was used for agriculture.

Aylechootlook 5 is protected by the Old Sumas Lake Bottom dike system that spans along the right bank of the Sumas River and left bank of the Vedder Canal. As a result, it is not at risk of flooding. However, flood mitigation options that involve separating the Sumas River from the Vedder River would, if implemented, require access through or in front of the reserve to expand the dike.

Sumas Cemetery 12 (Leq'á:mel First Nation)

Sumas Cemetery 12 is a former burial ground belonging to Leq'á:mel First Nation and is located on the left bank of the Sumas River along the hillside of Sumas Mountain approximately 1.5 km upstream of its confluence with the Fraser River. A railway passes through the reserve, splitting it into two areas.

While Sumas Cemetery 12 is located downstream of the area modelled for this study, the northern part of the reserve may be at risk of flooding and erosion during high flows in the Sumas River, Vedder River and Fraser River. Moreover, flood mitigation options that involve deepening and widening the Sumas River or separating the Sumas River from the Vedder River could, if implemented, disturb the reserve lands or the hillside below. These options would, therefore, need to be implemented such that Sumas Cemetery 12 would not be impacted by modifications to the channel, and such that risks of erosion to the cemetery are not increased.

Potential Archeological Sites

An archeological assessment is not included in the scope of this project. A preliminary search of online information has not yielded any known archaeological sides with the flood inundation area. Future work on this could be done if the City can access the provincial Remote Access to Archaeological Data (RAAD) system.

Impacts of Nooksack River Avulsion

The risks of an avulsion occurring along the Nooksack River near Everson were previously investigated in a 1993 study[34], which notes that a flood event larger than the November 1990 flood would be needed to cause an avulsion. The study shows the risk of an avulsion occurring during the 100-year flood was estimated to be 20%, corresponding to a joint probability of 0.2% (500-year return period). However, as this study was completed in 1993, changes since this time to the riverbed, overflow banks, climate and flood frequency estimates have likely impacted the probability of an avulsion occurring, and the avulsion risk analysis should be updated in the future. Moreover, morphological changes to the Nooksack River and its overflow banks in combination with climate change will continue to affect the probability of avulsion into the future.

According to the 1993 study, an avulsion would form a channel beginning at Everson and spanning 2 km to 3 km in length. The flow rate associated with an avulsion was estimated to be 600 m^3/s, which is over twice the overflow rate of the November 1990 flood. The estimated avulsion flow rate is also almost 50% higher than the 100-year cross-border flow rate (Scenario 2A & 2B) of 413 m^3/s and is of similar magnitude to the 200-year cross-border flow rate (Scenario 3) of 566 m^3/s. Thus, an avulsion of this magnitude could potentially double the flows into the Sumas Prairie during the 100-year and 200-year flow events, assuming minimal attenuation of the avulsion flows between Everson and the Sumas Prairie.

Flood damages within the Sumas Prairie could not be estimated for the avulsion event without additional modelling on both sides of the border and damage analysis, as the Sumas Prairie flow rates associated with an avulsion event would be much larger than those that were evaluated for this study. The largest flood event evaluated for this study was the 200-year flood under climate change conditions (Scenario CC-3), which was estimated to result in a cross-border flow rate of 735 m^3/s and total damages within the Sumas Prairie of $960 million (as estimated in Section 5). Thus, if it is assumed that an avulsion event doubles the flows into the Sumas Prairie, such an event would likely result in over $1 billion in damages.

The 1993 avulsion study also notes that major environmental damages could occur within the Sumas Prairie during an avulsion event if the avulsion washes out the Puget Sound Pipeline within the US. The study estimated that the oil spill cleanup costs within the Sumas Prairie using bioremediation and agriculture losses associated with two years of contaminated land would total $50 million in 1993 dollars, or almost $80 million in 2019 dollars[38]. This estimate does not, however, account for the growth in agricultural land that has occurred since the 1993 study.

4.6 Total Damages and Discussion

Total Damages

The total damages from the five flood scenarios assessed are summarized in Table 4-16. It should be noted that the damages provided in this assessment include both insured and non-insured losses.

Table 4-16: Total Damages for Five Flood Scenarios Under Current Climate Conditions

Scenario	Scenario Name	Damages ($ million)			
		Structure and Content Damages (HEC-FIA)	Agricultural Damages (FAO)	Economic Losses	Total
1	1990 Flood	$105	$41	$4	**$150**
2A	100-Year Flood	$316	$136	$10	**$462**
2B	100-Year Flood (no dike breaching)	$307	$144	$10	**$461**
2C	100-Year Flood (no Nooksack overflows)	$123	$84	$7	**$213**
3	200-Year Flood	$551	$271	$14	**$836**

Comparison with 1990 Flood Damages

An estimate of the damages that occurred as a result of the 1990 Nooksack overflow flood was previously provided in the 1991 report by Klohn Leonoff[37], which includes damages as documented by insurance providers for claims filed as of the date of the report. The documented private claim values totalling $456,000 and $623,600 that were provided in the report included infrastructure damages for roads and utilities, Highway 1, and the Southern Railway embankment. The total value of damages accounted for is $1,079,600. The report notes that not all claims had been settled at the time of the data collection for the report, as well as some residences were noted to have restrictive covenants for flood damages. To account for these, the report estimates the total damages may have been $1.5 million (in 1990 dollars).

The methodologies used for the current analysis have generated much larger values for damages from the modelled extents for the 1990 flood event. The predicted damages in 2019 dollars are $150 million, or two orders of magnitude larger than what was documented at the time.

Some of the minor discrepancies may be attributed to the adjustment of dollars for inflation. Adjusting the documented flood damages from 1990 dollars to 2019 dollars increases the number by approximately 72%[38] to $2.6 million. In addition to inflation, the population of the City of Abbotsford has increased substantially during this 29 year period. Based on information from the BC stats website[39], the population in the City of Abbotsford increased by 84% from 1990 to 2019. It is not known how this population is distributed in the flood inundation area compared to the City overall. If the population in the flood-affected area is assumed to increase proportionally to the City overall, the increase in population would likely drive an increase in the building and content damages in the area.

Other sources of increase in damages relative to the estimate in the 1991 report may include:

- Construction/repair cost increases over time;
- Higher value agricultural products relative to 30 years ago;
- Higher value agricultural buildings and equipment in the area relative to 30 years ago; and
- Under-reporting of damages based on claims. It may be that many (or most) damages were not insured and are therefore not accounted for in the reporting of damage claims.

Several assumptions regarding the extent of flooding impacts on farm animals and equipment are conservative and will tend to increase the estimated agricultural damages, such as:

- Assume a year's crop is impacted by the flood, either by loss of the current crop (if flood occurs during the growing or harvest season) or loss of the following year's crop (due to flood damages and cleanup preventing a new crop going in.
- Assume that animals are confined and/or restricted by fences or other barriers and are unlikely to be re-located to high ground out of the flood inundation area for the duration of the event. This assumption indicates high mortality of livestock due to flooding.

Structures Impacted in 1990 Flood Assessment

The 1991 report shows that damage claims were made for 18 residential structures and one commercial structure. The current model of the 1990 flood incorporates damages to 247 residential and 76 non-residential structures that are flooded.

Since many agricultural properties contain both types of structures, this totals 259 individual properties containing structures (whether residential, non-residential or both) that had damage accounted for in the current model of the 1990 flood scenario.

175 of those flooded residential structures are located in a higher density residential neighbourhood in Huntingdon (next to the US border), just east of Highway 11. When the structure damages from HEC-FIA for these properties are isolated, the properties actually represent approximately 70% of the total residential flood damages for the 1990 flood scenario. This area was subdivided in the early 20th century according to City of Abbotsford records, and it is unclear how many of the homes in this area may have been built before 1990, vs. after 1990.

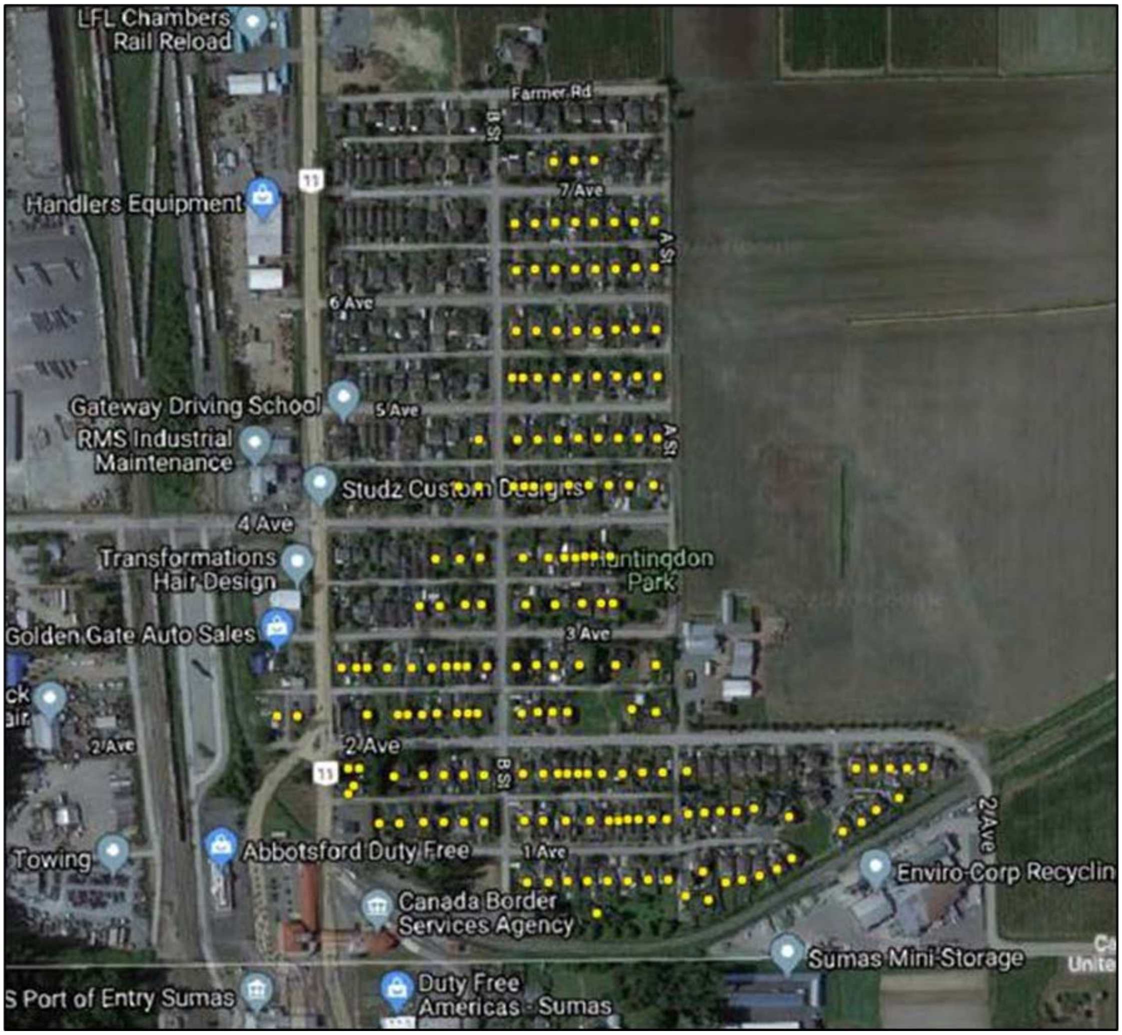


Figure 4-6: High Concentration of Residential Structures in Huntingdon (yellow dot indicates house was flooded during November 1990 flood in current model)

Agricultural Damages in 1990 Flood Assessment

The current model of the 1990 flood indicates 215 farms were impacted by the flooding event (162 were livestock types), whereas only 12 properties are reported to have claimed damages with an average of $10,000 per property[37]. The current model indicates $190,000/property in agricultural damages (including both insurable and non-insurable damages), representing a major increase in the damage per property expected.

The 1990 flood occurred in November, so no crops would have been damaged, and the flood occurred early enough relative to the following year's growing season that there may have been no impact the following year's crop. Ignoring all crop damages, the current model of the 1990 flood shows $35 million from livestock losses, of which $8.4 million is direct damages (damaged assets, damaged stored inputs and killed animals), the rest is loss in revenue. As noted above, these damage estimates conservatively assume the bulk of livestock that is located within the flood inundation area would not survive the flood (i.e., could not be relocated out of the flooded area) and this contributes to the high estimated livestock losses.

In addition, similar to the residential structures, more farm structures, including greenhouses, have been constructed on agricultural properties within the flood inundation area than were in existence in 1990. These newer farm structures would have increased the equipment and farm assets that are incorporated in the damage assessment.

5. Flood Mitigation Analysis

5.1 Previously Evaluated Flood Mitigation Options

Multiple flood mitigation options have been suggested and modelled in numerous studies since the 1990 flood event. This section summarizes the mitigation options that have been looked at in the past. These options generally consist of conveying flows to and through the Barrowtown dam towards the Fraser River more efficiently, as well as efforts to prevent dike breaching and recommendations for floodproofing. The four following studies have investigated and/or modelled flood mitigation options in the Sumas Prairie and are discussed throughout this section:

1. "Flooding of West Sumas Prairie: November 9-12, 1990" (Klohn Leonoff Ltd., 1991)[37]. Prepared for BC Ministry of Environment.
2. "The Sumas River Flood Routing Study - Interim Report" (Wilson Hydrotechnical Ltd., 1998)[4]. Prepared for the City of Abbotsford and BC Ministry of Environment.
3. "Sumas Prairie Flood Hazard Investigation: Mitigation Options Proposed for Modelling" (UMA Engineering Ltd., 2004)[40]. Prepared for the City of Abbotsford.
4. "Sumas Prairie Design Flood Simulation and Impact Mitigation: Phase 1 Project Summary" (KWL, 2014)[2]. Prepared for the City of Abbotsford.

Option 1 – Increasing the Capacity at Barrowtown Dam

Previous studies have investigated the impacts of modifying both the floodbox capacity and the pump station capacity at the Barrowtown Dam. The benefit of increasing the floodbox capacity is limited when downstream water levels are higher than upstream and the floodboxes are closed. During these periods, increasing the pump station capacity would allow Sumas River flows to continue downstream but requires higher installation and operational costs.

Option 1A – Increase Floodbox Capacity

This option involves increasing the Sumas River floodbox capacity at Barrowtown dam to reduce the backwater constriction at this location. However, increasing the floodbox capacity was not recommended by the 1991 Klohn Leonoff study because of the limited capacity of the Sumas River channel and because the floodbox cannot open when water levels upstream of the dam are lower than water levels downstream of the dam. This option was eliminated in the 2004 UMA report because the difference in water levels upstream and downstream of the dam were found to be less than 0.07 m during the 1990 flood, indicating that additional floodboxes would have minimal impact on water levels during flood conditions.

Option 1B – Increase Pump Station Capacity

This option involves installing pumps at the Barrowtown dam that would pump flows from the Sumas River across the Barrowtown dam. Unlike floodboxes, pumps can be operated when water levels are higher downstream of the dam than upstream of the dam.

The 1991 Klohn Leonoff study modelled pumping options with pump rates of 50, 100, and 200 m^3/s and found that the resulting increase in flow past the dam would result in minimal impact on upstream water levels. The study, therefore, did not recommend the use of pumps as an impactful flood mitigation effort.

The 1998 Wilson Hydrotechnical study modelled this option by assuming two of the existing pumps were switched from pumping the Sumas Lake Canal to pumping the Sumas River. The study did not recommend this approach, as it resulted in more flooded area within the Old Sumas Lake Bottom than the flooded area that was reduced in the Saar Creek sump and Arnold Slough sump.

The 1998 Wilson Hydrotechnical study then modelled the effects of installing a new pump station at the Barrowtown dam for the Sumas River with ten new pumps (90 m^3/s total capacity) rather than diverting two of the existing pumps. This option was found to effectively reduce flood levels and durations in the Saar Creek sump and Arnold Slough sump, but it did not impact the Marshall Creek sump where most of the flood damages are concentrated.

Option 2 – River Modifications Downstream of Barrowtown Dam

Modifications to the Sumas River downstream of the Barrowtown dam have been investigated to lower the water levels on the downstream side of the dam and allow for more flow to be discharged via the existing floodboxes. Two categories of options have been evaluated: (1) deepening and widening the Sumas River to increase its capacity, and (2) separating the Sumas River from the Vedder River to eliminate the impacts of Vedder River flows.

Option 2A – Channel Improvements to Sumas River

This option was first proposed in the 1991 Klohn Leonoff study, which suggested that channel improvements be carried out in the Sumas River between its confluence with the Vedder Canal and its confluence with the Fraser River, as water levels downstream of Barrowtown dam were more frequently found to be influenced by high flows in the Vedder Canal than from the Fraser River.

The Wilson Hydrotechnical 1998 study modelled the effects of deepening and enlarging the Sumas River downstream of Barrowtown dam to an invert of -1.0 m and to a width of approximately 180 m. Dredging and widening would be carried out from the Barrowtown dam to the Fraser River, resulting in a total dredged volume of approximately one million cubic metres. This option was found to provide a small benefit to the Saar Creek sump and Arnold Slough sump but no benefit to the Marshall Creek sump. The flood reduction benefits are also limited by how water levels typically rise in the Fraser River as flows drop in the Vedder Canal. High water levels in the Fraser River will, therefore, remain an issue with this option.

Challenges associated with maintaining an invert at -1.0 m may be detrimental to this option given the volume of sediment transported by the Vedder River. Moreover, the channel improvements would require land owned by the Department of National Defense (DND) to be acquired and modified, and the dredging effort would pose several environmental impacts and require significant coordination with regulatory agencies. For these reasons, downstream channel improvements may not be a feasible option.

Option 2B – Separate Sumas River and Vedder River Channels

This option was proposed by the UMA 2004 report and consists of separating the Sumas River from the Vedder River from their confluence to the confluence with the Fraser River. By separating the two rivers, the Vedder River would no longer impact water levels downstream of Barrowtown dam. Four alignment options were proposed for the two rivers as follows (see Figure 5-1):

a) **Dedicated Sumas River along the left bank of the Vedder River along the toe of Sumas Mountain**. This alignment option is not desirable because it would cross Sumas Cemetery IR 12 (Leq'á:mel First Nation) and would also require a new railway bridge and displace approximately 2 km of railway tracks.

b) **Relocate Vedder River through right bank of existing channel through DND lands**. This alignment option is also not desirable because it would position the river closer to the flood control dikes protecting the City of Chilliwack, could result in considerable fish habitat issues, and would also require a new railway bridge. Moreover, it would require acquiring and modifying land owned by DND.

c) **Construct an inverted siphon to allow the Sumas River to cross under the Vedder River and continue along the right bank of the Vedder River**. Compared to the relocated Vedder River alignment option, this alignment option would require a narrower channel, a shorter span for the new railway bridge, would be less impactful to DND lands, and would not impact flood protection and fish habitats along the Vedder River. However, this alignment option may present several challenges associated with the construction and maintenance of the inverted siphon.

d) **Tunnel the Sumas River through the Sumas Mountain from upstream of the Barrowtown dam to the Fraser River**. This alignment option is desirable because it would not impact the Vedder River and surrounding lands, including the lack of need for a separator dike that would otherwise require access through or in front of Aylechootlook IR 5 (Leq'á:mel First Nation). However, the tunnel option is expected to be more expensive than the previous three options. A short railway bridge may also need to be constructed at the outlet of the tunnel, depending on the configuration and alignment of the tunnel.

These options have not been modelled in previous studies.

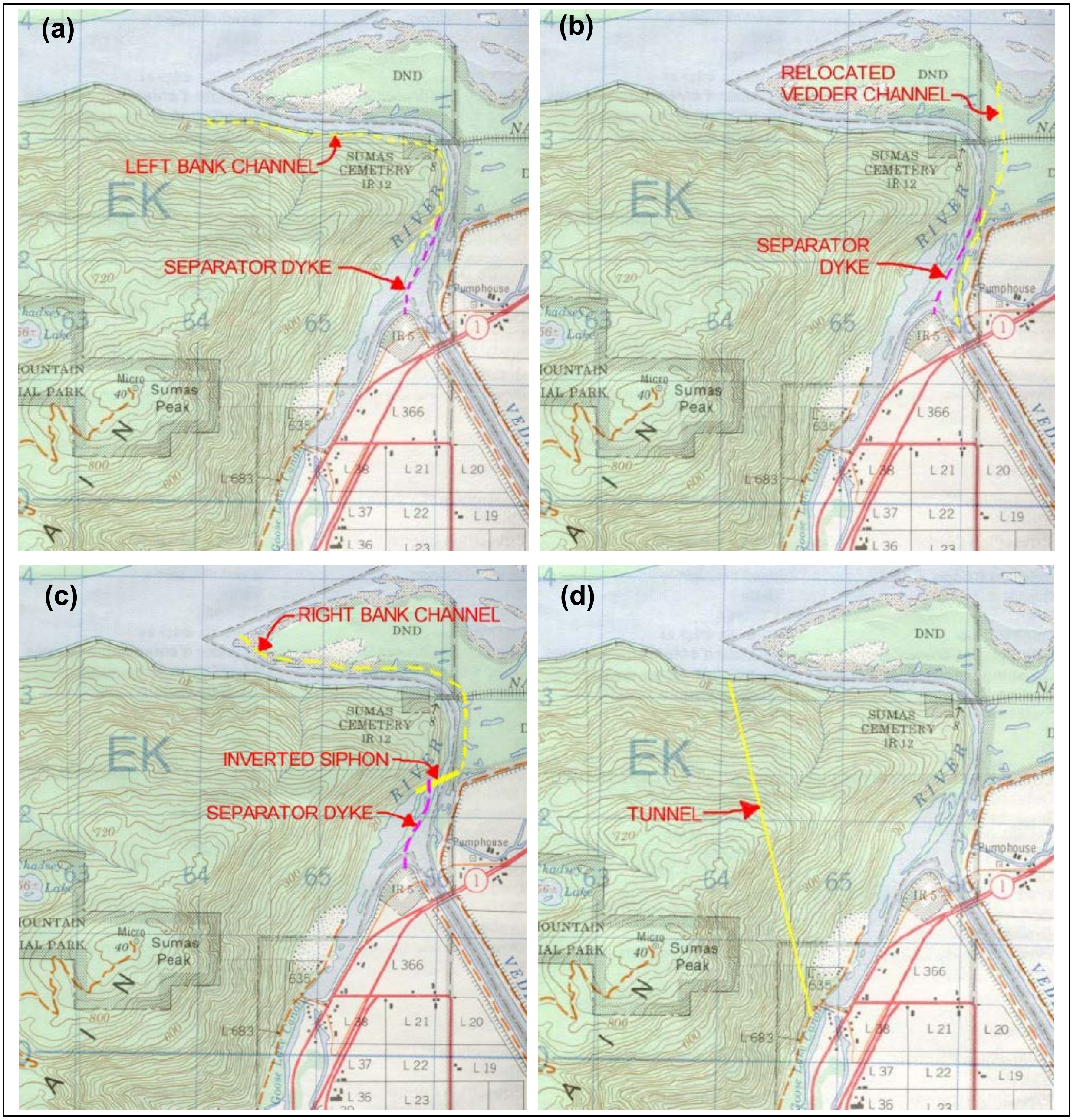


Figure 5-1: Sumas River and Vedder River Separation Options from 2004 UMA Report: (a) dedicated Sumas River along left bank of Vedder River, (b) relocate Vedder River through its right bank, (c) dedicated Sumas River along right bank of Vedder River (inverted siphon), (d) tunnel Sumas River

Option 3 – Floodway Alternatives

Two floodway alternatives have been evaluated in previous studies to reduce flooding in the Marshall Creek sump, one on the right bank of the Sumas River (Sumas River floodway) and one on the left bank of the Sumas River (Marshall Creek sump floodway). Both options are effective at reducing flooding in the Marshall Creek sump but create additional flooding issues downstream in the Saar Creek sump and Arnold Slough sump. Additional mitigation options further downstream may, therefore, be needed in combination with floodway options to achieve an overall reduction in flooding. Sketches of the proposed floodway alignments are provided in the 1991 Klohn Leonoff study (Figure 5-2) and the 1998 Wilson Hydrotechnical study (Figure 5-3).

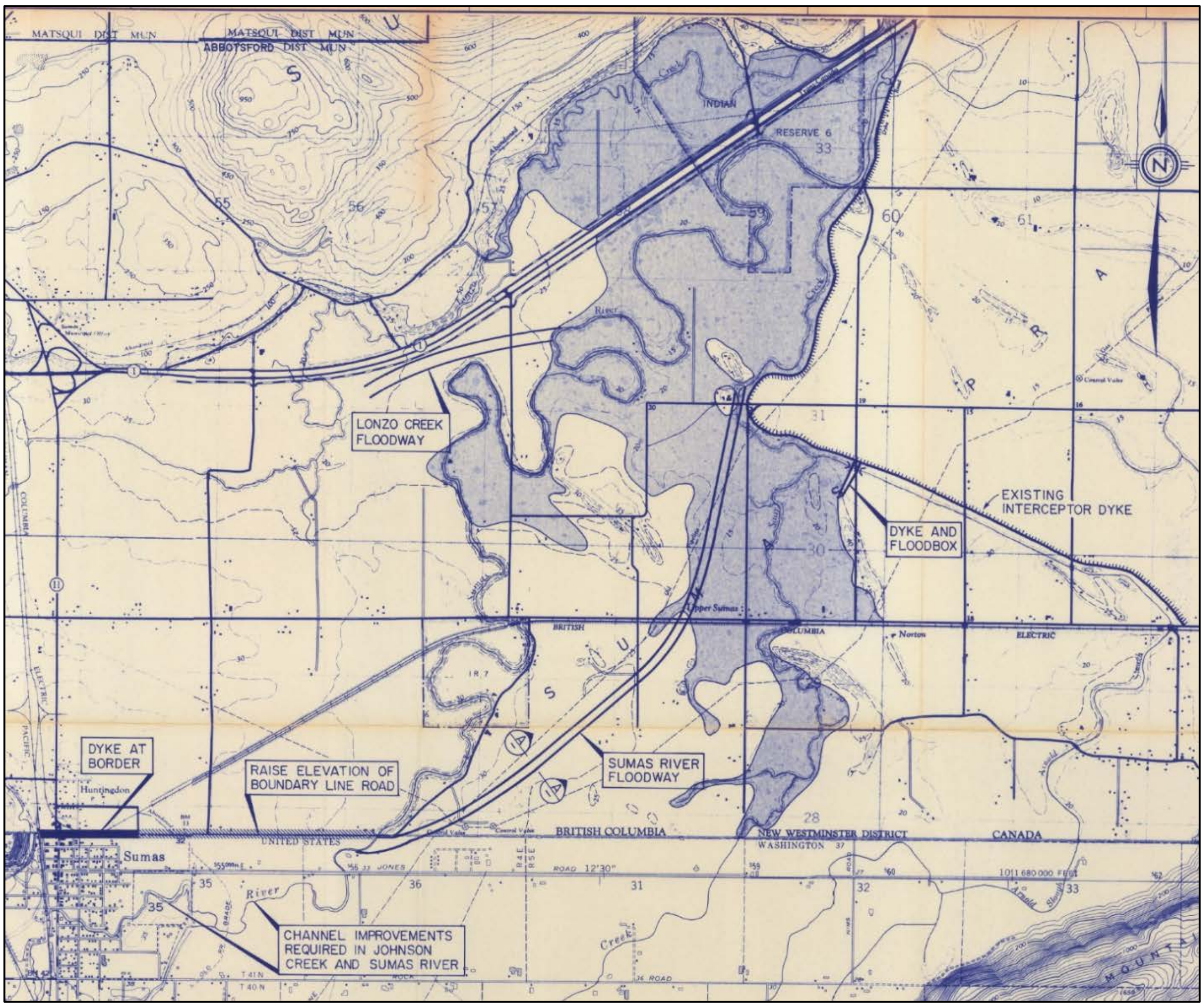


Figure 5-2: Recommended Flood Mitigation Measures from 1991 Klohn Leonoff Study

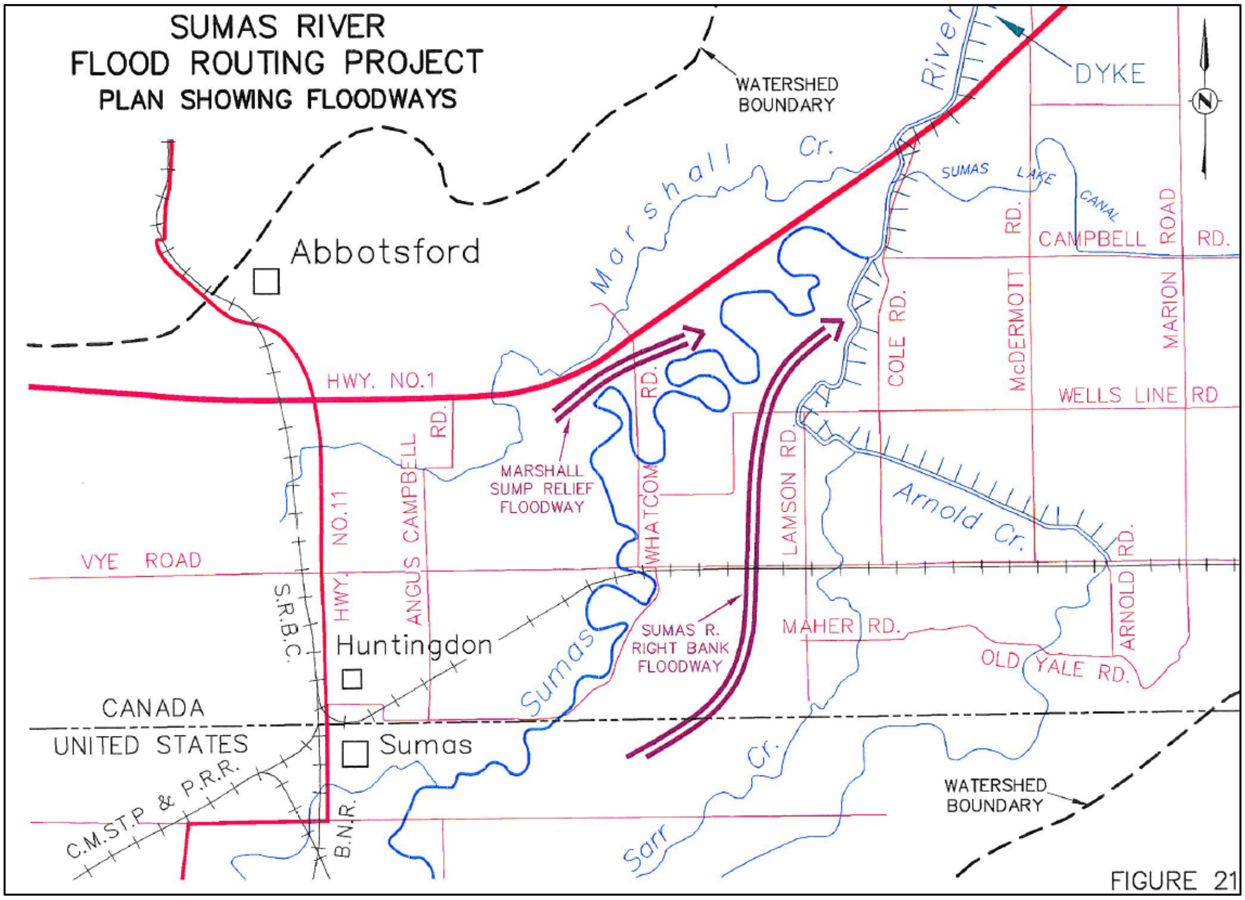


Figure 5-3: Recommended Floodway Alignments from 1998 Wilson Hydrotechnical Study

Option 3A – Sumas River Floodway

This option consists of constructing a floodway from the right bank of the Sumas River at the US border to Saar Creek near its confluence with the Sumas River. The floodway would pass through the Southern Railway, Vye Road and Wells Line Road, requiring new low-head bridge crossings at these locations. The floodway would also require Boundary Line Road to be raised by approximately 1 m to act as a dike and direct high flows into the floodway rather than overflowing the left bank of the Sumas River. The new Boundary Line Road dike would extend into an earthen dike at Huntingdon where the roadway bends. Highway 11 would then ramp over the new earthen dike at the US border crossing.

The Sumas River right bank floodway was first proposed in the 1991 Klohn Leonoff study, which recommended a 60 m wide channel bottom with a capacity of 200 m^3/s. The 1998 Wilson Hydrotechnical study then modelled this option assuming a 300 m wide channel with minimal side slopes to avoid impacting land uses within the floodway. The floodway option was found by the 1998 Wilson Hydrotechnical study to greatly reduce flooding in the Marshall Creek sump and to significantly increase the timing and volume of flood flows towards Barrowtown dam, allowing for increased flow through the floodboxes.

However, these benefits were found to come at the expense of increased flooding in the Saar Creek sump and Arnold Slough sump, increasing the risk of the Interceptor Dike and Sumas River Dike being overtopped. To mitigate the increased backwater flooding along the Arnold Slough, the 1991 Klohn Leonoff study suggests installing a new dike and flood box across the Arnold Slough just upstream of its confluence with Saar Creek. Alternatively, the 1998 Wilson Hydrotechnical study suggests that buildings in the Saar Creek sump and Arnold Slough sump could be floodproofed to prevent the additional flood risks.

Another issue with this option is that the associated Boundary Line Road dike could increase flood levels in the City of Sumas, as it would prevent high flows in Johnson Creek and the Sumas River from overflowing across the border. To mitigate increased flood levels in the City of Sumas, the 1991 Klohn Leonoff study suggests the implementation of channel improvements on the Washington State side in Johnson Creek and in the Sumas River to safely convey high flows from the City of Sumas to the floodway (see Option 7C). This would require significant work to be carried out by the US, which may limit the viability of the Sumas River floodway option.

Option 3B – Marshall (Lonzo) Creek Sump Floodway

This option consists of constructing a floodway from the Marshall Creek sump to the Sumas River downstream of its crossing with Whatcom Road. A ford would be constructed at Whatcom Road where it crosses the new floodway alignment. The Marshall Creek Sump floodway would collect both floodwaters from the Marshall Creek sump and left bank overflows from the Sumas River, conveying them past the existing floodplain constriction at Whatcom Road.

The Marshall Creek sump floodway was first proposed in the 1991 Klohn Leonoff study, which recommended a 90 m wide channel bottom with a capacity of 150 m^3/s. The 1998 Wilson Hydrotechnical study then modelled the floodway as a 50 m wide channel and found that it provides a significant reduction to flooding in the Marshall Creek sump, including reduced flooding on the north side of the TransCanada highway and reduced risk of highway overtopping.

According to the 1991 Klohn Leonoff study, the impacts of the Marshall Creek sump floodway on downstream water levels are expected to be minor since the floodway would still contain some storage. However, the 1998 Wilson Hydrotechnical study found that this floodway would increase flooding in the Saar Creek sump by several metres. The 1998 Wilson Hydrotechnical study therefore also modelled the impacts of channel improvements downstream of Barrowtown Dam and of increasing the pump capacity at Barrowtown Dam in conjunction with the Marshall Creek sump floodway to prevent increases in flooding in the Saar Creep sump and Arnold Slough sump. This combination of options was found to be effective at reducing flood levels in the Marshall Creek sump while maintaining flood levels in the Saar Creek sump and Arnold Slough sump.

Focusing on the Marshall Creek sump floodway option over the Sumas River floodway option was suggested by the UMA 2004 report because the Marshall Creek option:

1. Spans a shorter distance (less cost and impacts);
2. Has less impact on flood levels in the Saar Creek sump and Arnold Slough sump; and
3. Does not require the US to reroute floodwaters around the City of Sumas.

Since the Marshall Creek sump floodway would still increase downstream flood levels, the UMA 2004 report recommends further modelling of this option in combination with one of the following three downstream modifications:

1. Floodproofing in the Saar Creek sump and Arnold Slough sump;
2. New pump station at Barrowtown sized for the 100-year flood; and
3. Separated Vedder River and Sumas River channels using the inverted siphon alignment option.

Option 4 – Improvements to Interceptor Dike and Sumas River Dike

The dikes that protect the Old Sumas Lake Bottom are at risk of breaching, as they do not contain any overflow spillways and are vulnerable to overtopping during flood events greater than the 1990 flood. Two options have been discussed to address the vulnerabilities of the Interceptor Dike and Sumas River Dike.

Option 4A – Construct Relief Spillways

The 1998 Wilson Hydrotechnical study and the 2004 UMA report suggest installing several relief spillways along the dikes while keeping its existing crest elevation. The spillways should be sized and located such that floodwaters are distributed as broadly as possible to limit flood levels at any one area in the Old Sumas Lake Bottom. While this option would not reduce overall flooding, it would allow for flooding to be better controlled and would prevent the need for dike repairs due to breaches.

Option 4B – Raise Interceptor Dike and Sumas River Dike

The 1998 Wilson Hydrotechnical study discusses the option of raising the crest of the dikes to increase flow rates through the floodboxes at Barrowtown dam. However, raising the dikes would likely increase flood levels in the Saar Creek sump and Arnold Slough sump during extreme flood events, as floodwaters would not be relieved by overtopping into the Old Sumas Lake Bottom. Floodproofing may therefore be required for properties in the Saar Creek sump and Arnold Slough sump if the dikes are raised. The impacts of raising the dikes on 100-year and 200-year flood levels have not yet been investigated.

Option 5 – Improvements to Railway Embankment

The Southern Railway breached during the 1990 flood near Kenny Road, resulting in increased flood levels in the Marshall Creek sump. Two options were discussed in the 1991 Klohn Leonoff study to improve the railway embankment.

Option 5A – Reinforce Railway Embankment

This option involves reinforcing the Southern Railway embankment to prevent a recurrence of the 1990 flood breaching, which would reduce flood levels in the Marshall Creek sump as shown in the 2014 KWL modelling study. However, more volume would be directed towards the Saar Creek sump and Arnold Slough sump, resulting in additional overtopping of the adjacent Interceptor Dike in the 100-year and 200-year flood events.

Option 5B – Raise Railway Embankment

An alternative option is to raise and reinforce the railway embankment to create a new dike. However, this option was not recommended by the 1991 Klohn Leonoff study because the Sumas River has inadequate capacity to convey the increased flows that would result from the new dike. This option would likely further increase flooding in the Saar Creek sump and Arnold Slough sump.

Option 6 – Floodproofing

While all new buildings constructed in the Sumas Prairie must be constructed to a Flood Construction Level (FCL) equal to the 200-year flood level plus 0.6 m of freeboard, many older buildings remain below this level, and exceptions have been made for newer buildings located in areas such as the Old Sumas Lake Bottom where this would require several metres of fill as demonstrated by the 200-year event with dike breach scenario. Floodproofing could be carried out for buildings constructed below the FCL located within the floodplain through the construction of perimeters berms, as originally suggested in the 1991 Klohn Leonoff study. The study also identified challenges associated with constructing perimeter berms related to access for farming vehicles and internal drainage issues. The impact of constructing perimeter berms around individual buildings could also increase flood levels due to the loss of storage, and these impacts have not yet been investigated.

Option 7 – Measures in Washington State

Additional flood mitigation measures could be implemented in Washington State that would impact flood levels in the Sumas Prairie.

Option 7A – Block Overflow at Everson

The idea of constructing a dike at Everson to prevent overflows from Nooksack River into the Sumas River was first discussed in the 1991 Klohn Leonoff study. While the 2014 KWL modelling study shows that preventing the Nooksack River overflow would indeed eliminate many of the flooding issues in the Sumas Prairie and would also reduce the environmental impacts associated with asbestos in the floodwaters, this option would require significant channel improvements or other flood mitigation measures in the Nooksack River to prevent massive damages further downstream. Moreover, the overflow is naturally occurring, and full containment of the overflow event may not be acceptable to US agencies.

The configuration of such a structure required to block the Nooksack River overflow at Everson has not been discussed in previous studies. According to the 1991 Klohn Leonoff study, overflows from the Nooksack River occurred at three locations during the November 1990 flood (Figure 5-4). The largest overflow occurred along the southwest edge of Everson's urban core, the second largest overflow occurred from overtopping of Massey Road, and the smallest overflow occurred from overtopping of Emmerson Road. A 460 m long ring levee was constructed soon after the 1990 flood along the southwest edge of Everson to protect its urban core. This ring levee is often referred to as the "Lagerway Dike" or the "Everson Levee". According to the 2004 ONE-D model analysis of the Nooksack River overflows[41], the new levee contributes to increased overflows due to the narrower width that is now available for overtopping and because it blocks overflows that have overtopped the natural levee of the Nooksack River further upstream from returning to the river.

To completely block off Nooksack River overflows from entering Johnson Creek, the ring levee at Everson would need to be extended further upstream along Emmerson Road and Massey Road. While such an extension has not been discussed in previous studies, a sketch of this potential levee extension alignment is provided in Figure 5-5. The alignment shown in this sketch assumes Emmerson Road, Massey Road and Bisset Road would be raised and reinforced such that the roads act as a new levee. The levee extension would then continue south through private property along the natural levee of the Nooksack River until reaching a distance that is sufficiently far upstream to completely prevent any overtopping. The total distance of the assumed levee extension was would be approximately 2.5 km.

Figure 5-4: Overtopping Locations for Nooksack Overflow During November 1990 Flood from Klohn Leonoff Study

Figure 5-5: Potential Alignment for New Levee to Block Nooksack Overflow at Everson

Option 7B – Restore Gravel Mining

According to the 1991 Klohn Leonoff study, the cessation of gravel mining in the Nooksack River has contributed to increased overflows at Everson. Restoring gravel mining operations to remove gravel bars could reduce the potential for overflow. Initial actions were taken by the State of Washington in the 1990s to remove gravel and debris, and to reduce royalties on gravel removal.

Option 7C – Johnson Creek Channel Improvements and Dike

The NRITF made recommendations in the 1990s to investigate the construction of channel improvements and diking along Johnson Creek through the City of Sumas. These efforts would impact the location of where floodwaters cross into Canada, and they could be implemented in conjunction with the Sumas River floodway option (see Option 3A). It is unknown if further action has been taken to investigate this option or similar options in Washington State.

Option 7D – Flood Warning Systems

Flood warning systems have been in development for the Nooksack River watershed since the 1990s. During this time, emergency hotlines were established in Whatcom County and in BC, and Environment Canada began broadcasting the US National Weather Service forecasts and US flood warnings such that both sides of the border could monitor Nooksack River flood warnings. A staff gauge was installed by Whatcom County on the west bank of Johnson Creek south of South Pass Road, and the County developed a flood warning system using rain gauges and weather instruments located on the upper Nooksack River.

More recently, USGS have been operating water level gauges in the Nooksack River at North Cedarville (USGS 12210700) since 2004 and at the upstream end of Johnson Creek at West Main Street (also called West Columbia Street or Highway 544) (USGS 12211195) since 2013. Flood warnings are currently communicated from Whatcom County to the City of Abbotsford when water levels at the Nooksack River North Cedarville gauge are in the range of 147 to 149 feet and discharge is above 48,000 ft^3/s (1,360 m^3/s) for a duration of 18 hours or more. Records from a recent minor Nooksack overflow event in February 2020 indicate that the overflows that ultimately cross the US/Canada border are now occurring at a lower Nooksack River flow rate of approximately 1,000 m^3/s. As noted in Section 4, the changed flows in the Nooksack River should be incorporated into the next iteration of modelling on both sides of the border.

5.2 Flood Mitigation Options Not Previously Studied

In addition to the various flood mitigation options that have been considered since the 1990 flood, three additional options have been investigated for this project. The first option involves constructing a floodway centred along the Sumas River, and the other two options involve protecting higher density developments on the outskirts of the floodplain at Huntingdon and Arnold.

Sumas River Corridor Floodway (Option 8A)

Previous studies have investigated "left bank" and "right bank" floodways (see Option 3A and Option 3B) that include limitations on the benefits anticipated even with significant effort and costs. The previously discussed Marshall Creek sump floodway (left bank) is a short-spanning channel crossing Whatcom Road that does not prevent initial flooding of the sump and its upstream drainage path, including the community of Huntingdon located next to the US border. This community contains a high-density neighbourhood of single-family dwellings that become flooded from overflows crossing the US border during extreme floods, resulting in a high concentration of damages. Alternatively, the previously discussed Sumas River floodway (right bank) spanning from the US border to North of Wells Line Rd., requires diking along Boundary Road and channel improvements on the Washington State side in Johnson Creek and in the Sumas River to safely convey high flows from the City of Sumas to the floodway. A left bank floodway originating from the US border that would involve similar work to Boundary Road and Johnson Creek has not been investigated because the right bank route is preferable. In addition to these limitations, all previous floodway options were designed for much smaller flows than the 200-year flood flows under climate change conditions, which peak at 735 m^3/s crossing the US/Canada border.

For these reasons, a new floodway option is suggested that consists of a corridor centred along the Sumas River rather than along its left or right banks. This floodway aims to contain nearly all overflows flows that cross border from the Sumas River and Johnson River within its extents, based on the 200-year flood under climate change conditions, while also protecting the largest amount of properties possible. A conceptual sketch of such a floodway, with the edges depicted along existing property lines, is provided in Figure 5-6. The width of the floodway shown in the figure is based on a 1,100 m wide channel contained by dikes on either side. The 200-year with climate change event is estimated to have a maximum water depth within the floodway of approximately 2.5 m.

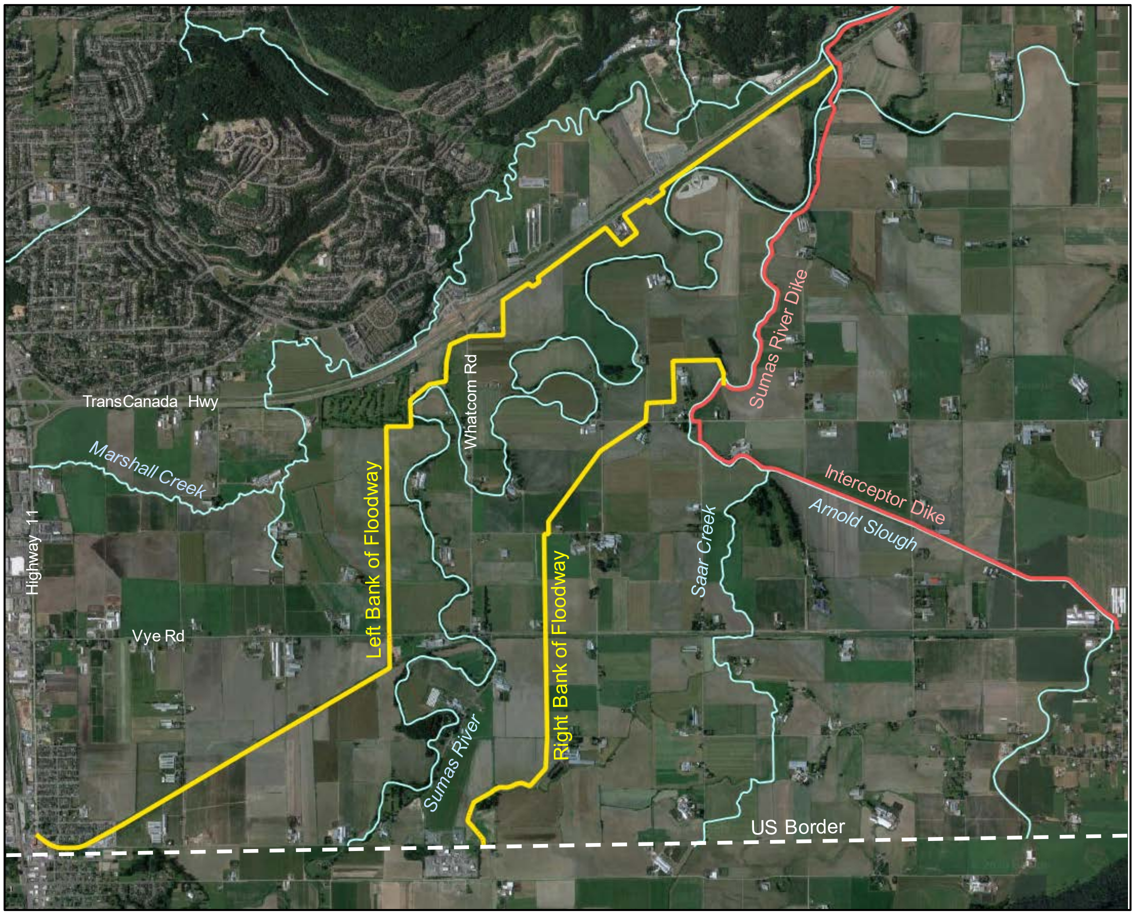


Figure 5-6: Sumas River Corridor Floodway Option

To prevent additional work that would be needed on the US side to safely direct flow into the floodway without increasing flooding south of the border, the left bank of the floodway would follow the south side of the Southern Railway embankment to where it meets with Highway 11. This tapering would allow for the wide swath of floodwaters that cross Boundary Road from the US to ease into the floodway. While some overflows from the Sumas River and Johnson Creek may still cross the border to the east of the right bank of the floodway and enter into Saar Creek, these overflows would be substantially smaller than those to the west and are expected to result in much lower levels of flooding along Saar Creek. To fully contain the overflows within the floodway, some additional work would be needed on the US side to tie the right bank of the floodway into high ground.

Further optimization of the floodway would be carried out during its design to locally reduce its width as possible while still providing capacity for the total 200-year with climate change flow. If desired, a secondary set of dikes could also be installed within the floodway to protect some properties during smaller flood events. The secondary dikes would be overtopped during very large, rarely occurring events, up to the 200 year with climate change event level.

At the downstream end, the right bank of the floodway would tie into the existing Sumas River Dike. The right bank of the floodway would need to cross Saar Creek, requiring a floodbox on Saar Creek to prevent backflows into Saar Creek and Arnold Slough. Like the other floodway options, further raising of the existing dikes would be needed due to the more constrained conveyance and higher depth of flow that the floodway would cause. The TransCanada Highway crossing of the Sumas River would need to be raised and widened to reduce the constriction at this location. The left bank of the floodway would need to cross Marshall Creek and be tied into high ground on the north side of Highway 1, requiring a floodbox at or near the mouth of Marshall Creek to prevent backflows into the Marshall Sump. All other roads that intersect with the new floodway dikes would need to be raised over the dikes, whereas roads within the dikes would be expected to flood. One exception is the Southern Railway, which would require removing the existing embankment and constructing a 1100 m viaduct over the floodway, as the existing embankment would impede flow through the floodway and lowering the railway in this area would not be desirable. The new viaduct may also require raising the approaches to the floodway, although this would ultimately depend on the design elevations of the floodway at this location.

Structures located within the floodway would need to be floodproofed. Floodplain covenants within the floodway would also need to be established with property owners. Ideally, the ground elevations within the floodway would be set such that agricultural land still meets the ARDSA criteria for flood durations during 10-year return period events. Pump stations may be needed for Marshall Creek and Saar Creek that would operate when water levels within the floodway are higher. Smaller pumps may also be needed at a few locations outside of the floodway if the water levels within the floodway are too high to support gravity drainage during 10-year ARDSA events, although further optimization of the floodway dike alignments could be carried out to reduce local drainage issues.

Local Huntingdon Area Dike (Option 8B)

The community of Huntingdon which contains a high concentration of single-family dwellings, located east of Highway 11 and next to the US border, is subject to flooding during extreme Nooksack River overflow events. The damage assessment for this project predicts a large concentration of damages in this area. Protecting the community would considerably reduce overall damages within the Sumas Prairie. Since the volume of flooding within Huntingdon is small in comparison to the total flow crossing the border, dike protection for the community would likely have negligible impacts on flood levels in the rest of the Sumas Prairie. Dike elevations would also not need to be drastically higher than existing ground elevations, as the depth of flooding at Huntingdon is below 0.6 m during the 200-year flood under climate change conditions.

A conceptual alignment for a dike around Huntingdon is shown in Figure 5-7. This 1.7 km dike would mostly follow the north side of the Southern Railway from Highway 11 to its crossing with 2nd Avenue. Due to the limited room available on the north side of the railway, a sheet pile flood wall is envisioned for this segment of the dike. At the dike crossing with 2nd Avenue, the road may or not may need to be raised, depending on the design elevation of the dike. On the north side of 2nd Avenue, the dike would then continue along the east side of the community until it meets the driveway for 34715 Farmer Road. This segment of the dike is expected to be earth-filled. Continuation of the dike back towards Highway 11 would again depend on final design elevations, but this extension is not expected because elevations gradually increase along Farmer Road towards Highway 11 and this area is not within the 200-year with climate change flood extents. The dike is not expected to adversely impact flooding in the US.

Based on the 200-year flood under climate change conditions, the Huntingdon Area Dike is estimated to protect 273 structures assessed at $61 million (structure value only).

Figure 5-7: Huntingdon Area Dike Option

Local Arnold Area Dike (Option 8C)

Another area containing a higher density of structures is the community of Arnold, which is located on the east side of Arnold Slough, south of the Southern Railway and Vye Road. While lower density than Huntingdon, Arnold contains numerous houses and agricultural buildings that are expected to experience flooding during extreme Nooksack overflow flood events. Protecting this community would also noticeably reduce overall damages within the Sumas Prairie. The dike would need to be approximately 3 m high to protect the Arnold area from the 200-year flood, including a 600 mm freeboard.

A conceptual alignment for a dike to protect the village of Arnold is shown in Figure 5-8. This 3.3 km dike would connect to the existing Interceptor Dike, beginning at the intersection of Vye Road with Arnold Road. The dike would cross below the Southern Railway before continuing along the left bank of Arnold Slough until it reaches the US border, where it would then head east and connect to the toe of Vedder Mountain on the Canadian side of the border. The alignment shown in Figure 5-8 assumes that the outside toe of the dike would be located 5 m from the top of the natural levee of Arnold Slough. A 23 m footprint would be needed for an earth-filled dike assuming a 5 m crest width and 3:1 side slopes. For locations where an earth-filled dike would impede existing structures, flood walls would instead need to be constructed around the structures as depicted in Figure 5-8. Sheet piles would likely be used to construct the flood walls, although other flood wall technologies could be used to suit the local site constraints and aesthetics.

Based on the 200-year flood under climate change conditions, the Arnold Area Dike is estimated to protect 125 structures assessed at $19 million (structure value only).

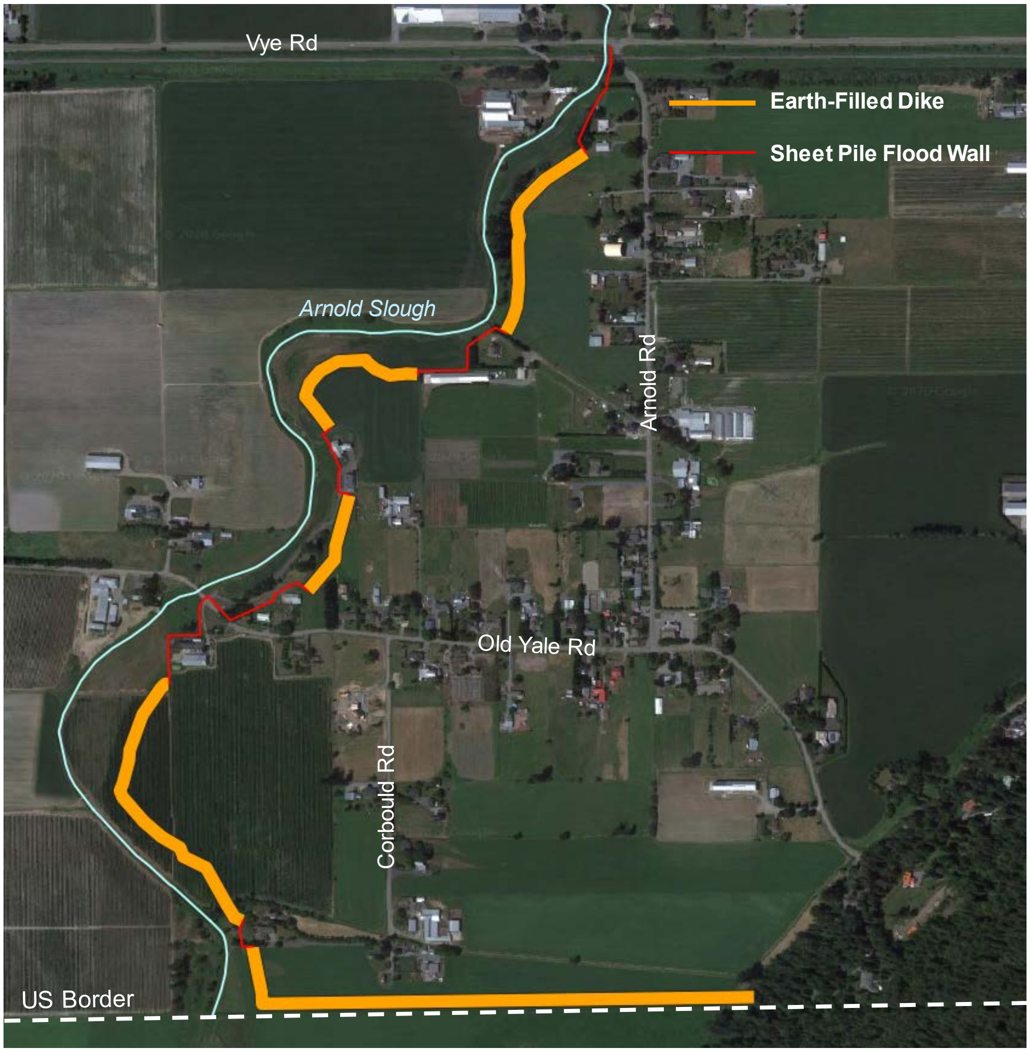


Figure 5-8: Arnold Area Dike Option

5.3 Selected Flood Mitigation Options

There are no simple solutions for flood mitigation for the Nooksack River overflow flood because the floodwaters cannot be contained within the existing channel of the Nooksack River and the overflow occurs in a natural floodplain. Only some of the above previously evaluated flood mitigation options have been modelled, and none of them (other than preventing the Nooksack River overflow) have yet been simulated using the most updated version of the Sumas Prairie model developed in 2014 by KWL using MIKE FLOOD. The scope of this project involves modelling three (3) options using the MIKE FLOOD model, followed by flood damage assessments and benefit-cost analyses on the selected options. Selection of the most appropriate options to model as part of this project has considered their practicality, and many of the previously discussed issues present challenges that render them as low priorities. A summary table of the benefits and drawbacks for previously discussed flood mitigation options is provided in Appendix G.

The three options selected for this project following discussions with the Nooksack River International Task Force are detailed in Table 5-1. These three options are comprised of combinations of the previously discussed options, as described in the table. Further details on the selection process the components of each option are provided in the summary table in Appendix G.

Table 5-1: Recommended Flood Mitigation Approaches for Modelling and Benefit-Cost Analysis

Recommended Mitigation Approach	Description	Incorporated Flood Mitigation Options
Mitigation Option #1: Marshall Creek Sump Floodway with Sumas Mountain Tunnel	Construct a new floodway from Marshall Creek sump through Whatcom Road in combination with tunneling Sumas River high flows through Sumas Mountain	Option 2B(d): Tunnel Sumas River through Sumas Mountain Option 3B: Marshall Creek Sump Floodway
Mitigation Option #2: Dike Raise and Floodproofing	Raise Interceptor & Sumas River dikes in combination with floodproofing each building (ring dikes) and constructing area dikes for high-density areas.	Option 4B: Raise Interceptor Dike and Sumas River Dike Option 6: Floodproofing Option 8B: Local Huntingdon Area Dike Option 8C: Local Arnold Area Dike
Mitigation Option #3: Eliminate Nooksack Overflows	Construct a structure at Everson to block all overflows from the Nooksack River	Option 7A: Block Overflow at Everson

The Huntingdon and Arnold area dikes, which are relatively smaller-scale measures that would provide a large amount of flood reduction benefits, were identified by the City as potential future standalone projects. Thus, an additional evaluation of the Huntingdon and Arnold area dikes was completed and is provided in Appendix I, including benefit-cost analyses. These options as standalone projects were not further investigated in the report due to them being incomplete mitigation solutions for the Sumas Prairie, and are instead integrated within Mitigation Option #2.

A question arose whether the impact of the Nooksack overflow on the floodplain on the Canada-side of the border could be mitigated using a dike along the border (instead of the dike/levee along the Nooksack River in Everson as in Mitigation Option #3). Constructing a dike along the border would have significant challenges, including that a flow regulating structure would be needed in the dike at the Sumas River, Saar Creek, and Arnold Slough channels to limit the flow to the 'without Nooksack overflow' flow values for all stages of the flow hydrograph. A simple culvert that was sized for the 200-year without Nooksack overflow peak flow during a 200-year Nooksack overflow event would not be able to adequately limit the flow during smaller return periods, hence the need for a mechanical structure that would need to be programmed to adjust based on Sumas River upstream flows (e.g. based on the return period of rainfall event or a flow gauge on the Sumas River that is outside of the Nooksack overflow influence). The height of the dike along the border would need to be based on the water level of the ponded area on the south side of the border that would result; a model simulation of the overflow in Washington State and in British Columbia would be needed to determine this peak water level. Such a border dike would cause increased flooding in the City of Sumas and in the agricultural areas south of the border. For these reasons, Mitigation Option #3 assumed a dike along the Nooksack River instead of along the border. A dike along Nooksack River would also provide protection from Nooksack overflows to cities and communities in Washington State including Everson, Nooksack, Sumas, Hampton and Clearbrook. An additional evaluation of the US/Canada border dike option is provided in Appendix J, including a benefit-cost analysis. However, it is noted that these analyses do not include any evaluation of impacts to properties south of the US/Canada border.

5.4 Flood Mitigation Modelling

Each of the three selected mitigation options described in Table 5-1 was modelled using the MIKE FLOOD 1D/2D model of the Sumas Prairie for two following flood events:

1. 100-year flood (existing climate conditions); and
2. 200-year flood (climate change conditions).

Embankment breaching and dike breaching was allowed for in the simulations when water levels reached the respective breach depths as described in Chapter 2. Thus, the previously simulated Scenarios 2A (100-year flood under existing climate conditions) and CC-3 (200-year flood under climate conditions conditions) act as the unmitigated baseline conditions for the flood mitigation analysis. Assumptions for these models are summarized in Table 5-2.

Using these two flood events, the following six (6) mitigation scenarios were modelled:

- **Scenario M1-1**: Mitigation Option #1 – Marshall Creek Sump Floodway with Sumas Mountain Tunnel – 100-year flood (existing climate conditions)
- **Scenario M1-2**: Mitigation Option #1 – Marshall Creek Sump Floodway with Sumas Mountain Tunnel – 200-year flood (climate change conditions)
- **Scenario M2-1**: Mitigation Option #2 – Dike Raise and Floodproofing – 100-year flood (existing climate conditions)
- **Scenario M2-2**: Mitigation Option #2 – Dike Raise and Floodproofing – 200-year flood (climate change conditions)
- **Scenario M3-1**: Mitigation Option #3 – Eliminate Nooksack Overflow – 100-year flood (existing climate conditions)
- **Scenario M3-2**: Mitigation Option #3 – Eliminate Nooksack Overflow – 200-year flood (climate change conditions)

A summary of the model components for each flood mitigation scenario is presented in Table 5-2.

Table 5-2: Summary of Flood Mitigation Scenario Model Components

Scenario ID	Sumas & Vedder Hydrograph Inputs	Nooksack Overflow Hydrograph Inputs	Total Cross-Border Peak Flow (m^3/s)	Peak Fraser River Water Level (m CGVD28)	Road & Railway Embankment Breach	Sumas River Dike Breach
M1-1	100-year	100-year	413	5.80	yes	no
M1-2	200-year (CC)	200-year (CC)	735	6.51	yes	yes
M2-1	100-year	100-year	413	5.80	yes	no
M2-2	200-year (CC)	200-year (CC)	735	6.51	yes	no
M3-1	100-year	(none)	61	5.80	no	no
M3-2	200-year (CC)	(none)	99	6.51	no	no

5.5 Flooding Impacts for Mitigation Scenarios

Gridded flood depth raster files at 5 m resolution were generated for the six flood mitigation scenarios from the MIKE FLOOD results following the same GIS procedure as for the baseline flood scenario results. Flood depth mapping for the four climate change scenarios are presented in Figures C-1 to C-6 to in Appendix C.

Mitigation Option #1 Results

- Adding the tunnel increases the volume of flow out of the Sumas River and slightly lowers the river water level at the upstream side of the Barrowtown Dam and in the Old Sumas Lake Bottom.
- In the 200-year climate change event, the flow through the tunnel is insufficient to reduce the flood water level such that the Sumas Dike does not overtop and breach. The tunnel option was previously envisioned for much lower flows and given the relatively small water level difference (1.7 m maximum for a short duration of time) between the Sumas River upstream of the Barrowtown Dam and the Fraser River at the downstream end of the tunnel, the tunnel capacity is limited, flowing for only approximately 12 hours before the Sumas River Dike breaches and the Sumas River water levels drop to lower than the Fraser River levels. Tunnel capacity would be greater when the Fraser River is lower. Because conservative assumptions of Fraser River water levels were used in this study and previous modelling studies, a future study could be conducted to determine likely Fraser River water levels during a Sumas River flood and the impact of these on the tunnel flows.
- Adding the Marshall floodway slightly reduces the flooding in the Marshall Creek sump, however it also slightly increases flooding in the area east of Whatcom Road at the downstream end of the floodway.
- The combination of the tunnel and Marshall floodway provides a small reduction in peak water levels in the Old Sumas Lake Bottom for the 200-year climate change flood where the Sumas Dike overtops and breaches. Overall water levels in the Old Sumas Lake Bottom are, however, increased during the 100-year flood as a result of the increased conveyance provided by the Marshall floodway.

Mitigation Option #2 Results

- Raising the Interceptor and Sumas River Dikes increases the protection for the Old Sumas Lake Bottom, preventing overtopping and breaching, and reducing flood depths and extents.
- Adding the local area dikes and the ring dikes around structures eliminates the structural damages throughout the Sumas Prairie.
- Both the dike raising and local area dike mitigation works increase flood depths in the unprotected areas, causing the same or greater flooding in the unprotected agricultural fields. For the 100-year flood event, water levels are generally increased by less than 0.2 m in the Marshall Sump area and 0.3 to 0.5 m elsewhere. For the 200-year climate change flood, water levels are generally increased by 0.2 to 0.5 m in the Marshall Sump area, 1.0 to 1.5 m in the Saar-Arnold area, and 1.7 to 2.0 m downstream of the TransCanada Highway crossing.

Mitigation Option #3 Results

- Eliminating the Nooksack River overflow limits the flooding that would occur in the Johnson Creek watershed, the City of Sumas and the City of Abbotsford. However, it would likely increase flooding and damages along the Nooksack River downstream of Everson. Only the Canada-side flooding and damage reduction was assessed for this study.
- The Sumas River Dike is not sufficiently high to prevent overflows into the Lake Bottom during the 200-year with climate change flood. Although not included in this study, should this mitigation option be pursued further in the future, raising of low spots in the dike would be a worthwhile addition.

5.6 Damage Assessment for Mitigation Scenarios

The damages associated with each of the baseline and mitigation scenarios was estimated using the same approaches and assumptions as previously discussed for the damage assessments presented in Chapter 4. Only quantified damages are discussed for the mitigation options, and qualitative damages are not included.

Structure and Content Damages

The structure and content damages were estimated using the HEC-FIA analysis. Results for the baseline and mitigation scenarios are summarized in Table 5-3.

Table 5-3: Mitigation Scenario Residual Structure and Content Damages

Scenario	Description	Structure Damage ($ million)	Content Damage ($ million)	Total ($ million)
2A	Baseline: 100-yr (existing climate)	$188	$127	**$316**
CC-3	Baseline: 200-yr (climate change)	$365	$277	**$642**
M1-1	Mitigation Option #1: Marshall floodway & tunnel - 100-yr (existing climate)	$178	$123	**$301**
M1-2	Mitigation Option #1: Marshall floodway & tunnel - 200-yr (climate change)	$349	$270	**$619**
M2-1	Mitigation Option #2: dike raise & floodproofing - 100-yr (existing climate)	$0	$0	**$0**
M2-2	Mitigation Option #2: dike raise & floodproofing - 200-yr (climate change)	$0	$0	**$0**
M3-1	Mitigation Option #3: eliminate Nooksack overflow - 100-yr (existing climate)	$70	$52	**$123**
M3-2	Mitigation Option #3: eliminate Nooksack overflow - 200-yr (climate change)	$152	$108	**$260**

Agricultural Damages

Based on the mitigation options, Table 5-4 summarizes the modelled economic loss for each of the baseline and mitigation options.

Table 5-4: Mitigation Scenario Residual Agricultural Damages

Scenario	Description	Agricultural Damage ($ million)
2A	Baseline: 100-yr (existing climate)	**$136**
CC-3	Baseline: 200-yr (climate change)	**$304**
M1-1	Mitigation Option #1: Marshall floodway & tunnel - 100-yr (existing climate)	**$133**
M1-2	Mitigation Option #1: Marshall floodway & tunnel - 200-yr (climate change)	**$301**
M2-1	Mitigation Option #2: dike raise & floodproofing - 100-yr (existing climate)	**$112**
M2-2	Mitigation Option #2: dike raise & floodproofing - 200-yr (climate change)	**$141**
M3-1	Mitigation Option #3: eliminate Nooksack overflow - 100-yr (existing climate)	**$84**
M3-2	Mitigation Option #3: eliminate Nooksack overflow - 200-yr (climate change)	**$170**

Business and Transportation Economic Impacts

Philip Davies of Davies Transportation Consulting Inc. estimated the economic impacts to businesses and transportation for flooding results from the modeled mitigation scenarios (see Appendix F). In general, the business and transportation impacts are linked to the duration of interruption for the businesses and transportation infrastructure. The damages are calculated based on the duration of flooding for specific infrastructure, and loss of revenue for estimated business closures based on the flooding. The business impacts are therefore linked to the duration of flooding of the roads and access for each of the scenarios. Impacts to buildings and stock (if any) are incorporated separately in the structure and contents (see section above). These results are summarized in Table 5-5.

Table 5-5: Business and Transportation Economic Impacts

Scenario	Highway 1 Closure Duration (days)	Sumas Border Closure Duration (days)	Southern Railway Repairs Needed?	Business Impacts ($/day)	Business Closure Duration (days)	Total Damages ($ million)
2A	3.5	1.5	yes	$330,000	4	**$10**
CC-3	4.8	1.7	yes	$350,000	5	**$14**
M1-1	3.2	1.5	yes	$330,000	4	**$10**
M1-2	3.3	1.7	yes	$330,000	4	**$10**
M2-1	3.8	1.5	yes	$300,000	4	**$11**
M2-2	6.3	1.7	yes	$300,000	7	**$18**
M3-1	2.3	0	no	$300,000	3	**$7**
M3-2	5.5	0	no	$300,000	6	**$16**

Summary of Damages and Losses

A summary of the total damages for the baseline and mitigation scenarios is provided in Table 5-6.

Table 5-6: Mitigation Scenario Total Residual Damages Summary

Scenario	Scenario Name	Damages ($ million)			
		Structure and Content Damages	Agricultural Damages	Economic Losses	Total
2A	Baseline – 100-yr (existing climate)	$316	$136	$10	**$462**
CC-3	Baseline – 200-yr (climate change)	$642	$304	$14	**$960**
M1-1	Mitigation #1 – 100-yr (existing climate)	$301	$133	$10	**$443**
M1-2	Mitigation #1 – 200-yr (climate change)	$619	$301	$10	**$930**
M2-1	Mitigation #2 – 100-yr (existing climate)	$0	$112	$11	**$123**
M2-2	Mitigation #2 – 200-yr (climate change)	$0	$141	$18	**$160**
M3-1	Mitigation #3 – 100-yr (existing climate)	$123	$84	$7	**$213**
M3-2	Mitigation #3 – 200-yr (climate change)	$260	$170	$16	**$445**

6. Benefit-Cost Analysis

6.1 Mitigation Works Class D Cost Estimation

Class D cost estimates were carried out for each of the three mitigation options and are provided in Appendix H. A summary of the Class D cost estimates is presented in Table 6-1. Cost estimates provided are high-level lump sum estimates in 2019 dollars. Class D costs are prepared with little or no site information based on unit costs from similar projects and as such are considered indicative for planning purposes only. Planning, conceptual design, and investigation would be required to more accurately determine costs for these projects. Due to the high level of uncertainties for costing, a 30% contingency is added to the estimated cost, as shown.

The Class D cost estimate summary in Table 6-1 has been broken down by key items for each mitigation option. For Mitigation Option #2, cost estimates for raising the Sumas River Dike and Interceptor Dike were based on previous Class D costing of this dike work that was issued by KWL in 2018[42]. For Mitigation Option #3, costing was only carried out for the levee work that would be needed at Everson to prevent an overflow, and does not include the cost of any other mitigation work that would be needed downstream along the Nooksack River to prevent the resulting increases in flood damages.

Table 6-1: Mitigation Works Capital and O&M Class D Costs Summary

Flood Mitigation Option	Item	Capital Cost ($ million)	Annual O&M Cost ($ million)
Mitigation Option #1: Marshall Creek Sump Floodway with Sumas Mountain Tunnel	Marshall Creek Sump Floodway	$12	**$1.7 / year**
	Tunnel Through Sumas Mountain	$375	
	Engineering & Construction Management (20%)	$77	
	Contingencies (30%)	$116	
	Total (excl. GST)	**$580**	
Mitigation Option #2: Dike Raise and Floodproofing	Raise Sumas River Dike & Interceptor Dike	$172	**$1.0 / year**
	Huntingdon Area Dike	$4	
	Arnold Area Dike	$32	
	Floodproofing	$19	
	Engineering & Construction Management (20%)	$45	
	Contingencies (30%)	$68	
	Total (excl. GST)	**$339**	
Mitigation Option #3: Eliminate Nooksack Overflows	Everson Levee Extension	$20	**$0.1 / year**
	Engineering & Construction Management (20%)	$4	
	Contingencies (30%)	$6	
	Total (excl. GST)	**$29**	

Land acquisition costs for the proposed dike works in Mitigation Option #2 were estimated based on guidance from the City. As per the City's Corporate Services Department, land values for rural properties vary widely, from $80,000 per acre ($20 per m^2) for working farmland (pasture, no berries) to $120,000 per acre ($30 per m^2) for planted farmland (berries) on a working farm. Prices for land on small acreages are much higher since they are purchased as estates, typically have very large houses, and the owners typically do not rely on their property as their primary source of income. Land prices for small acreage rural properties are often between $200,000 to $250,000 per acre ($49 to $62 per m^2). The properties impacted by the proposed dikes in Mitigation Option #2 are mostly large acreage, and an average unit land cost of $25 per m^2 was selected for the cost estimate based on discussions with the City. This land acquisition cost was also assumed for the proposed Everson Levee extension works in Mitigation Option #3.

Annual operation and maintenance (O&M) costs are also included in Table 6-1. Operation and maintenance activities for Mitigation Option #1 are expected to consist of dredging, debris removal and repairs to the floodway and tunnel. Operation and maintenance activities for Mitigation Options #2 and #3 are expected to consist of typical dike maintenance including slope repairs, animal burrow repairs, vegetation management, restoration of dike crest elevation and floodbox maintenance. All options will also require annual and post-flood inspection of the mitigation infrastructure.

Since the level of effort required to carry out the above operation and maintenance tasks is highly uncertain, operation and maintenance costs were estimated using a simplified approach where efforts were assumed to be a function of the level of protection provided by the mitigation measures. Using this approach, operation and maintenance costs were assumed to be equal to the capital costs multiplied by the probability of occurrence for the design flood event. All mitigation options were designed to the 200-year climate change flood, which was estimated to have a 360 year return period, or a 0.28% probability of occurrence, based on existing climate flood frequency curves (as described in the following section on benefit-cost analysis results).

6.2 Benefit-Cost Analysis Results

In benefit-cost analysis for flood mitigation options, the "benefits" are typically the value of flood damages avoided by the implementation of a given mitigation option. Flood damages avoided are calculated as the difference between the present value of flood damages under existing conditions and the present value of residual damages post-mitigation, evaluated over the service life of that mitigation option. The benefit-cost ratio is the ratio of lifespan flood damages avoided to the life cycle cost of the mitigation works.

The benefit-cost analysis results are provided in Table 6-2, and damage curves depicting the estimated flood damages for given return periods for each flood mitigation scenario are provided in Figure 6-1. The damage curve associated with no flood damages avoided (baseline) was developed using the previously estimated damages and losses for the following four flood scenarios:

- **Scenario 1**: November 1990 flood (35-year return period)
- **Scenario 2A**: 100-year flood
- **Scenario 3**: 200-year flood
- **Scenario CC-3**: 200-year flood under climate change conditions

Scenarios 2B and 2C were excluded from the baseline damage curve since they represent different embankment breaching and Nooksack overflow conditions from the above four scenarios. Scenarios CC-1, CC-2A and CC-2B were also excluded from this damage curve since damage assessments were not carried out for these scenarios as part of the scope of this project. Damage curves for the three flood mitigation options were developed using the previously estimated damages and losses for their respective 100-year existing climate and 200-year climate change scenarios.

Annualized damages were calculated for each damage curve by determining the area under each curve. For this calculation, the return periods must first be converted into probabilities. Thus, smaller flood events with higher probabilities of occurrence have more weight on annual damages than larger flood events with lower probabilities of occurrence. It should be noted that since the focus of this study was on large flood events (35-year and larger), there remains a large uncertainty about the flood damages of smaller flood events (e.g., 2-year, 5-year, 10-year) that would have a greater impact on annual damages.

Additional assumptions that were made for the benefit-cost analysis are as follows:

- Assumed probability is associated with existing climate conditions and that the 200-year climate change flood has an existing return period of 360 years based on 2005 flood frequency analysis of Nooksack overflows at Everson[1]. The Nooksack overflow flood frequency curve estimates the 200-year Nooksack overflow to be 17,000 ft^3/s (480 m^3/s). This flow was assumed to increase by 30% to 22,100 ft^3/s (630 m^3/s) under climate change conditions, which corresponds to a return period of 360 years on the Nooksack overflow flood frequency curve.
- Assumed all mitigation options perform as expected with 100% reliability up to the 200-year (climate change) return period event.
- Assumed no mitigation benefits for flood events larger than the 200-year climate change flood.
- The 5-year flood was assumed to be the flood associated with zero damages. As no damage assessment has been carried out for lower return period storms, the return period of the zero damages flood was assumed based on best judgement of the types and locations of flood damages that occur in the Sumas Prairie. While smaller magnitude damages and losses likely occur during 5-year and more frequent flood events, these damages were excluded to conservatively estimate the benefit-cost ratios.
- Damages for the November 1990 flood for the mitigation options were not modelled and were therefore assumed to follow a similar trend as the non-mitigation scenarios.
- Linear interpolation assumption (on log return period x-axis and non-log damage value y-axis) applied for return periods between all other modelled scenarios.
- Lower bound discount rate of 2% as suggested by B.C. Reg. 74/2014[43].
- Upper bound discount rate of 8% as suggested by the Treasury Board of Canada[44]. This 8% discount rate was selected for this study as the upper bound value over the 7% discount rate suggested by FEMA (OMB Circular No. A-94[45]) to analyse a larger range and to include a Canadian reference.
- Assumed 100-year lifespan of all mitigation options/works.
- Assumed no future development or change in land use, whereas the benefit-cost ratio would generally increase with increasing development or higher value land use within flood hazard areas.

Table 6-2: Mitigation Options Benefit-Cost Ratios Summary

Flood Mitigation Option	Annualized Damages ($ million)	Discount Rate of 2%			Discount Rate of 8%		
		Damages Avoided Over Lifespan [present value] ($ million)	Life Cycle Cost [present value] ($ million)	Benefit-Cost Ratio	Damages Avoided Over Lifespan [present value] ($ million)	Life Cycle Cost [present value] ($ million)	Benefit-Cost Ratio
Baseline: (no mitigation)	$26	-	-	-	-	-	-
Mitigation Option #1: Marshall Creek Sump Floodway with Sumas Mountain Tunnel	$25	$40	$654	**0.06**	$12	$602	**0.02**
Mitigation Option #2: Dike Raise and Floodproofing	$9	$768	$382	**2.0**	$223	$351	**0.6**
Mitigation Option #3: Eliminate Nooksack Overflows	$14	$552	$34	**16.1**	$160	$31	**5.1**

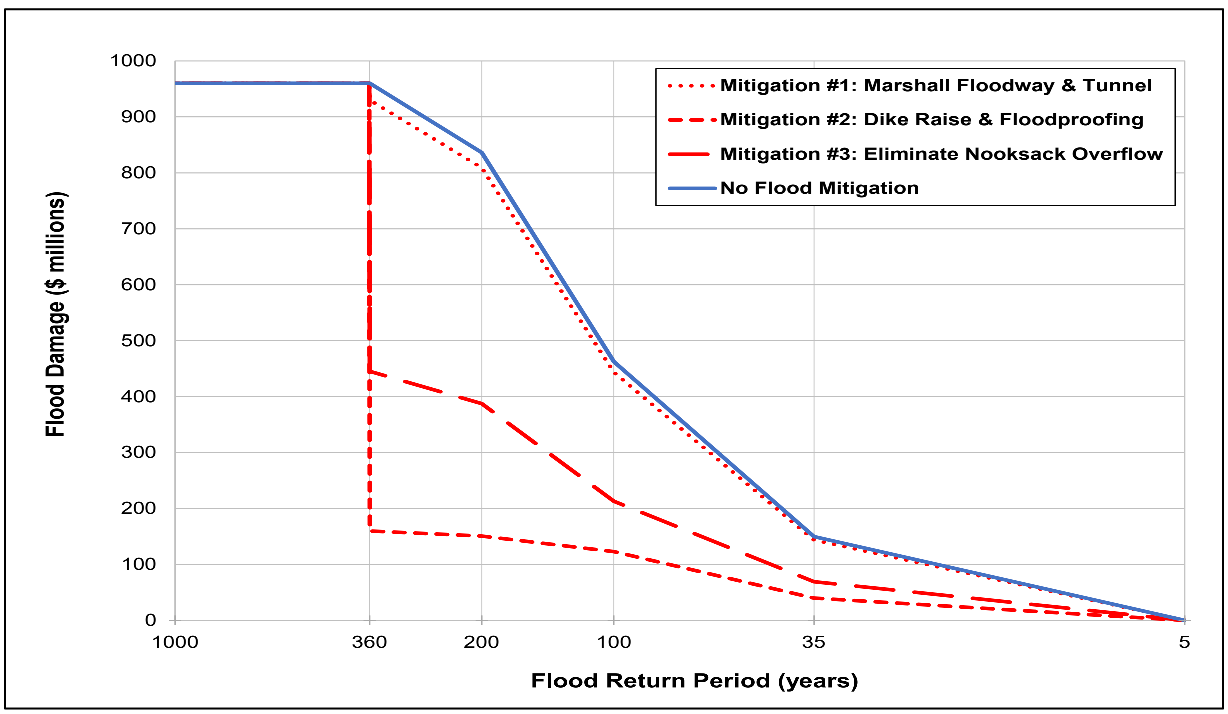


Figure 6-1: Mitigation Option Damage vs. Return Period Curves

As shown in Table 6-2 above, Mitigation Option #1 was found to provide minimal benefit for its cost and is therefore not recommended. The high cost of this option is driven by the tunnel component which does not provide sufficient flood reduction benefit in the simulated extreme flood events. The 1998 Wilson Hydrotechnical study found that the Marshall Creek sump floodway (with downstream capacity improvements) provides flood reduction benefits during the 1990 flood (35-year return period). However, the capacity of the floodway and the tunnel simply do not provide sufficient relief in the larger events to significantly reduce the flood levels. In particular, they do not prevent overtopping and failure of the Sumas River dike during the 200-year plus climate change event. While the 1990 flood was not specifically modelled for the flood mitigation options, the benefits at that level have been interpolated based on the modelling of the existing conditions scenarios for the 1990 flood. Based on this interpolation, the benefits provided by this mitigation approach at the 1990 flood level are not sufficient to drive the overall benefit-cost ratio of Mitigation Option #1 toward a favourable ratio of 1.0 or above.

Mitigation Option #2 was found to have a benefit-cost ratio of 2.0 when assuming a 2% discount rate and a benefit-cost ratio of 0.6 when assuming a 8% discount rate. This option is therefore recommended from a benefit-cost analysis perspective based on a lower discount rate, although the cost of mitigation becomes higher than the damages avoided when a more conservative discount rate is assumed. While other factors beyond costs should be considered when evaluating any flood mitigation option, particular consideration of non-monetary factors would be needed for this option where the cost of mitigation could be similar to the cost of the mitigated damages. Nevertheless, it may be found that future development or changes to land use in the floodplain increases the benefit-cost ratio above 1.0 at the higher discount rates. Note that there are less annualized flood damages for Mitigation Option #2 than for Mitigation Option #3, as floodproofing provides additional damage reduction from more frequently occurring flood events in the Sumas River when the Nooksack River does not overflow.

Mitigation Option #3 appears to provide the highest benefit-cost ratios when looking only at Canada-side damages, as the cost to expand the existing levee system at Everson to block the Nooksack River overflows is significantly lower than the flood damages in the Sumas Prairie that are avoided by preventing the overflow flood. While not quantified as part of this study, this option would also provide damage reduction benefits within the US between Everson and the Canadian border, whereas additional flood mitigation efforts would be needed along the Nooksack River to prevent the increase in flood damages associated with blocking off the overflow. The benefit-cost ratio provided in this study for this option is therefore only from a Canadian perspective, whereas **additional analysis work is needed on the US side to provide the overall benefit-cost ratio, covering benefits and costs on both sides of the border**.

6.3 Climate Change Impacts on Benefit-Cost Ratios

Benefit-cost ratios were also estimated assuming that the flood occurrence probabilities were associated with climate change conditions. For this analysis, it was assumed that Nooksack overflows at Everson would increase by 30% under climate change conditions. Flows from the Nooksack overflow flood frequency curve[1] were therefore increased by 30% to develop a flood frequency curve for climate change conditions. Overflow rates associated with the existing flood frequency curve for the various flood scenarios were then read off the climate change flood frequency curve to estimate their respective future return periods as follows:

- The November 1990 flood return period decreased from 35 years to 27 years.
- The 100-year flood return period decreased to 62 years.
- The 200-year flood return period decreased to 128 years.

- The 200-year climate change flood return period decreased from 360 years back to 200 years.

The 3-year flood was assumed to be the flood associated with zero damages under climate change conditions. Since the Nooksack Overflow flood frequency curve estimates zero overflow at a 5-year return period, this return period was estimated based on an assumed trend for future changes in flood frequency. Damage curves for climate change conditions are presented in Figure 6-2, and the resulting impacts on benefit-cost ratios for each mitigation option are provided in Table 6-3. Benefit-cost ratios are expected to increase by approximately 50%, as the predicted increase in frequency of large flood events will increase annual damages (or damages avoided from mitigation measures).

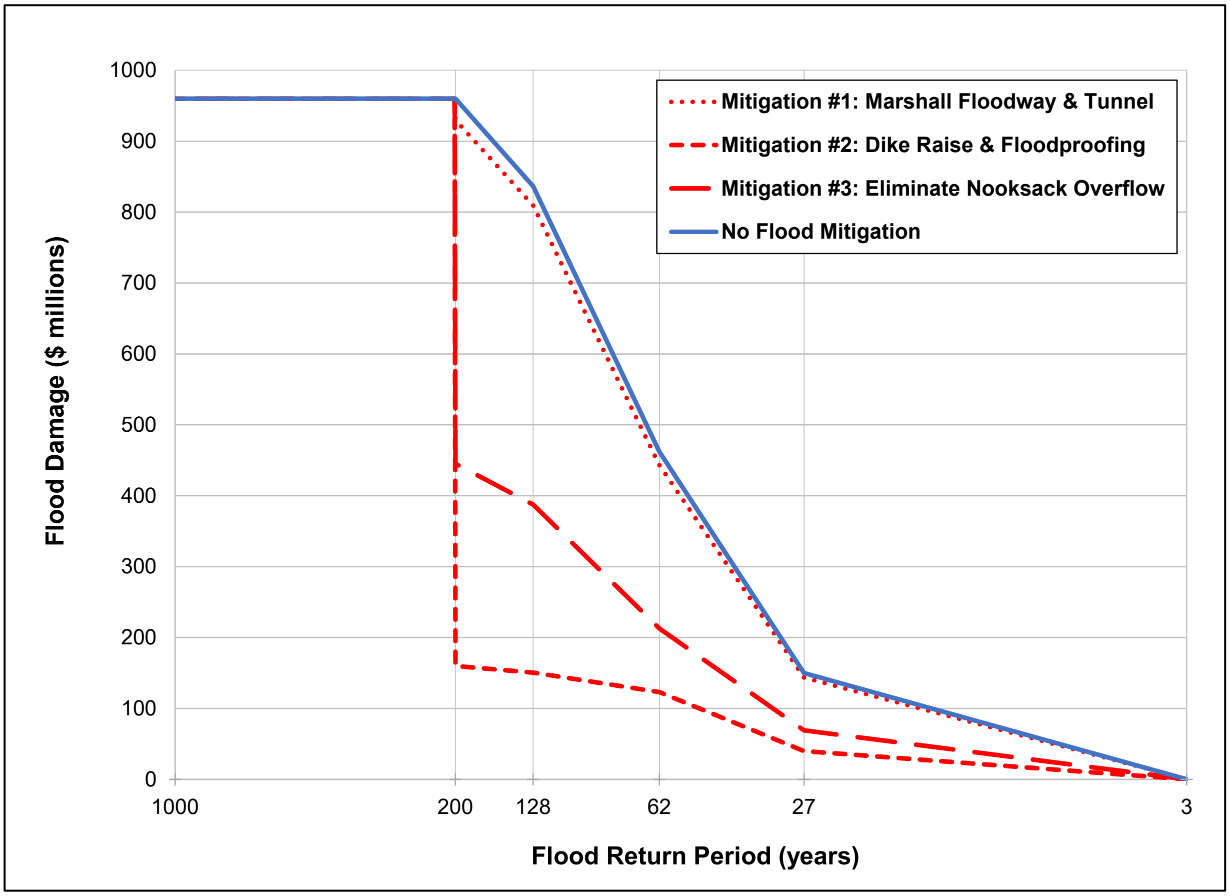


Figure 6-2: Mitigation Option Damage vs. Return Period Curves for Climate Change Conditions

Table 6-3: Climate Change Impacts on Benefit-Cost Ratios

Flood Mitigation Option	Benefit-Cost Ratio Assuming Impacts of Climate Change on Flood Occurrence Probabilities	
	Discount Rate of 2%	Discount Rate of 8%
Mitigation Option #1: Marshall Creek Sump Floodway with Sumas Mountain Tunnel	0.1	0.03
Mitigation Option #2: Dike Raise and Floodproofing	3.1	1.0
Mitigation Option #3: Eliminate Nooksack Overflows	24.8	7.9

6.4 Benefit-Cost Analysis Conclusions

The intent of this benefit-cost analysis work is to assess and evaluate the selected mitigation options for comparative purposes and to inform future work both on the Canada-side and the US-side of the border on this issue. Additional work must be done to assess the impacts of mitigation options on flooding in the US, and further examine the transfer of risk concerns for the options being evaluated. Therefore, none of the three mitigation options analyzed are recommended to be implemented at this time. Mitigation Options #1 and #2 have benefit-cost ratios that are too low to justify implementation, but the evaluation of Mitigation Option #3 is incomplete without additional work and accounting of the costs and benefits on the US side.

7. Conclusions and Recommendations

7.1 Conclusions

This study expanded upon the previous 2D MIKE FLOOD modelling completed for the Sumas Prairie to simulate the 200-year flood, climate change impacts on the 100-year and 200-year floods, and three flood mitigation options. Damage assessments carried out for the modelled scenarios show that the November 1990 flood would result in $150 million in damages if it occurred again today, whereas the 100-year and 200-year flood scenarios would result in $462 and $836 million in damages, respectively. Damages caused by the 200-year flood are almost double the damages caused by the 100-year flood, as the 200-year flood was estimated to overtop and breach the Sumas River Dike, causing substantial flooding in the Old Sumas Lake Bottom. The impacts of climate change and sea level rise were found to exacerbate 200-year flooding damages to $960 million.

Following a review of all work to date on potential flood mitigation efforts for the Sumas Prairie, this study found that there are no simple solutions for mitigating such flood damages that result from Nooksack River overflow flood events. Moreover, any measures carried out in the upper regions of the Sumas Prairie (e.g., Marshall Creek sump) will need to be performed in combination with measures carried out in the lower regions (e.g., Saar Creek sump, Arnold Slough sump, Old Sumas Lake Bottom, Barrowtown Dam) to avoid transferring flood risks to these adjacent areas. While many options have been discussed and modelled in previous studies, the area needed for conveyance of large flood flows will always impact existing lands. Thus, floodproofing would be required to protect many of the existing structures that are otherwise unable to be protected, whereas a large portion of the existing agricultural land will always be needed to store and convey flood flows. Alternatively, blocking off the Nooksack River overflow at Everson would greatly reduce flooding in the Sumas Prairie at the expense of additional flooding impacts downstream of Everson along the Nooksack River.

This study modelled, costed, and provided benefit-cost analysis for three selected flood mitigation options. The results from these analyses are summarized as follows:

- Mitigation Option #1 involves constructing a new floodway from the Marshall Creek sump through Whatcom Road in combination with tunneling Sumas River high flows through Sumas Mountain from upstream of Barrowtown Dam to the Fraser River. The overall objective of this option is to reduce flood levels in the Marshall Creek sump without increasing flood levels further downstream. However, such a floodway was found to provide minimal reduction in flood levels in the Marshall Creek sump for the large flood events evaluated in this study (100-year existing climate conditions and 200-year climate change conditions), as both the floodway and the tunnel have limited capacity to convey the large flood volumes. This option therefore provides minimal benefit for its cost. The option was suggested in previous studies that assume less extreme flood events such as the November 1990 flood, and it could perhaps be better suited for preventing damages from smaller flood events, albeit at a high construction cost associated with the tunnel. Larger versions of the floodway and tunnel would likely not be feasible, as a larger floodway would greatly impact existing land and buildings, and a larger tunnel would be of significant cost. Similarly, upgrading the pumps at Barrowtown Dam in lieu of constructing a tunnel would also be of significant cost and would be impractical for such infrequent flood flows.
- Mitigation Option #2 involves raising the dikes that protect the Old Sumas Lake Bottom in combination with floodproofing each building in the remaining unprotected areas with ring dikes and constructing area dikes for the higher density communities. The flood protection benefits that this option provides are similar to its overall costs, indicating that it could be feasible from a benefit-cost

perspective. A major consideration for this option is that it will raise water levels by up to 2 m outside of the Old Sumas Lake Bottom during the 200-year climate change flood.

- Mitigation Option #3 involves expanding the existing levee system at Everson to block the Nooksack River overflows. This option provides the highest benefit when isolating the damages it prevents within Canada, although additional analysis is needed on the US side to include the damages that are also prevented within the US as well as the additional mitigation that would be required along the Nooksack River. Until this additional work is completed, none of the three mitigation options evaluated for this study are recommended to be implemented at this time.

7.2 Recommendations for Future Work

Additional work that could be undertaken to improve upon this study is summarized as follows:

- Modelling of the 200-year climate change event on the Nooksack River with the latest US-side model and developing a better estimate for the hydrographs for the cross-border overflow flood flows.
- Updating the US-side model with the Nooksack River channel changes (sediment aggradation) observed in recent years and rerunning the 100-year and 200-year floods. Updating the inflows into the Canada-side model based on results of the above US-side model, quantifying the effects of the updated cross-border flow hydrographs on the flooding in the Sumas Prairie, and qualitatively assessing the potential changes to the benefit-cost ratios developed in this study.
- Updating the US hydraulic model to model the effects of the proposed Mitigation Option #3, dike along the Nooksack River to prevent the overflow flood, along the Nooksack River downstream of Everson and also in the Johnson and Sumas watersheds on the US side. Estimating the damages and benefits of this scenario on the US-side using the same assumptions that were used in this study to allow for direct comparison and calculation of a total benefit-cost ratio.
- Expanding the flood mitigation analysis by simulating and carrying out damage assessments for more frequent flood events (e.g., November 1990, 10-year, 5-year and 2-year) to more accurately estimate the zero damages flood and annual damages. Annual damages and benefit-cost ratios of flood mitigation options are highly sensitive to floods that have higher probabilities, rather than the more extreme floods (200-year climate change) that the mitigative efforts are designed for. Moreover, the selection of flood mitigation options should be re-evaluated if the mitigation is instead intended for smaller flood events, as refined versions of or alternatives to the mitigation options selected for this study may be found to be more applicable for higher frequency floods.
- Refining the mitigation option that shows the most promise (i.e., elimination of the overflow flood), and assess feasibility and benefits of variations such as a dike along the US-Canada border.
- Model the impacts of expected future development and changes to land use, which would increase the benefit-cost ratios of the flood mitigation options if the value of the properties within the floodplain are increased.

Report Submission

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Statement of Limitations

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This document represents KWL's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

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Revision History

Revision #	Date	Status	Revision	Author
1	November 30, 2020	Final	Updated costs, additional benefit-cost work (Appendices I and J)	JTM/DZ
0	May 31, 2020	Final		JTM/DZ

OQM CERTIFIED

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Appendix A

Flood Depth Maps for Flood Scenarios Under Existing Climate Conditions

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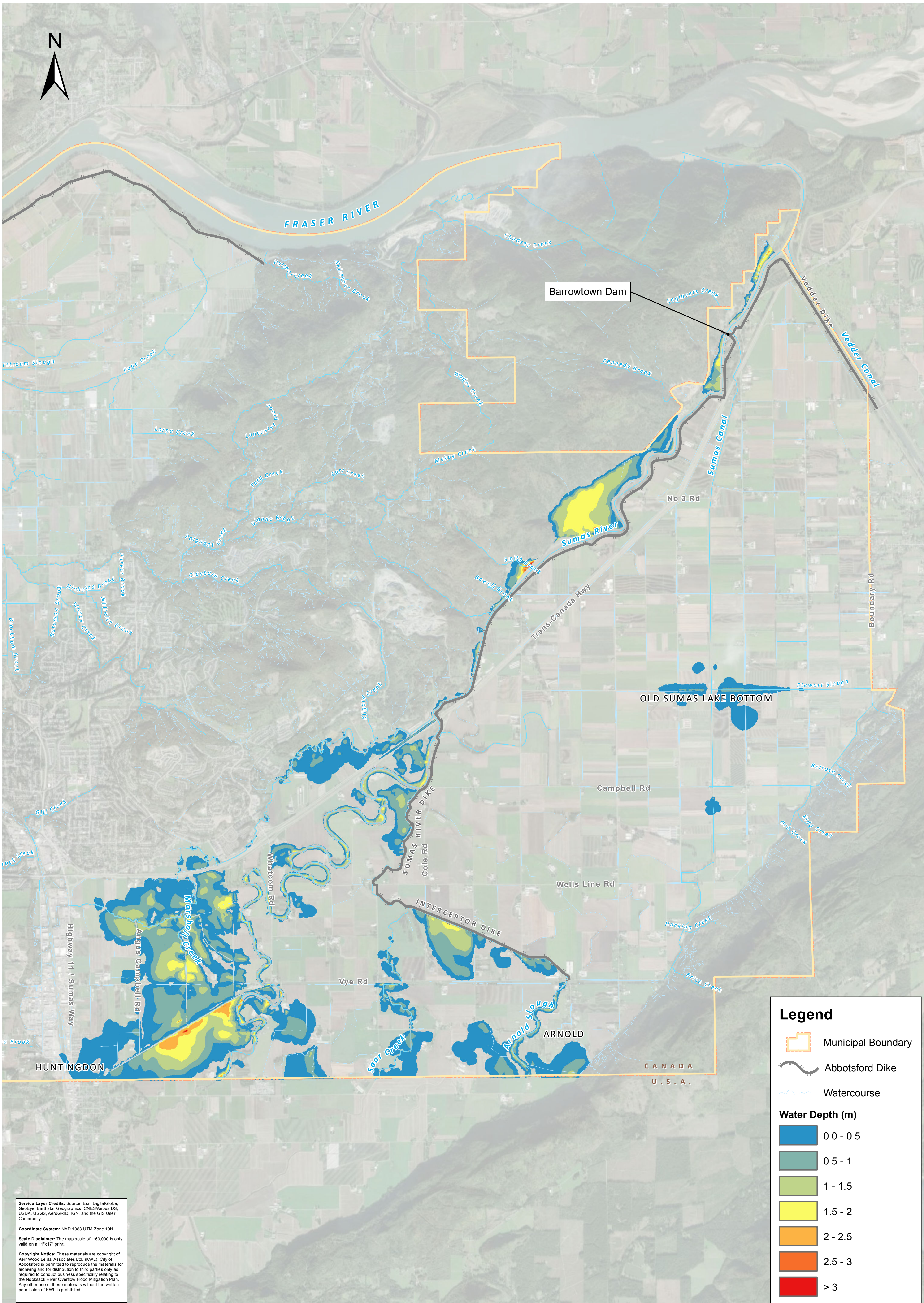

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Scenario 1 Hydraulic Model Results: 1990 Flood Event

Figure A-1

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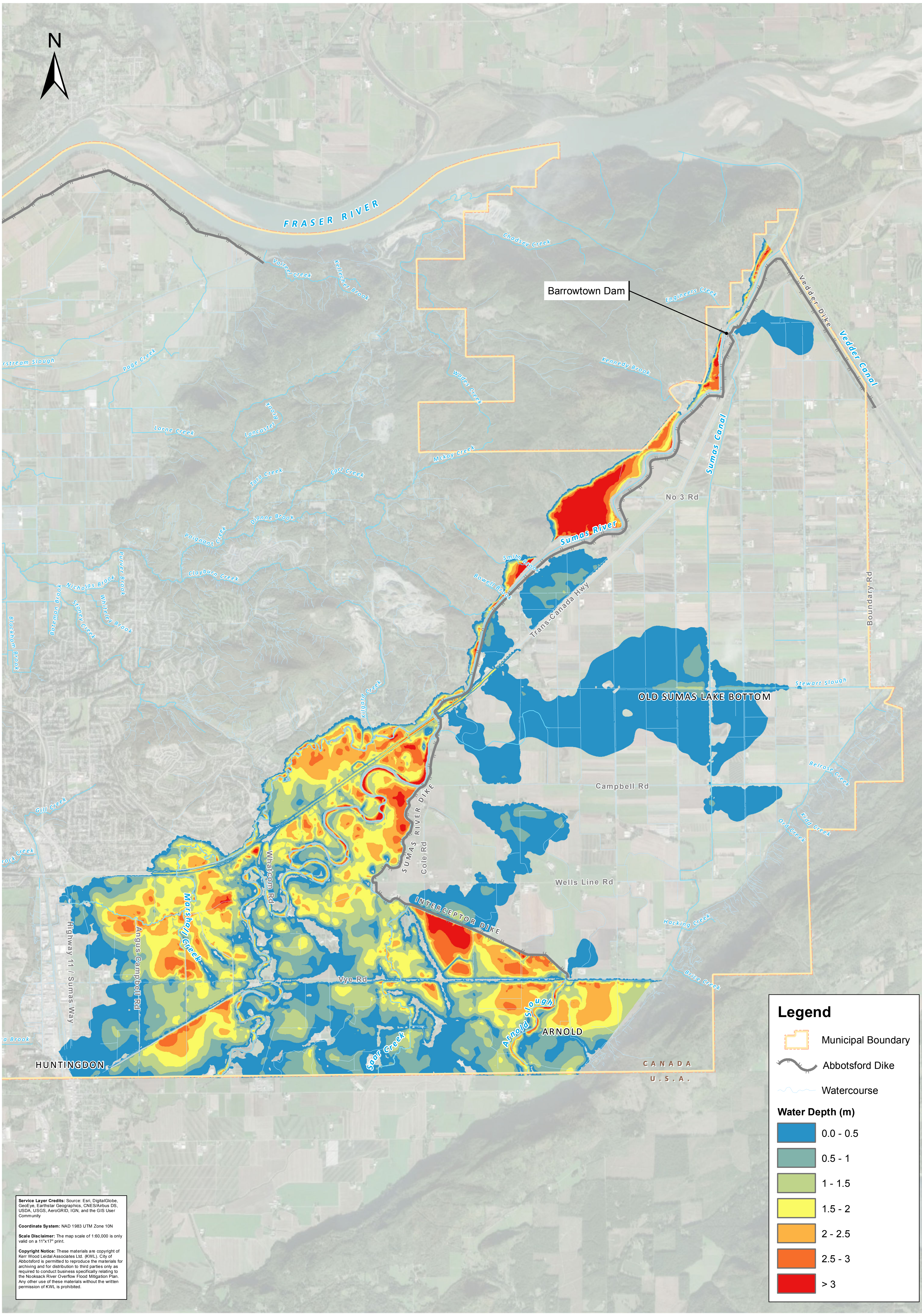

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Coordinate System: NAD 1983 UTM Zone 10N

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Scenario 2A Hydraulic Model Results: 100-Year Flood Including Nooksack Overflow, Embankment Breaches and No Dike Breaches

Figure A-2

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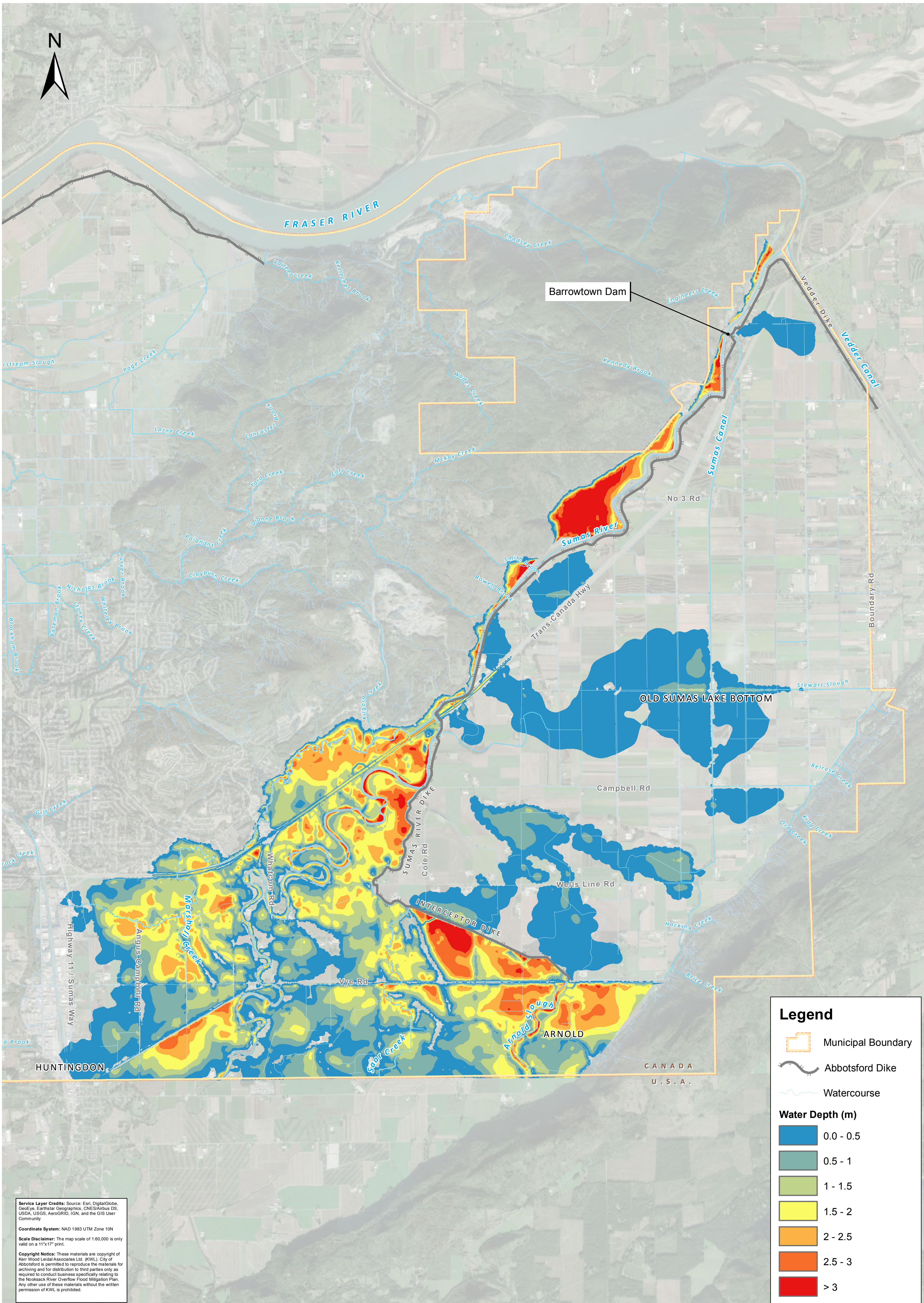

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Scenario 2B Hydraulic Model Results: 100-Year Flood including Nooksack Overflow, No Embankment Breaches and No Dike Breaches

Figure A-3

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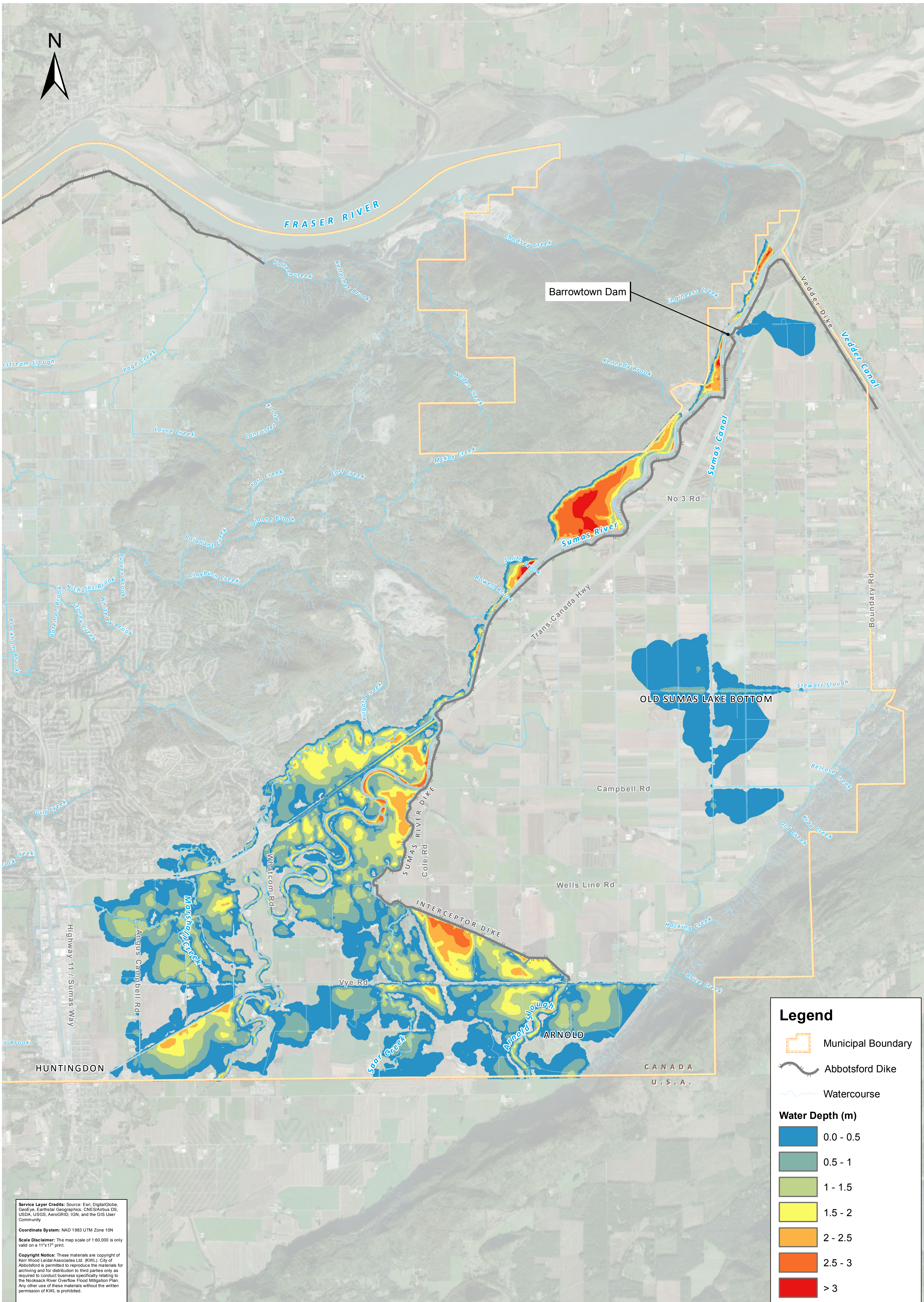

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Scenario 2C Hydraulic Model Results: 100-Year Flood with No Nooksack Overflow, No Embankment Breaches and No Dike Breaches

Figure A-4

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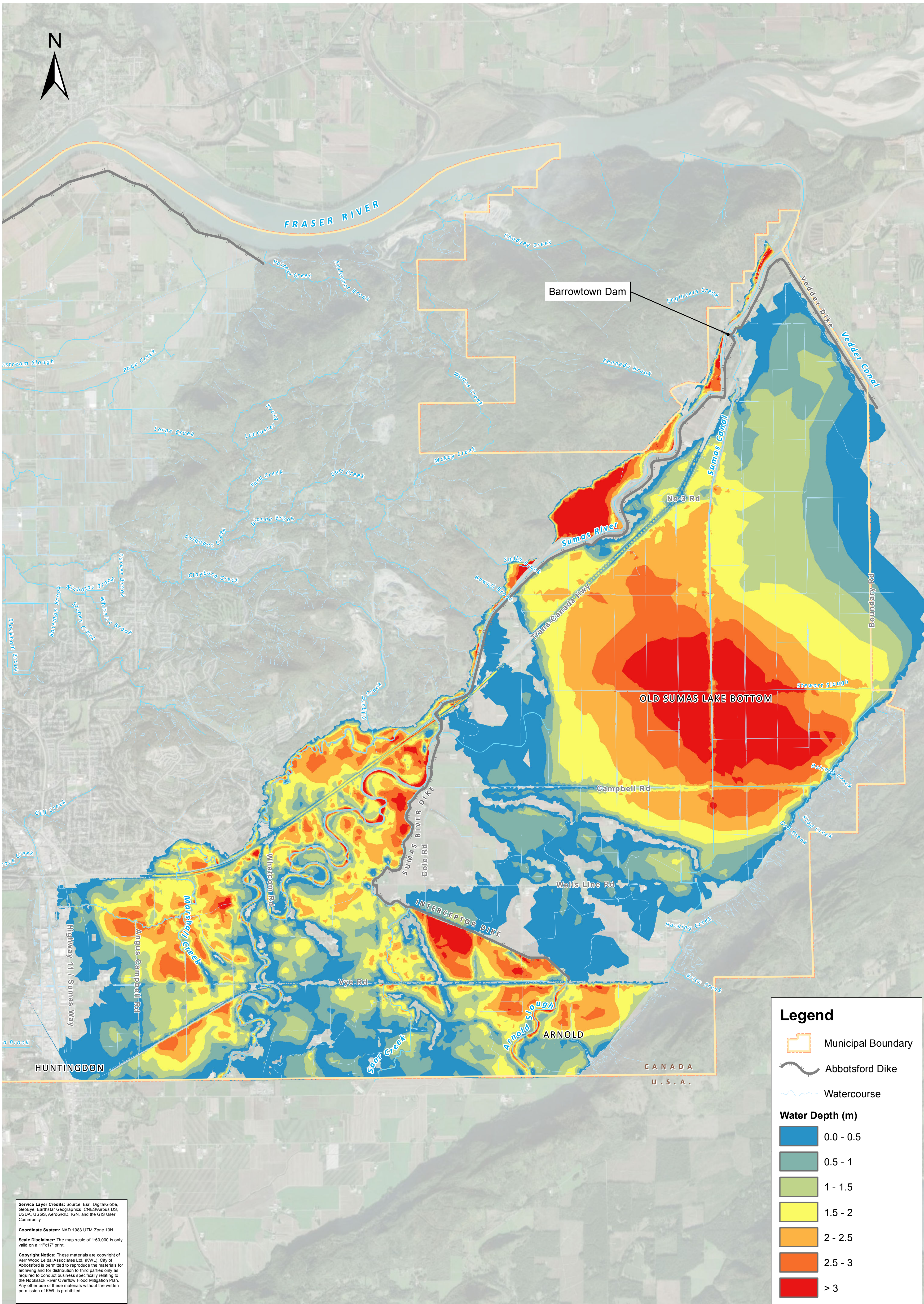

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Scenario 3 Hydraulic Model Results: 200-Year Flood including Nooksack Overflow, Embankment Breaches and Dike Breaches

Figure A-5

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Appendix B

Flood Depth Maps for Flood Scenarios Under Future Climate Change Conditions

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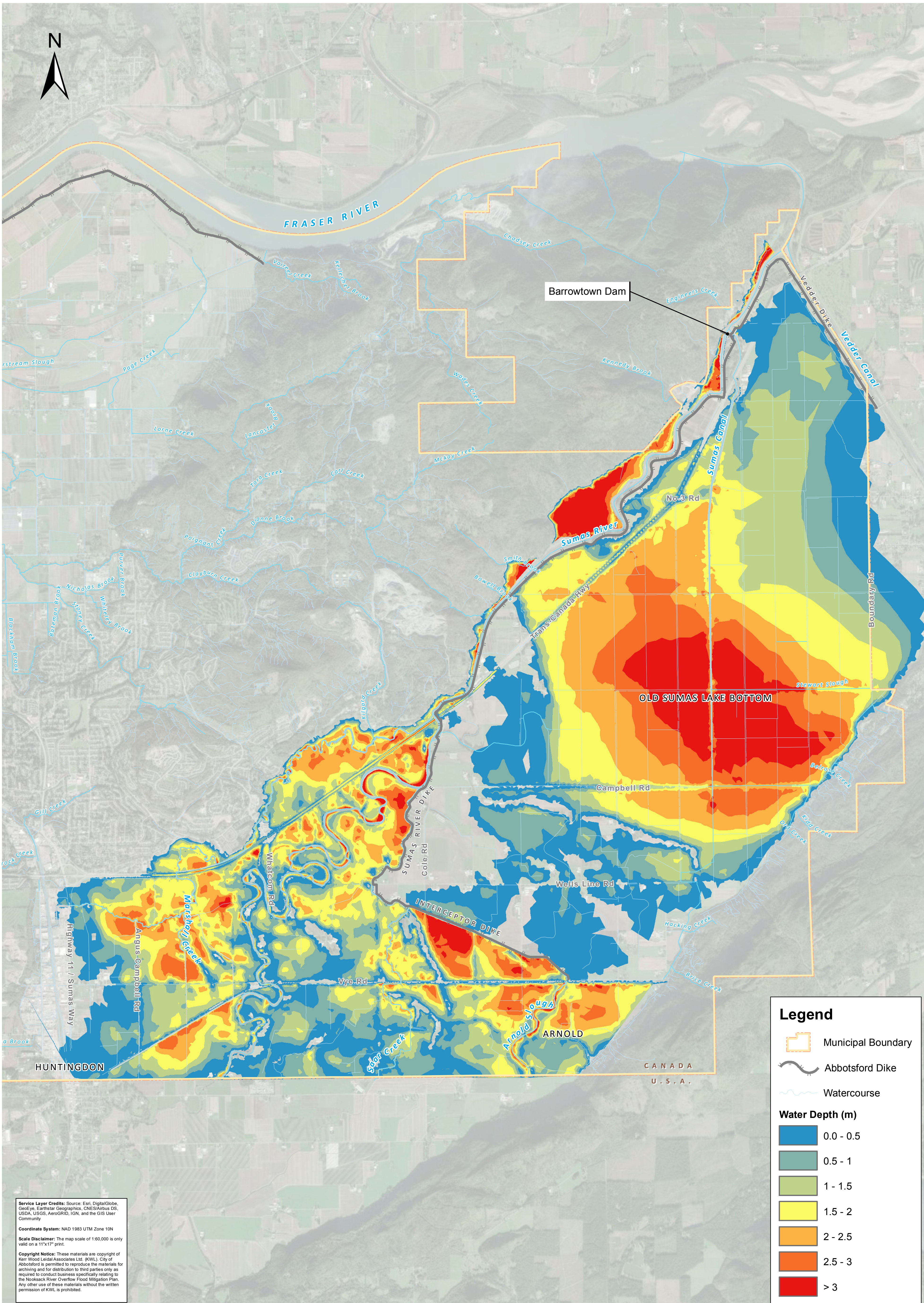

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Scenario CC-2A Hydraulic Model Results: 100-Year Flood under Climate Change Conditions including Nooksack Overflow, Embankment Breaches and Dike Breaches

Figure B-1

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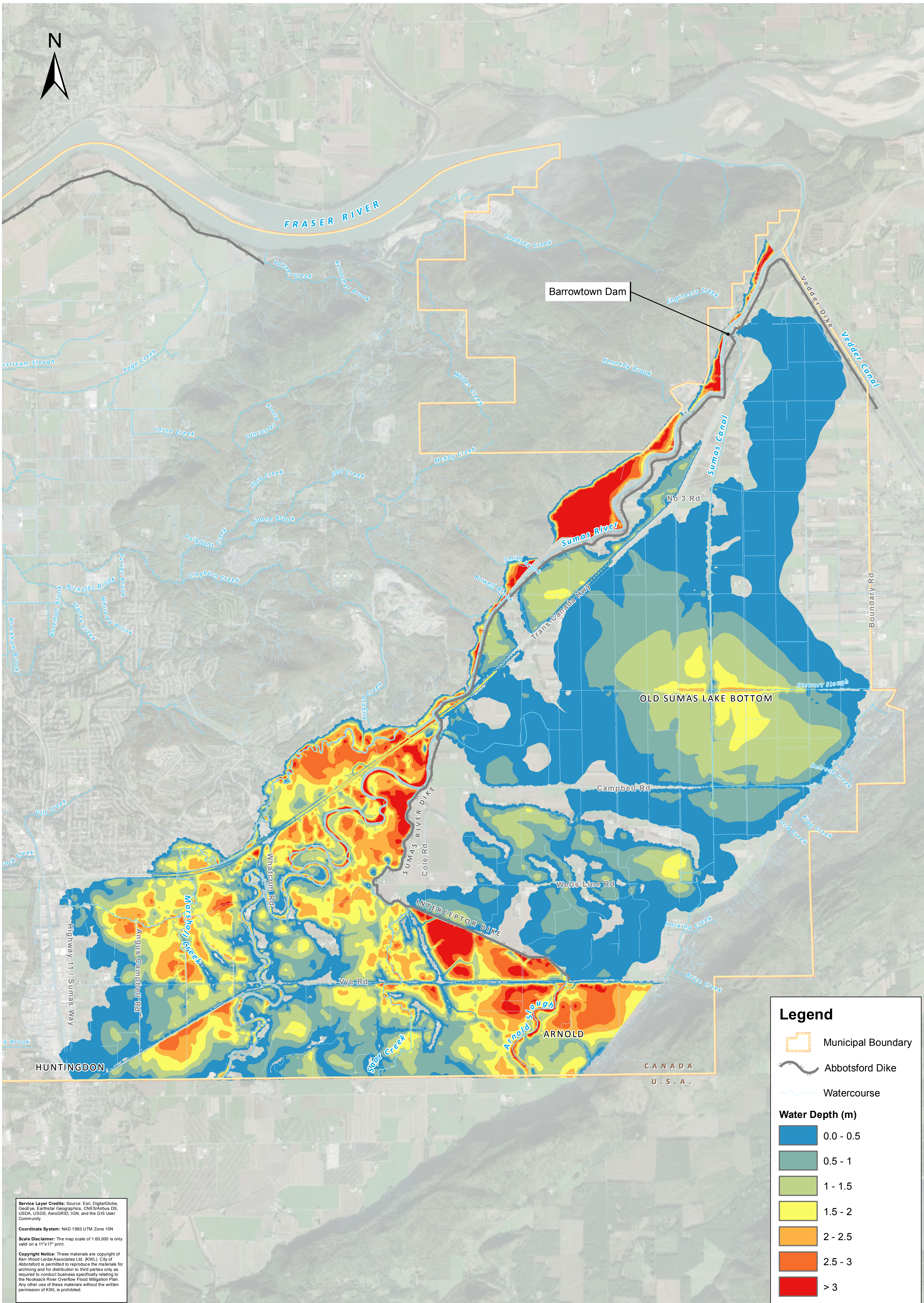

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Scale 0 250 500 1,000 (m) 1:60,000

Scenario CC-2B Hydraulic Model Results: 100-Year Flood under Climate Change Conditions including Nooksack Overflow, No Embankment Breaches and No Dike Breaches

Figure B-2

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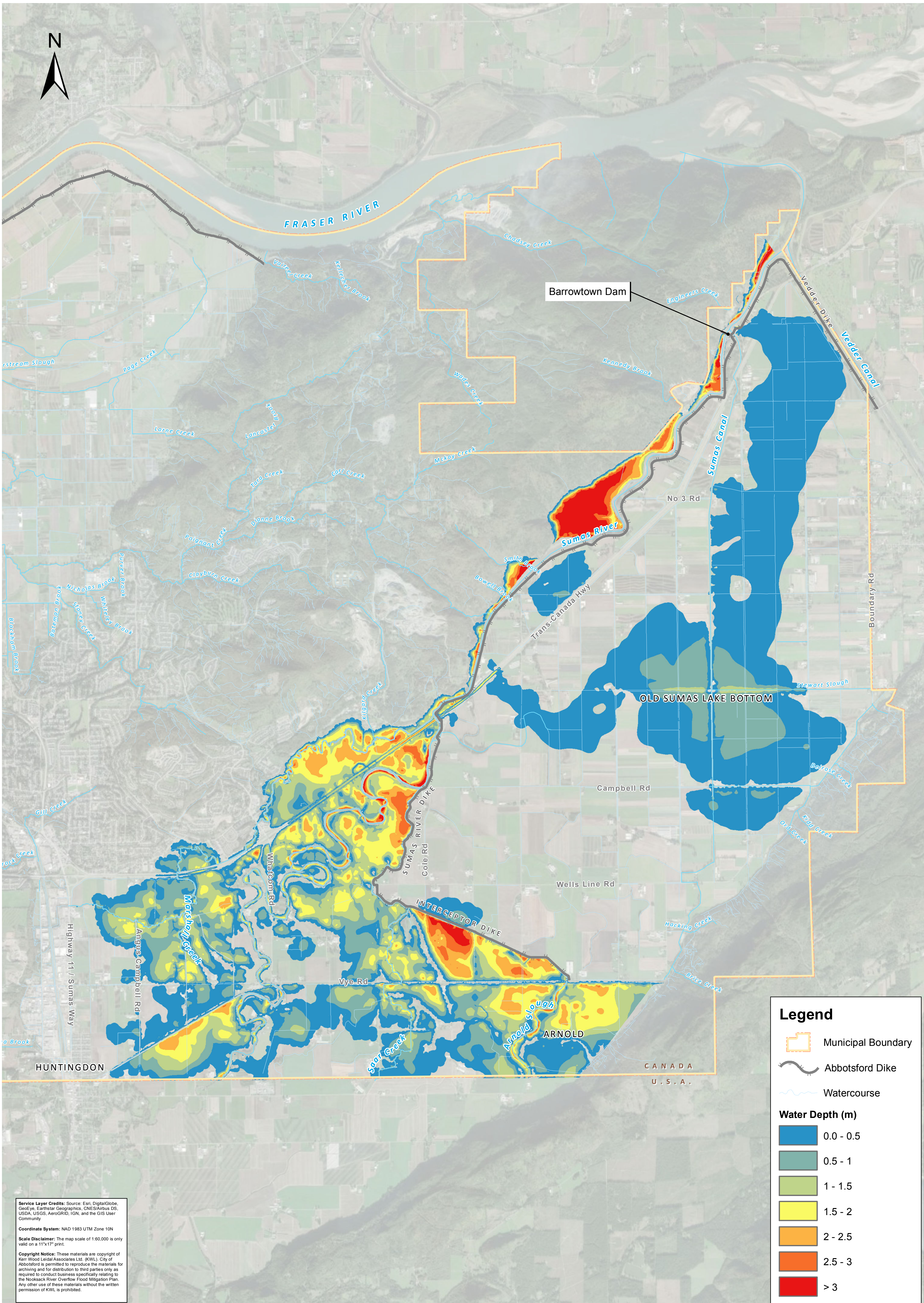

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Scenario CC-2C Hydraulic Model Results: 100-Year Flood under Climate Change Conditions with No Nooksack Overflow, No Embankment Breaches and No Dike Breaches

Figure B-3

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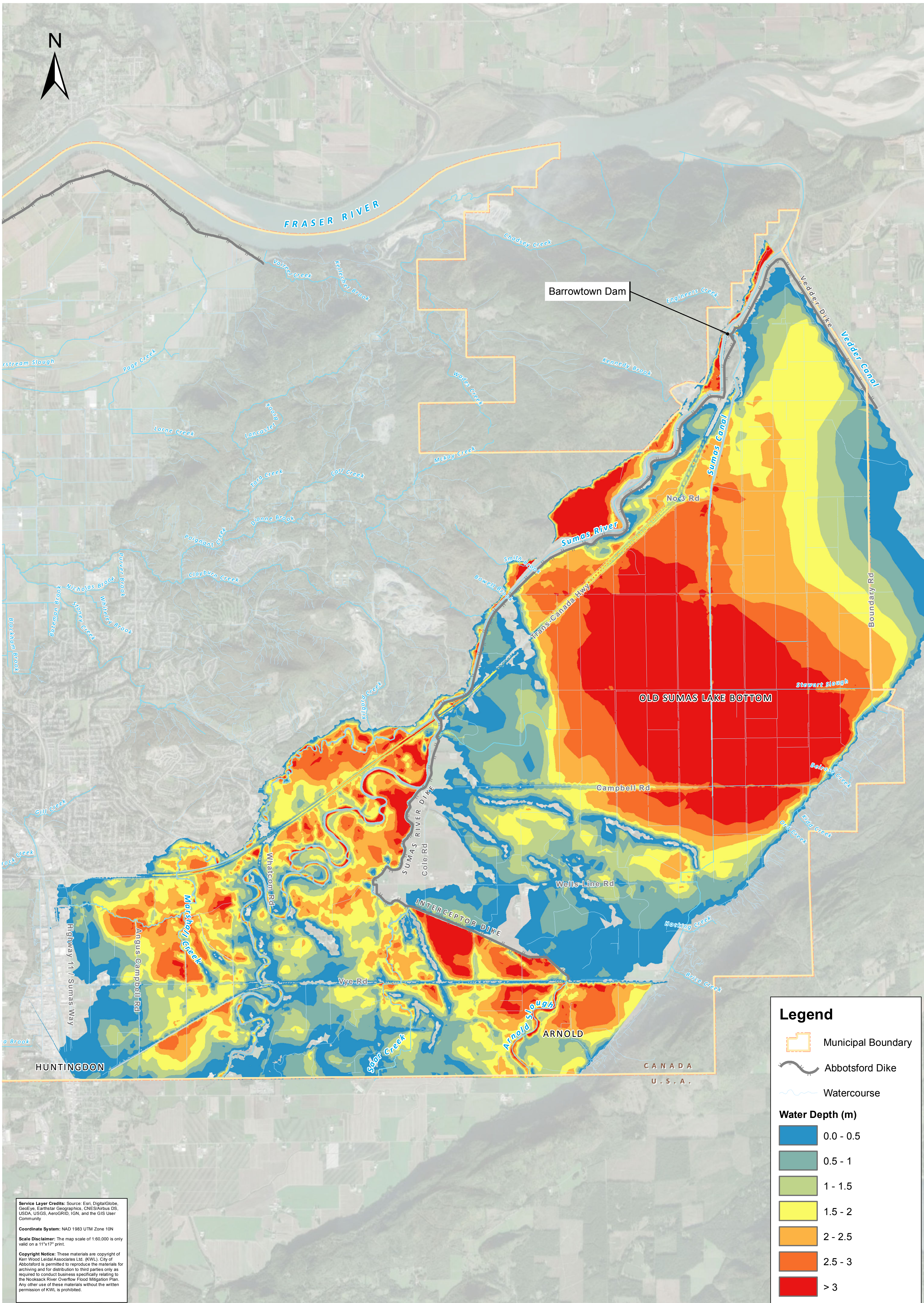

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Scenario CC-3 Hydraulic Model Results: 200-Year Flood under Climate Change Conditions including Nooksack Overflow, Embankment Breaches and Dike Breaches

Figure B-4

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Appendix C

Flood Depth Maps for Flood Mitigation Scenarios

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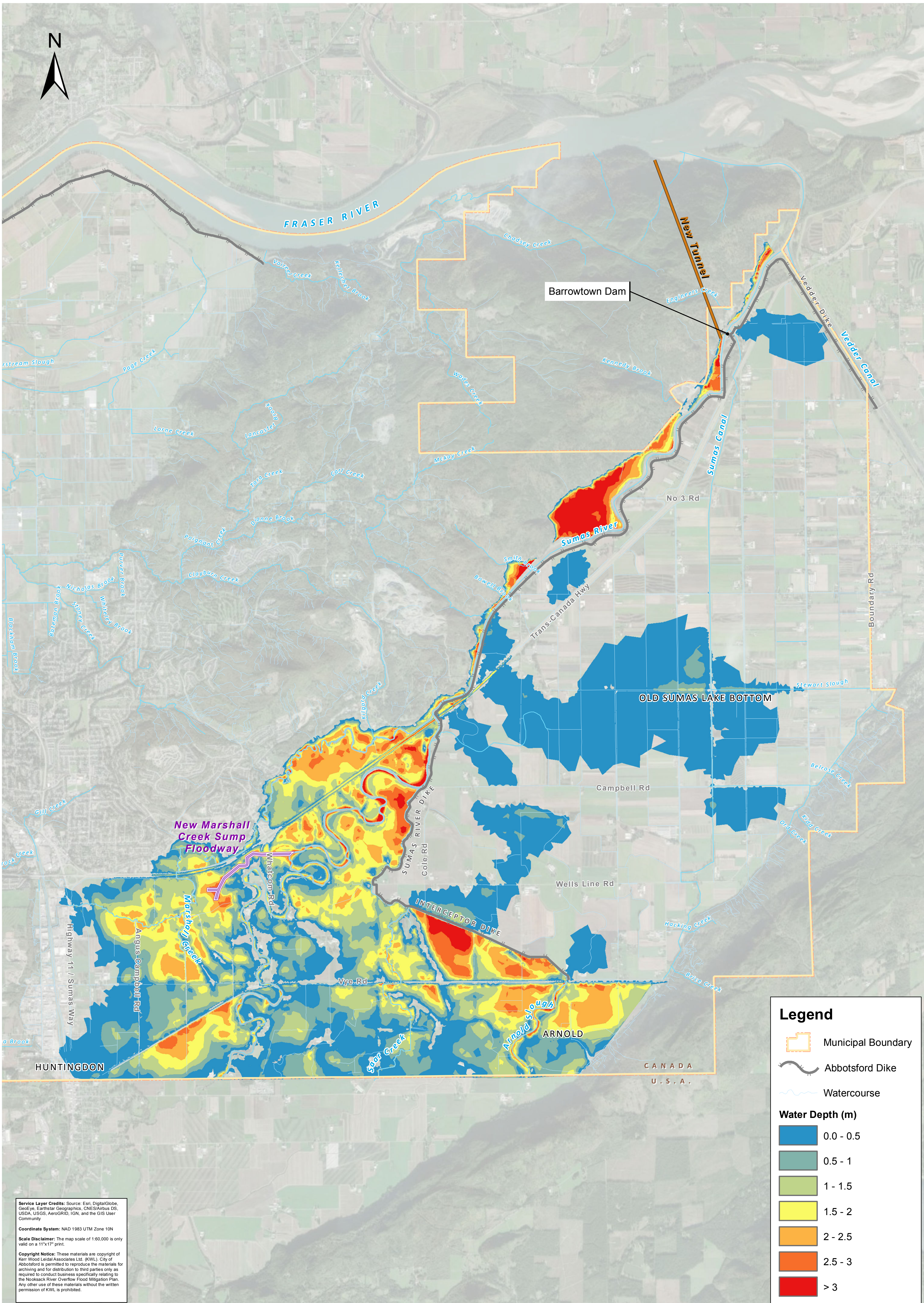

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Scenario M1-1 Hydraulic Model Results: Mitigation #1 - Marshall Floodway & Tunnel - 100-Year Flood

Figure C-1

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Nooksack River Overflow Flood Mitigation Plan

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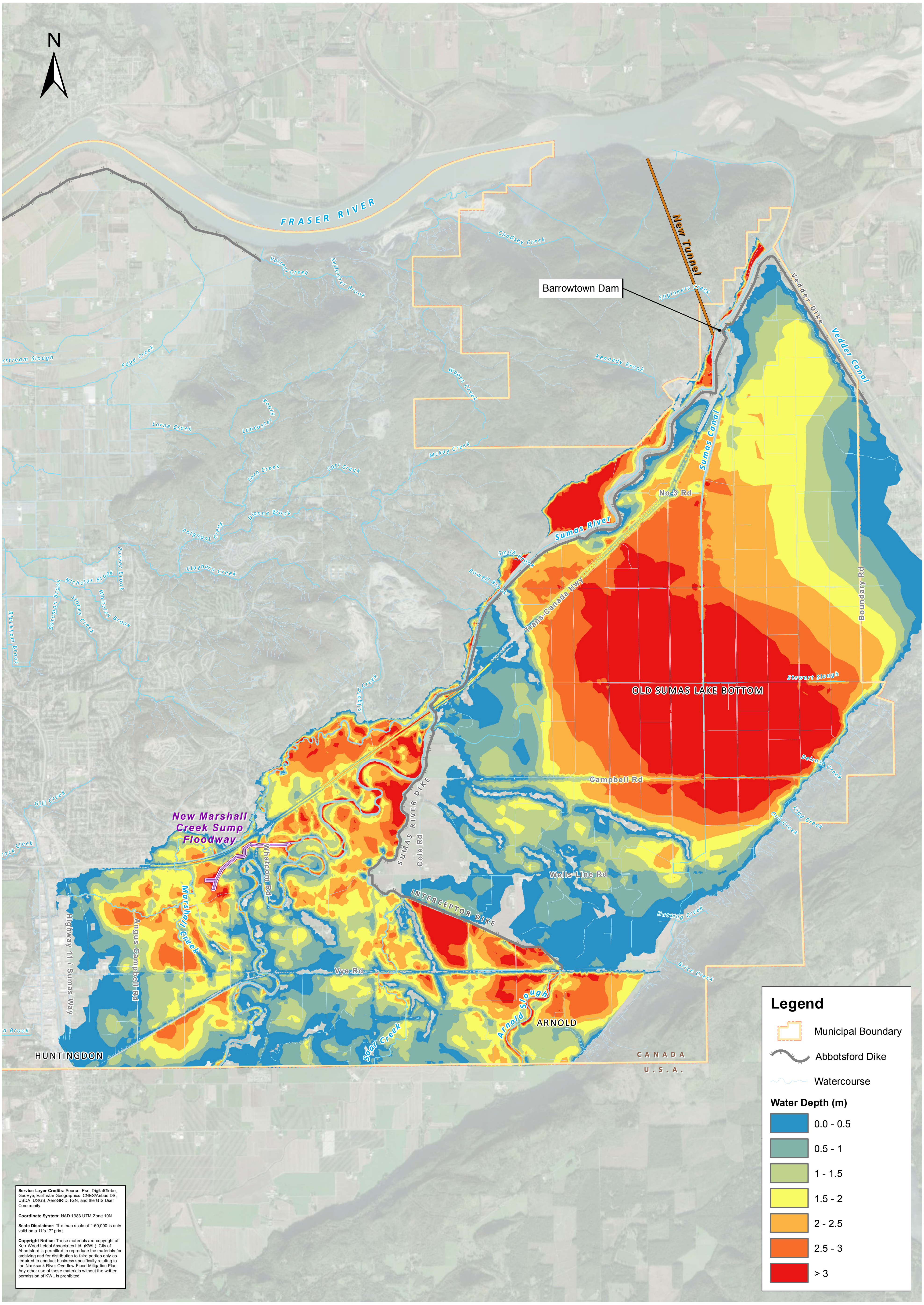

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Scenario M1-2 Hydraulic Model Results: Mitigation #1 - Marshall Floodway & Tunnel - 200-Year Flood (Climate Change)

Figure C-2

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Nooksack River Overflow Flood Mitigation Plan

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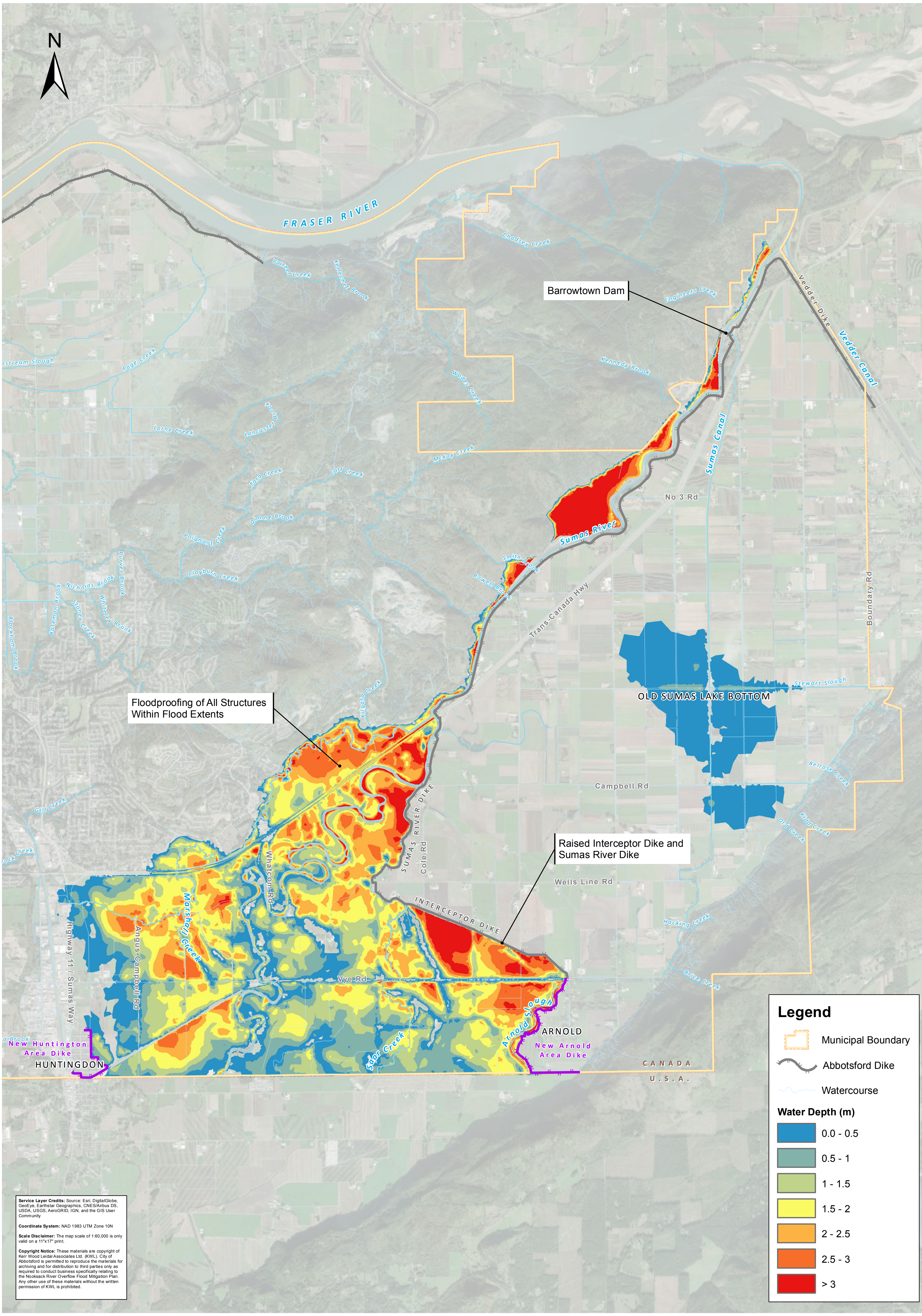

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Scale 0 250 500 1,000 (m)

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Scenario M2-1 Hydraulic Model Results: Mitigation #2 - Dike Raise and Floodproofing - 100-Year Flood

Figure C-3

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Nooksack River Overflow Flood Mitigation Plan

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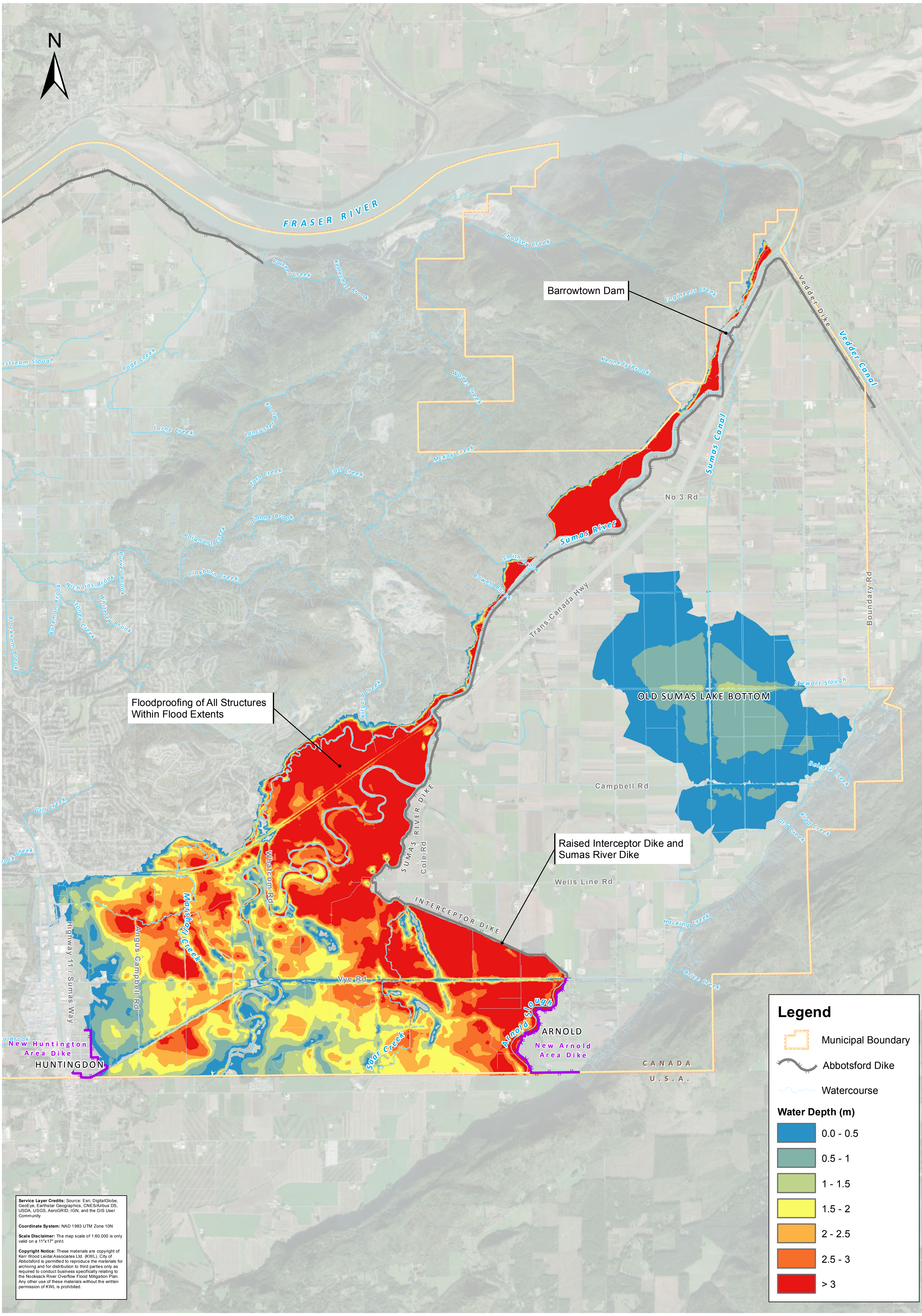

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Scenario M2-2 Hydraulic Model Results: Mitigation #2 - Dike Raise and Floodproofing - 200-Year Flood (Climate Change)

Figure C-4

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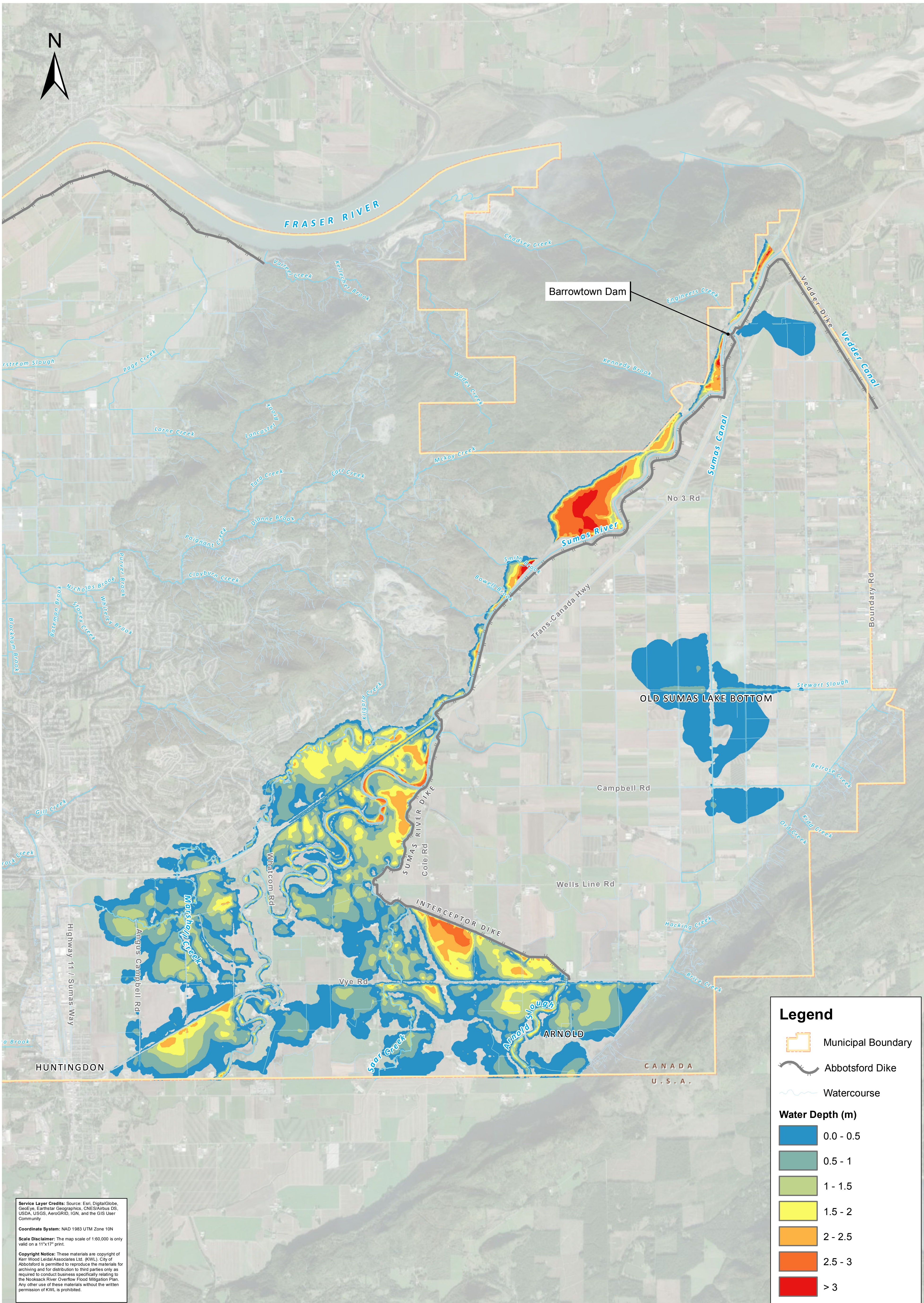

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Coordinate System: NAD 1983 UTM Zone 10N

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Scenario M3-1 Hydraulic Model Results: Mitigation #3 - Eliminate Nooksack Overflow - 100-Year Flood

Figure C-5

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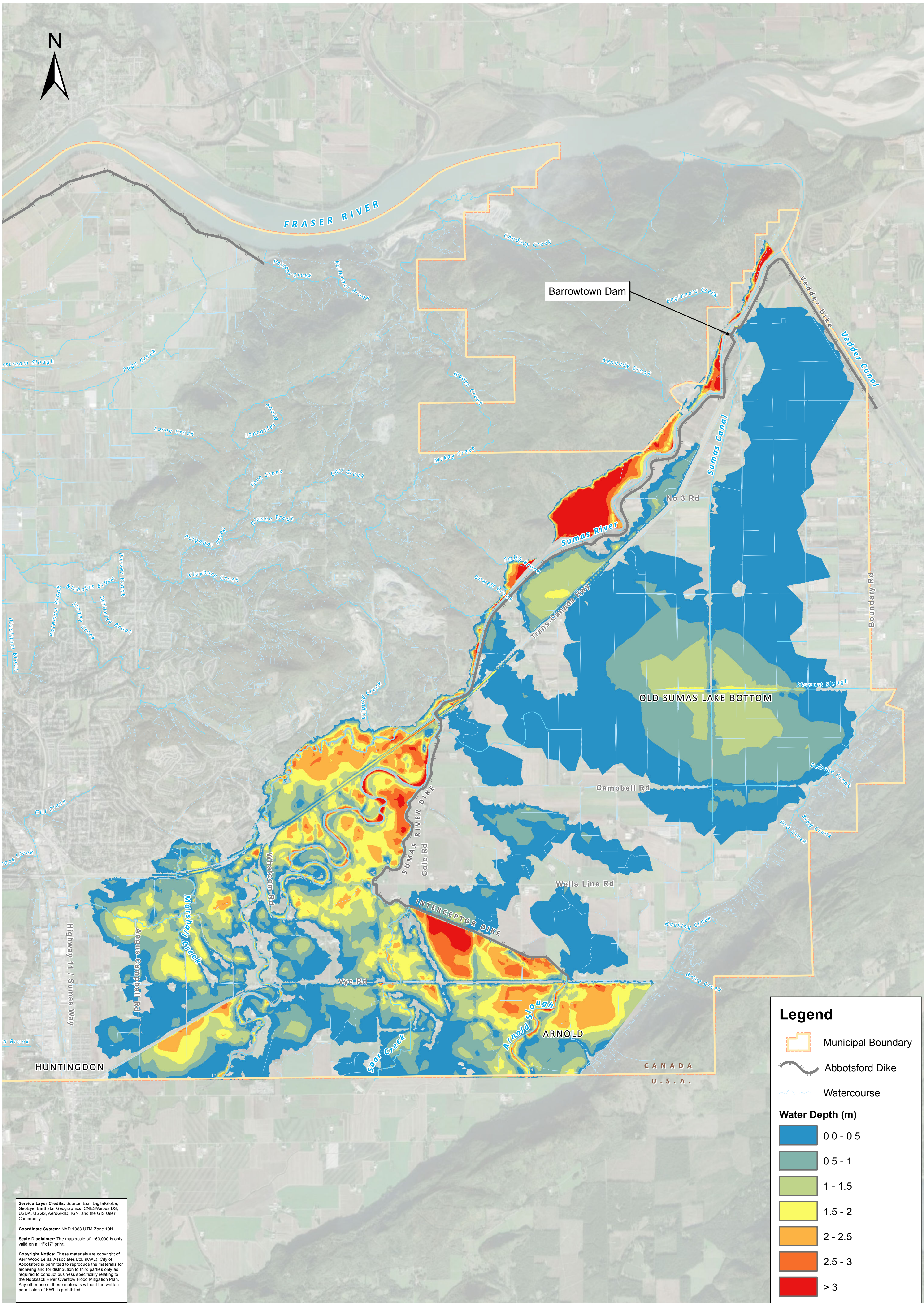

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Scenario M3-2 Hydraulic Model Results: Mitigation #3 - Eliminate Nooksack Overflow - 200-Year Flood (Climate Change)

Figure C-6

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Appendix D

Structure and Content Depth-Damage Curves

Table D-1: Structure Depth-Damage Curves for Residential Buildings

Depth	Percentage of Total Structure Value Damaged (%)													
	A1-B	A2-B	B1-B	B2-B	C1-B	C2-B	D1	MW1	A1-NB	A2-NB	B1-NB	B2-NB	C1-NB	C2-NB
-2.7	0	0	0	0	0	0								
-2.6	27.2	22.9	38.3	18.9	21.3	14.5								
-2.4	32.0	33.7	46.6	25.8	27.8	22.5								
-2.1	35.3	38.6	51.6	30.0	32.0	27.9								
-1.8	35.3	38.6	51.6	30.0	32.0	27.9								
-1.5	36.0	40.8	53.2	31.4	33.7	30.0								
-1.2	39.5	44.3	55.2	32.8	34.5	30.9								
-0.9	39.5	44.3	55.2	32.8	34.5	30.9								
-0.6	42.0	48.1	59.8	36.7	38.2	35.5	0							
-0.3	42.1	48.2	60.0	36.9	38.4	35.8	5.7							
0	43.0	49.7	61.8	38.2	39.5	37.2	5.7	0	0	0	0	0	0	0
0.1	69.3	63.3	70.7	79.1	81.5	79.1	77.0	68.3	46.2	27.0	23.4	66.2	69.5	66.8
0.3	70.0	64.3	71.9	80.0	82.6	80.5	86.2	76.0	47.4	29.1	26.4	67.7	71.3	68.9
0.6	79.5	78.6	80.2	87.0	89.6	89.2	86.2	91.9	64.0	57.5	48.1	78.9	82.9	82.8
0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table D-2: Contents Depth-Damage Curves for Residential Buildings

Depth	Percentage of Total Contents Value Damaged (%)													
	A1-B	A2-B	B1-B	B2-B	C1-B	C2-B	D1	MW1	A1-NB	A2-NB	B1-NB	B2-NB	C1-NB	C2-NB
-2.7	0	0	0	0	0	0								
-2.6	23.9	17.5	22.6	17.4	27.1	28.9								
-2.4	33.1	27.4	33.9	27.2	32.3	35.0								
-2.1	42.7	30.6	37.5	31.3	35.5	38.8								
-1.8	46.4	33.9	40.1	34.5	38.5	39.9								
-1.5	46.8	34.1	41.0	35.4	38.9	39.9								
-1.2	46.9	34.3	41.1	35.8	38.9	39.9								
-0.9	47.0	34.4	41.2	35.8	39.0	39.9								
-0.6	48.4	36.8	42.6	38.8	44.9	39.9								
-0.3	49.9	40.5	50.5	45.5	54.6	43.8								
0	49.9	40.5	50.5	45.5	54.6	43.8	0	0	0	0	0	0	0	0
0.1	72.2	67.1	72.6	70.5	77.3	73.6	50.3	45.5	44.5	44.7	44.6	45.9	50.1	53.0
0.3	87.2	82.8	88.9	81.9	89.4	83.7	78.5	69.0	74.4	71.1	77.6	66.8	76.7	71.0
0.6	95.2	91.9	93.5	90.3	94.6	87.9	88.2	86.5	90.3	86.4	86.9	82.2	88.0	78.5
0.9	98.2	98.5	99.7	96.7	99.0	99.2	99.6	98.9	96.4	97.5	99.4	93.9	97.8	98.7
1.3	98.6	99.9	99.9	99.5	99.9	100	100	100	97.3	99.9	99.8	99.0	99.8	100
1.5	98.6	100	99.9	99.6	99.9	100	100	100	97.3	100	99.8	99.2	99.8	100
1.8	100	100	100	100	100	100	100	100	100	100	100	99.8	100	100
2.1	100	100	100	100	100	100	100	100	100	100	100	99.8	100	100
2.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table D-3: Structure Depth-Damage Curves for Non-Residential Buildings

Depth	Percentage of Total Structure Value Damaged (%)			
	S1	S2	S3	S5
0	0	0	0	7.7
0.1	56.8	38.1	28.9	52.3
0.3	68.6	50.0	54.2	82.3
0.6	71.4	54.8	58.8	83.1
0.9	73.0	54.8	61.9	83.8
1.2	74.6	57.1	65.0	84.6
1.5	83.8	71.4	72.6	88.5
1.8	88.6	73.8	81.8	90.0
2.7	100	90.5	100	100
3.0	100	100	100	100

Table D-4: Contents Depth-Damage Curves for Non-Residential Buildings

Depth	Percentage of Total Contents Value Damaged (%)							
	A1	C6	C7	G1	H1	I1	L1	N1
0.0	0	0	0	0	0	0	0	0
0.2	31.8	15.3	16.0	4.6	13.9	15.9	12.5	12.4
0.3	33.4	29.9	30.8	25.3	27.1	56.9	31.2	25.1
0.6	57.6	46.6	45.1	46.0	36.1	96.0	45.8	65.7
0.9	100	61.8	69.0	87.4	45.1	97.8	72.9	93.9
1.2	100	78.5	81.0	97.7	72.2	100	83.3	100
1.5	100	91.7	90.5	100	91.0	100	85.4	100
1.8	100	100	97.3	100	100	100	89.6	100
2.1	100	100	98.3	100	100	100	92.7	100
2.4	100	100	100	100	100	100	95.8	100
2.7	100	100	100	100	100	100	97.9	100
3.0	100	100	100	100	100	100	100	100
3.3	100	100	100	100	100	100	100	100
3.7	100	100	100	100	100	100	100	100
3.9	100	100	100	100	100	100	100	100

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Appendix E

Agricultural Loss Analysis Methodology

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Technical Memorandum

DATE: May 31, 2020

TO: File

FROM: Yuko Suda, P.Eng.
Paulina Buskas, EIT

RE: **NOOKSACK RIVER OVERFLOW FLOOD MITIGATION PLAN**
Agricultural Economic Loss Assessment
Our File 510.184-300

The purpose of this memorandum is to outline the methodology used to calculate the agricultural economic loss and review the results from the Nooksack River overflow.

For the purpose of this assessment, economic loss was defined as "Expense or fall in revenue arising out of a disaster, failure of a product, or other events under or beyond a management's control." The following are not included in this assessment:

- Loss in future opportunity;
- Loss in profits of an asset (e.g., decrease in property value);
- Loss in future interests due to lost revenue;
- Benefits derived by others due to the flooding event (e.g., nurseries supplying replacement plants or unaffected farms capitalizing on the gap in market); and
- Other intangible losses or damages (e.g., loss of pollinator colonies, such as bees, leading to reduced pollination in the future years).

In addition to the above, damaged crops and assets that are insured (and paid out in the event of flooding) are still taken as full losses, for the purpose of this assessment, as they represent losses to the insurance companies.

Modelling Approach

There are two modelling approaches that were considered to determine the economic loss of a flood event to the agriculture in Abbotsford:

1. HEC-FIA Modelling; and
2. Damage and Loss Computation Methodology - Food and Agriculture Organization (FAO) of the United Nations.

Each of these are discussed further below.

HEC-FIA

HEC-FIA is described as follows:

> "*The Hydrologic Engineering Center's (HEC) Flood Impact Analysis (HEC-FIA) software is a tool to help identify the consequences from a single event. HEC-FIA was developed by HEC in collaboration with the Risk Management Center (RMC) and the Engineering Research and Design Center (ERDC). HEC-FIA evaluates consequences from events defined by hydraulic model output such as gridded data (e.g., depth and arrival time Grids) or HEC's Data Storage System (HEC-DSS) Stage Hydrographs. The consequences HEC-FIA computes include economic losses (losses to structures and their contents), agricultural losses, and expected life loss from these hydraulic events*." (https://www.hec.usace.army.mil/software/hec-fia/)

The advantages of this software include:

- Crop-by-crop level assessment for over 100 crop types;
- Detailed calculations, based on rate of crop loss per flood duration, fixed costs, variable costs, harvest costs, yields, and unit pricing; and
- Accounts for delayed plantings (and associated loss of yield), and planting of secondary crops due to delay (and associated reduction in revenue).

The disadvantages of this software include:

- Data, to the level of detail required for the model, is not conventionally available in BC/Canada (e.g., date of first planting, date of last planting, date of harvest, cost of harvest etc);
- Inability to assess the accuracy of the model, including carrying out calibration and verification processes;
- Does not take into account the reduced yields for perennial crops in subsequent years; and
- Does not take into account livestock losses.

Food and Agriculture Organization – Damages and Loss Computation Methodology

The FAO's Damages and Loss Computation Methodology (the FAO method) is enclosed with this technical memorandum and is discussed in their *2017 Impact of Disasters and Crises on Agriculture and Food Security Report*:

> *"Detailed assessments of economic loss and damages are regularly carried out by governments and multilateral organizations following large-scale disasters using different methodologies. However, when applied to agriculture, these assessments often fail to capture the specificities of the sector and result in an imprecise or under-estimated evaluation of disaster impact. Moreover, given the lack of a universal assessment methodology, disaster impact tends to be estimated based on variations of either PDNA [Post-Disaster Needs Assessment] or Economic Commission for Latin America and the Caribbean (ECLAC) -derived methodologies, making it impossible to compare results across countries or disasters. it is often difficult to determine which methodology, criteria and parameters have been used and which elements of agricultural damage and loss have been considered.*

Aiming for a standardized approach to assessing disaster damage and loss in agriculture, FAO has developed a methodology that is both holistic enough to be applied in different disaster events and in different country/regional contexts, and precise enough to consider all agricultural subsectors and their specificities. In addition, a common streamlined methodology can help address the prevailing knowledge gap on disaster impact on the sector and provide a useful tool for assembling and interpreting existing information about both past and future events."
(FAO, 2017)

This method assesses five agricultural sectors:

- Crops;
- Livestock;
- Forestry;
- Aquaculture; and
- Fisheries.

The advantages of this methodology include:

- Includes more agricultural types than HEC-FIA, including livestock assessment;
- Allows for detailed- or high-level assessment, depending on the information available;
- Allows for some level of sensitivity analysis, using min, average, and max values;
- Does not require as detailed information as the HEC-FIA method.

The disadvantages of this software include:

- More suited to assessing an actual even that has occurred in the past where economic values are known, rather than a theoretical event.

Discussion

The key difference between the HEC-FIA method and the FAO method are:

- HEC-FIA is a modelling software that is used to predict agricultural damages resulting from a predicted flooding event (at some point, either present or in the future), where as the FAO Damages and Loss Computation Methodology is a methodology to tabulate actual financial impacts of a large-scale disaster event that has actually occurred in the past to facilitate consistent reporting across other regions and other disasters.
- The HEC-FIA method takes into detailed consideration the growing methods (e.g., date of planting, date of harvest, etc), the costs of production and price of the commodity, and compares that to the timing of the flood. The FAO method on the other hand does not consider the methods and timing of production and simply calculates the pre-and post-disaster crop value, post-disaster maintenances costs, and replacement costs of the affected assets.

After review of both methods, the FAO method was selected for the purpose of this assessment for two key reasons. First the HEC-FIA method does not account for livestock, therefore a different method or the FAO method would need to be used to assess the economic loss. Second, HEC-FIA requires detailed crop information (type of crop for each modelled grid, the date of first planting, the date of first harvest, cost of harvest, cost of production, price of crop, etc) that is generally not readily available in Canada, as well as a modelled flood date, which is not known for this assessment. The FAO method, on the other hand, can be applied to this project using broader economic data that can be obtained from Statistics Canada for the region.

Modelling Methodology and Process

The FAO method identifies three types of impacts:

1. Production Loss (PL) – Value of lost production and is measured by the difference in expected (i.e., pre-disaster) and actual value (i.e., post-disaster) of production and post-disaster maintenance costs.
2. Production Damage (PD) – Value of damaged/destroyed stored inputs (e.g., seeds), stored production (e.g., harvested products in storage), and replacement costs of lost perennial trees and livestock.
3. Asset Damage (AD) – Replacement cost of fully destroyed assets, and repair/rehabilitation costs of partially damaged assets, such as machinery, equipment and tools.

The sum of the above damages represents the economic loss to agriculture from a disaster, as follows:

$$Impact\ to\ Agriculture = PL + PD + AD$$

The process that is described in this section, then, is the tasks completed in order to populate the information required for the above calculation.

Application of the FAO Method to the Nooksack River Overflow Assessment

The methodology to assess the economic loss from the flooding of the Nooksack River to agricultural activities is divided into to three tasks, as follows:

1. **Characterisation of Farm Operations**: The purpose of this work is to identify the location, amount (hectares), and type of agriculture occurring within the study area.
2. **Rate of Agricultural Loss by Type**: This analysis will determine the rate of loss for each day or depth of flooding during the flooding event.
3. **Economic Loss Assessment**: This will determine the economic loss of the flooding event on the agricultural operation within the flood zone.

Information Sources

The following information sources have been used for this analysis:

- City of Abbotsford GIS data (parcel data);
- Statistics Canada (online 2016 census data for the Abbotsford Consolidated census subdivision and custom data request[1]);
- Ministry of Agriculture, including the Production Insurance Office; and
- Online literature.

[1] Received November 29, 2019.

Task 1 - Characterisation of Farm Operations

Characterization of farm operations is available through two sources:

- City of Abbotsford parcel data, which indicates farm status and BC land use code. This data is available on a parcel-by-parcel basis.
- Statistics Canada 2016 census data[2]. This data is only available for City of Abbotsford as a whole (i.e., the Census Consolidated Subdivisions level, which is the smallest size the data is available at due to confidentiality reasons). The information available includes:
  - North American Industry Classification System (NAICS), Industry Group Code;
  - Total number of farms;
  - Total farm capital, including farm machinery and equipment, livestock and poultry, land and buildings;
  - Total farm area;
  - Total gross farm receipts (excluding sales of forest products) in the calendar year prior to the census or for the last complete accounting (fiscal) year prior to the census; and
  - Total farm business operating expenses in the calendar year prior to the census or for the last complete accounting (fiscal) year prior to the census.

It should be noted that census data is self reported by the farm operators, and thus the level of accuracy and whether, and to what extent, some values are over or under reported is unknown.

In the subsequent task (Task 3: Financial Impact Assessment) the Statistics Canada 2016 Census values will be used to assess the economic loss, however the system used by Statistics Canada to categorize business type by the North American Industry Classification System (NAICS), where as the City of Abbotsford uses BC Land Use Codes. The approach that was employed is to use City of Abbotsford Parcel data for actual land use types, and Statistics Canada Census data for economic information.

Table 1 shows the BC land use types for the agricultural lands in the City of Abbotsford and the study area, and Table 2 shows the Statistics Canada 2016 census data.

Table 1: Farm Characteristics in the Study Boundary Area and City of Abbotsford using City of Abbotsford Parcel Data (BC Use Code).

BC Use Code	Description	Abbotsford			Study Boundary		
		Count	Area (ha)	Percentage (Area)	Count	Area (ha)	Percentage (Area)
110	Grain & Forge	295	1,831	8.5%	110	709	8.2%
111	Grain & Forge - Vacant	56	515	2.4%	32	344	4.0%
120	Veg & Truck	135	1,186	5.5%	85	815	9.5%
121	Veg & Truck - Vacant	38	341	1.6%	32	262	3.0%
130	Tree Fruits	6	30	0.1%	-	-	0.0%

[2] The reporting date for the 2016 census data was May 10, 2016.

BC Use Code	Description	Abbotsford			Study Boundary		
		Count	Area (ha)	Percentage (Area)	Count	Area (ha)	Percentage (Area)
140	Small Fruits	702	4,345	20.3%	128	860	10.0%
141	Small Fruits-Vacant	66	567	2.6%	22	197	2.3%
150	Beef	154	1,022	4.8%	30	225	2.6%
151	Beef - Vacant	4	19	0.1%	-	-	0.0%
160	Dairy	238	3,469	16.2%	108	1,834	21.3%
161	Dairy - Vacant	82	815	3.8%	47	496	5.8%
170	Poultry	246	1,467	6.8%	46	369	4.3%
180	Mixed	171	944	4.4%	33	145	1.7%
181	Mixed - Vacant	3	30	0.1%	2	23	0.3%
190	Other	513	3,742	17.5%	158	1,511	17.5%
191	Other - Vacant	120	1,115	5.2%	72	823	9.6%
	Total	**2,829**	**21,437**	**100.0%**	**905**	**8,613**	**100.0%**

Table 2: Farm Characteristics reported by Statistics Canada for the City of Abbotsford (2016).

NAICS Industry Group - Code	Distribution: North American Industry Classification System (NAICS), Industry Group	Total number of farms	Total farm area - Acres	Total farm area - Hectares
111100	Oilseed and grain farming	12	488	197
111200	Vegetable and melon farming	64	4,313	1,745
111300	Fruit and tree nut farming	434	11,536	4,668
111400	Greenhouse, nursery and floriculture production	152	5,351	2,165
111900	Other crop farming	75	4,852	1964
112100	Cattle ranching and farming	175	18,798	7,607
112200	Hog and pig farming	11	365	148
112300	Poultry and egg production	252	7,878	3,188
112400	Sheep and goat farming	21	350	142
112900	Other animal production	111	2,196	889
	Total	**1,307**	**56,127**	**22,714**

It is noted that there are differences between the City of Abbotsford Parcel data and the Statistics Canada Census data. The Statistics Canada data indicates 1,307 farm operations within the City of Abbotsford, however the City of Abbotsford's parcel data estimates 2,829 farm parcels within city boundaries. In addition, Statistics Canada estimates 22,714 hectares of farmed area, while the City of Abbotsford parcel data reports a total of 21,437 hectares of farmed parcels (6% difference). There are a number of reasons for the difference in values including:

- City of Abbotsford data is based on farm parcels, whereas Statistics Canada is based on farm businesses. In some cases, farmers may operate on multiple parcels of land, leading to more farmed parcels than farm businesses. This is not an unreasonable assumption, as many land owners do not necessarily farm, but rather lease land to other farm operators to farm.
- The Statistics Canada farm size is a self-reported number, where as City of Abbotsford Parcel Data is based on actual parcel size (calculated using GIS). The information provided by farmers may be approximate, rounded, or based on production area (not total land area).
- Statistics Canada Census data is based on farmers reporting farm activities, possibly, from their base of business or from their home address. Some farming activities may be located in an adjacent census subdivision (e.g., Langley or Chilliwack), while the owner/operator is located within the Abbotsford subdivision.

For the purpose of this study, the City of Abbotsford Parcel data is proposed to be used for:

- Farm status;
- Farm use type; and
- Farm area.

The City of Abbotsford Parcel is proposed, as the flood-based damage is based on a parcel-by-parcel analysis, rather than at a business-by-business basis. However, as discussed further in this technical memorandum, the Statistics Canada census data will be used to determine economic loss, and therefore NAICS codes must be assigned to each parcel.

Assignment of NAICS Classification to BC Land Use Classifications

In order to relate the NAICS and BC Land Use Codes, NAICS code descriptions were matched to similar land use descriptions in the BC Use Code. As there were more BC Use Codes than NAICS codes and as all NAICS codes had to be accounted for, assumptions were made regarding the grouping of different classifications:

- BC Use Codes for Grain & Forge (110 and 111), Beef (150 and 151), and Dairy (160 and 161) were combined and associated with a combined NAICS group for Oilseed and Grain (11100), and Cattle (112100). This grouping was created, under the assumption that most grain and forage farming in Abbotsford was for the purpose of cattle/dairy farming, and therefore many of the NAICS codes were under cattle farming. It was determined that this combination is likely suitable as oilseed/grain farming and cattle ranching have similar sales per acre. Oilseed and grain farming also only accounts for 0.9% of the total farm area and 0.3% of the total farm sales.
- NAICS codes that were not mentioned in the BC Use Code (Greenhouse, nursery, floriculture, hog and pig farming, sheep and goat farming, other crop farming) were combined into the Other category (190 and 191). When combined, the area percentages were similar between the BC Use Code and NAICS code (22.7% and 23.3%, respectively).

The following table outlines the NAICS assignments to each BC Land Use Code, and the comparison of the codes.

Table 3: BC Use Code and NAICS Assignments for Abbotsford

BC Use Code	BC Use Code Description	NAICS Code	NAICS Description	BC Use Code Percentage (Area)	NAICS Percentage (Area)	Percentage Difference (Area)
120	Veg & Truck	111200	Vegetable & Melon	11.6%	7.7%	3.90%
121	Veg & Truck - Vacant					
180	Mixed					
181	Mixed - Vacant					
130	Tree Fruits	111300	Fruit & Tree Nut	23.0%	20.6%	2.40%
140	Small Fruits					
141	Small Fruits-Vacant					
110	Grain & Forge	111100 and 112100	Oilseed, Grain, & Cattle	35.8%	34.4%	1.40%
111	Grain & Forge - Vacant					
150	Beef					
151	Beef - Vacant					
160	Dairy					
161	Dairy - Vacant					
170	Poultry	112300	Poultry & Egg	6.8%	14.0%	-7.20%
190	Other	112900,111400, 111900, 112200, and 112400	Greenhouse, Nursery, Floriculture, Hog & Pig, Sheep & Goat, Other crop and animal production	22.7%	23.3%	-0.60%
191	Other - Vacant					

Task 2 - Rates of Agricultural Loss

In order to determine the economic loss of flooding on agriculture, the FAO method requires the amount of agricultural loss to be quantified during these events. Agricultural losses were grouped in the following categories:

- Annual crops (e.g., vegetables);
- Perennial crops (e.g., blueberries and apple trees);
- Live stocks (e.g., poultry, cattle, and pigs); and
- Assets (tractor, machinery, etc).

The following sources for establishing rates of crop loss were used:

1. From online literature review;
2. Sumas River Flooding Assessment report; and
3. Anecdotal evidence and experience.

Annual Crop

Two different methods for annual crop loss exist. First is the survival rate of the crops, and the second, the saleable rate of the crops impacted.

The survival rate of crops can depend on the following:

- Duration of flooding;
- Depth of flooding;
- Crop stage (i.e., seedling vs mature crop).

The survival rate of annual crops due to flooding varies by crop type and studies have been carried out by various organization.

The sellable rate of crops is the percentage of the crops (or value of) that were impacted by flooding that can be sold. However, the biggest concern with selling produce that have been impacted by flooding is the risk of contamination and the ability to harvest. Sources of contamination include food-borne diseases (such as cryptosporidium, Escherichia coli, and salmonella), chemical contamination (such as from pesticides) and from other contamination (e.g., asbestos).

Although currently in British Columbia, there does not appear to be laws governing sales of crops affected by flooding, there are guidelines should this happen:

> *"Contamination Due to Flooding - Evaluate production areas for potential flooding. Flood waters can carry sewage, animal waste and other contaminates onto the production site. This is a particular concern for fresh fruit and vegetables that are grown close to the ground and can be eaten raw. If flooding has occurred, talk to provincial and/or federal agricultural specialists to discuss safe food options or concerns." Source:*
> https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/food-safety/good-agricultural-practices/8-1-soil-environment-evaluation

In the United States, the Food and Drug Administration (FDA) takes a slightly stricter approach:

> *"A. Safety of food crops when flood waters contacted the edible portions of the crops*
>
> *If the edible portion of a crop is exposed to flood waters, it is considered adulterated under section 402(a)(4) (21 U.S.C. 342(a)(4)) of the Federal Food, Drug, and Cosmetic Act and should not enter human food channels. There is no practical method of reconditioning the edible portion of a crop that will provide a reasonable assurance of human food safety. Therefore, the FDA recommends that these crops be disposed of in a manner that ensures they are kept separate from crops that have not been flood damaged to avoid adulterating "clean" crops (Ref. 1, 2, 3)."*

In some cases, there have been instances where the flooded crops were prohibited for human consumption (e.g., Hurricane Florence in 2018[3]). In these cases, options to use the crops for animal feed may be possible and steps may need to be taken to confirm its safety.

Given predicted flooding route, it is likely that the crops impacted from the Nooksack River flooding will come in contact with a number of potential substances, including:

- Sewage and septage (e.g., flooding manholes, flooded septic systems, flooded waste lagoons, and livestock fecal matter);
- Chemical (e.g., hydrocarbons from roads and storage, pesticides, and herbicides); and
- Other sources (e.g., asbestos, and road run-off).

Harvesting in flooded fields is also a significant challenge, as typical harvest equipment (tractors and trucks) cannot enter the fields without risking getting trapped in the mud. This may require manual harvesting and transportation, which increases harvest expenses, potentially exceeding revenue.

Based on the above, it is assumed that any annual crop impacted by flooding would be unsellable, due to the risk of contamination and the challenges bringing the crops to market, and likely the cost to salvage these crops (e.g., through selling for animal feed) may exceed the potential revenue.

The timing of the flooding is assumed to occur immediately before the harvest date, as this represents the time when the most inputs have been applied to the farm, but before the harvest is carried out (i.e., revenue is generated).

Perennial Crops

Flooding affects perennial crops in three different ways:

1. Loss of that year's crops (e.g., due to failed pollination, fruit drop, and contamination);
2. Loss of the plant; and
3. Future reduction in production.

The loss of that year's crops will be the same as the analysis completed in the annual crops section, due to the risk of contamination and the difficulty harvesting during flooding events.

[3] https://www.ncagr.gov/paffairs/release/2018/Floodedcropscanntbeusedforhumanfood.htm

Loss of the plant (such as an apple tree or blueberry bush) occurs due to the lack of oxygen to the root soil microorganisms and the plant root due to hypoxic or anaerobic conditions within the soil because of the displaced air space. This can either result in the direct loss of the plant (i.e., wilting or damage beyond repair) or open up the plant to subsequent pathogens (Crane, 1987).

The rate of plant loss depends on a number of conditions, such as plant and species type, ambient and water temperatures, stage of the plant (e.g., dormant or active), and the presence of pathogens and their tolerance to flooded conditions.

For the purpose of this study, the loss rate of blueberries reported by "Effect of Flooding Duration, periodic Flooding, Season, and Temperature on Growth, Development, and Water Relations of Young Rabbiteye Blue Berry (*Vaccinium rshei Reade*) Plants" (Crane, 1987), was used. Based on their study a loss rate of 3.4% for every 24 hours of flooding was selected.

Future reduction in production due to flood damaged plants (i.e., not lost) has not been assessed for this study, however the reduction in revenue due to having to replant new stock has been.

For the purpose of this assessment the following is used:

- The year's harvest is all lost (due to contamination or inability to harvest);
- 3.4% of the crops are lost for every 24 hours of flooding;
- Production loss in subsequent years of plants that were not lost are not taking into account, however the reduction in revenue due to lower yields of newly planted plants are included, and
- The flooding occurs immediately before harvest, as this represents the time when the most inputs have been expended, however before revenue is generated.

Livestock

Losses in livestock farming can include:

- Loss due to death of the livestock;
- Delay in sale due to disease (assumes disease can be treated and subsequently be sold for human consumption);
- Decrease in sale price due to selling at less than optimal stage or weight.

The loss in livestock can occur directly from the flooding event (i.e., drowning), however can be lost due to sickness including:

- Infection from minor scrapes,
- Infection from sewage borne communicable diseases (e.g., E. coli),
- Sickness due to malnutrition (as they cannot be fed for days),
- Sickness due to loss of power on site, resulting in unsanitary or hazardous conditions (e.g., high level of ammonia); and
- Other causes (e.g., from stress, infection from not being milked, injury from other animals, etc.).

Similar to vegetables crops, based on Canada's and British Columbia's strict food laws, including rigorous food safety requirements, once an animal becomes diseased, it cannot be sold for human consumption until it has become healthy and has been approved for slaughter by an inspector. Based on these strict regulations, it is believed that once a farm is significantly impacted by flooding most or all of the animals on the farm will be destroyed, or the cost to treat the animals to the point of sale can exceed the animal's value (i.e., negative revenue). It is expected that veterinary care may be delayed due to lack of access to the site and high demand for veterinary care in the area after such an event. Costs (financial and non-financial) include:

- The time to receive assessment and treatment due to access issues to the farm site.
- The cost to assess the animal by a veterinarian and receive the approval to slaughter the animal.
- The cost to treat the animal for the disease, and then receive the approval from the veterinarian; and
- The cost of selling the animal at less than the pre-slaughter value (e.g., for pet food, rather than human consumption, or selling at a less than optimal weight).

For the purpose of this assessment, once a certain threshold is reached, it will be assumed that all the animals lose their value due to disease, subsequent need for treatment, and death. The following threshold have been selected:

- Poultry: 0.1 m
- Cattle: 0.3 m
- Others: 0.1 m

<u>Loss in Production</u>

As difference animals have different life spans (i.e., at the time of slaughter) this must be taking to account to determine the production impact. The average age of animals at slaughter varies by animal, but also by their use (e.g., dairy cattle vs beef cattle, boilers vs laying hens). The following age at the flooding event is used for this analysis:

- Poultry: 8 weeks
- Cattle: 1.5 years[4]
- Others: 1 year

This is used to determine how many years of production loss (i.e., magnitude of lost investment) is calculated. For example, a poultry operation would only see a maximum of 8 weeks of investment loss, whereas a cattle operation may see a maximum investment loss of 3 years.

<u>Discussion</u>

For the purpose of this assessment the following is used:

- After a minimum flooding threshold is exceeded, livestock are assumed to have lost all value due to the subsequent costs that can be incurred to treat/dispose the livestock; and
- It is assumed that livestock production is generally year-round, however the timing of the flooding is assumed to occur immediately before slaughter (i.e., representing the maximum inputs but no revenue).

[4] The average age of cattle is assumed to be 3 years, however as there will be a range of cattle (from new born to 3 years) during a flood event, the average age is used.

Task 3: Financial Impact Assessment

The following table outlines the variables that are required to complete the FAO method, the process selected for this study, and the source/justification for the selection.

Table 4: FAO Method Variable, Selection and Justification.

Variable	Value	Source/Justification
Annual Crop Production		
Pre-disaster value of destroyed stored inputs (e.g., seeds, fertilizer)	N/A	Since the worst-case damage occurs right before harvest, it is assumed that all stored inputs have already been expended.
Pre-disaster value of destroyed stored annual crops (e.g., harvested crops in storage)	N/A	Annual crops are typically not stored on site long-term and under the assumption that the worst-case damage occurs right before harvest, there would be no stored crops.
Difference between expected and actual value of crop production in non-fully damaged harvested areas	N/A	Once an annual crop is damaged, it is assumed to be unsellable, there all produce is assumed to be fully destroyed.
Pre-disaster value of destroyed standing crops in fully-damaged areas	100% of annual farm revenue	It is assumed that all farm revenue is lost for the year.
Short-run post-disaster maintenance costs (expenses used to temporarily sustain production activities immediately post-disaster)	10 % of annual farm revenue	This is the cost of post-disaster cleanup, beyond what is typically done post-harvest. No historical values were available for this, and therefore was selected based on judgement.
Perennials Crop Production		
Pre-disaster value of destroyed stored inputs	N/A	Since the worst-case damage occurs right before harvest, it is assumed that all stored inputs have already been expended and that inputs are not stored past a single production year.
Pre-disaster value of destroyed stored perennial crops	N/A	Perennial crops are typically not stored on site long-term and under the assumption that the worst-case damage occurs right before harvest, there would be no stored crops.
Replacement value of fully damaged trees	Cost of tree replacement, including the loss of production in subsequent years, to maturity.	This is the 10 year cumulative operating margin, at which point the plant is considered fully mature. This is based on blueberry production data available from the BC Ministry of Agriculture.

Variable	Value	Source/Justification
Difference between expected and actual value of crop production in non-fully damaged harvested areas	100% of annual farm revenue	It is assumed that all farm revenue is lost for the year.
Pre-disaster value of destroyed standing crops in fully-damaged area	N/A	This is included in the above variable (i.e., 100% revenue loss)
Short-run post-disaster maintenance costs (expenses used to temporarily sustain production activities immediately post-disaster)	10 % of annual farm revenue	This is the cost of post-disaster cleanup, beyond what is typically done post-harvest. No historical values were available for this, and therefore was selected based on judgement.
Livestock		
Pre-disaster value of stored inputs (fodder and forage)	1 % of annual expenditures	Assumed that only 1 month of expenditures are stored on site and that 13 % of expenditures are stored inputs[2].
Pre-disaster value of destroyed stored animal products	N/A	Assumed that animal products will not be stored on site (i.e., processed at an approved processing plant and packaged and stored at a separate facility)
Pre-disaster net value of dead animals	100 % of the livestock portion of the farm capital.	Assumed that all animals lose their value (due to death or subsequent disease and care).
Difference between expected and actual value of production (of livestock products)	100 % of the annual farm revenue, divided by the average age of livestock at flooding event.	Animals impacted by the flooding event, exceeding a certain threshold, will be considered to have lost all value.
Short-run post-disaster maintenance costs expenses used to temporarily sustain production activities immediately post-disaster)	10 % of farm receipts.	This is the cost of post-disaster cleanup, beyond what is typically done post-harvest. No historical values were available for this, and therefore was selected based on judgement.
Assets		
Repair / replacement cost of partially / fully destroyed assets at pre-disaster price	100 % of farm capital, excluding livestock and property. Assets are considered fully damaged at 1.5 m depth, and damages are prorated based on depth.	This is assuming most assets are stored on the ground level, and that generally assets are not piled above 1.5 m off the ground.

Note:
1. Costs and Returns of Sample Ranching Businesses in Various areas Of British Columbia, Ministry of Agriculture, Government of BC, 2013.

Tasks to assess the overall economic impact to agriculture the following sub-tasks must be completed:

- Develop unit values that will be applied to each farm from the above table, namely:
    - Annual revenue ($/ha) for each agricultural type,
    - Farm capital ($/ha), excluding livestock and property, for each farm type,
    - Value of livestock ($/ha) for each farm type, including livestock type,
    - Annual expenditures ($/ha) for each farm type, and
    - Replacement value of destroyed trees ($/ha); and

Annual Revenue and Expenditures

Annual revenue (gross farm receipts) and expenditures (operating expense) for the City of Abbotsford is reported by Statistics Canada and was divided by all farm area (by type) for Abbotsford, based on the parcel data, as follows:

Table 5: Unit Revenue and Expenditures Development.

<table>
<tr><th colspan="4">City of Abbotsford Parcel Data</th><th colspan="2">NAICS Assignments</th><th colspan="2">Statistics Canada Data (2016) For Abbotsford</th><th colspan="2">Unit Rates ($/Ha)</th></tr>
<tr><th>Use Code</th><th>Use Code Description</th><th>Total Area (Ha)</th><th>Total Area (Ha)</th><th>NAICS Code</th><th>NAICS Description</th><th>Total Gross Farm Receipts</th><th>Total Farm Business Operating Expenses</th><th>Gross Farm Receipts Per Area</th><th>Farm Business Operating Expenses Per Area</th></tr>
<tr><td>120</td><td>VEG & TRUCK</td><td>1,186</td><td rowspan="4">2,501</td><td rowspan="4">111200</td><td rowspan="4">Vegetable & Melon</td><td rowspan="4">$30,607,729</td><td rowspan="4">$26,307,753</td><td rowspan="4">$12,238</td><td rowspan="4">$10,519</td></tr>
<tr><td>121</td><td>VEG & TRUCK - VACANT</td><td>341</td></tr>
<tr><td>180</td><td>MIXED</td><td>944</td></tr>
<tr><td>181</td><td>MIXED - VACANT</td><td>30</td></tr>
<tr><td>130</td><td>Tree Fruits</td><td>30</td><td rowspan="3">4,942</td><td rowspan="3">111300</td><td rowspan="3">Fruit & Tree Nut</td><td rowspan="3">$77,302,963</td><td rowspan="3">$61,408,057</td><td rowspan="3">$15,641</td><td rowspan="3">$12,425</td></tr>
<tr><td>140</td><td>SMALL FRUITS</td><td>4,345</td></tr>
<tr><td>141</td><td>SMALL FRUITS-VACANT</td><td>567</td></tr>
<tr><td>110</td><td>GRAIN & FORGE</td><td>1,831</td><td rowspan="6">7,670</td><td rowspan="6">111100_112100</td><td rowspan="6">Oilseed, Grain, & Cattle</td><td rowspan="6">$132,182,811</td><td rowspan="6">$103,049,125</td><td rowspan="6">$17,233</td><td rowspan="6">$13,435</td></tr>
<tr><td>111</td><td>GRAIN & FORGE - VACANT</td><td>515</td></tr>
<tr><td>150</td><td>BEEF</td><td>1,022</td></tr>
<tr><td>151</td><td>BEEF - VACANT</td><td>19</td></tr>
<tr><td>160</td><td>DAIRY</td><td>3,469</td></tr>
<tr><td>161</td><td>DAIRY - VACANT</td><td>815</td></tr>
<tr><td>170</td><td>POULTRY</td><td>1,467</td><td>1,467</td><td>112300</td><td>Poultry & Egg</td><td>$417,560,410</td><td>$361,639,549</td><td>$284,718</td><td>$246,588</td></tr>
<tr><td>190</td><td>OTHER</td><td>3,742</td><td rowspan="2">4,856</td><td rowspan="2">112900_111400_ 111900_112200_ 112400</td><td rowspan="2">Greenhouse, Nursery, Floriculture, Hog & Pig, Sheep & Goat, Other Crop and Animal Production</td><td rowspan="2">$195,416,863</td><td rowspan="2">$168,859,494</td><td rowspan="2">$40,239</td><td rowspan="2">$34,770</td></tr>
<tr><td>191</td><td>OTHER - VACANT</td><td>1,115</td></tr>
</table>

Values of Farm Capital and Livestock

The market values for farm machinery, equipment, livestock, and poultry in the City of Abbotsford were obtained from Statistics Canada. The portion of market value for each item type relative to the total market value reported by Statistics Canada was determined. This distribution of market value into smaller categories was applied to the total farm capital for each NAICS code, excluding livestock, which was only assigned to NAICS codes that had livestock. It was assumed that each NAICS code has the same distribution of farm capital. As this section is focused on agricultural assessment, the evaluation of land and building damage due to flooding was not included.

Table 6: Distribution of Farm Capital.

City of Abbotsford Parcel Data			NAICS Assignments			Statistics Canada Data (2016) for Abbotsford	Unit Rates
Use Code	Use Code Description	Total Area (ha)	NAICS Code	NAICS Description	Total Area (ha)	Total Farm Capital [1.]	Unit Farm Capital Per Area ($/ha)
120	Veg & Truck	1,186	111200	Vegetable & Melon	2501	286,288,669	$114,471
121	Veg & Truck - Vacant	341					
180	Mixed	944					
181	Mixed - Vacant	30					
130	Tree Fruits	30	111300	Fruit & Tree Nut	4942	1,235,969,772	$ 250,076
140	Small Fruits	4,345					
141	Small Fruits-Vacant	567					
110	Grain & Forge	1,831	111100_112100	Oilseed, Grain, & Cattle	7670	1,314,501,363	$ 171,372
111	Grain & Forge - Vacant	515					
150	Beef	1,022					
151	Beef - Vacant	19					
160	Dairy	3,469					
161	Dairy - Vacant	815					
170	Poultry	1,467	112300	Poultry & Egg	1467	833,845,561	$ 568,566
190	Other	3,742	112900_111400_111900_112200_112400	Greenhouse, Nursery, Floriculture, Hog & Pig, Sheep & Goat, Other crop and animal production	4856	1,007,143,564	$ 207,383
191	Other - Vacant	1,115					

Note:
1. Including property value

Based on the breakdown of farm capital, as reported by Statistics Canada, the capital assets were divided into sub-categories, as follows.

Table 7: Breakdown of Farm Capital (Statics Canada, 2016 Census Data)

Farm capital	Market Value of Total Farm Capital	Proportion of Total Capital (Without livestock)	Proportion of Total Capital (With livestock)
Value of land and buildings, owned 10	$3,471,377,797	76.51%	74.39%
Value of land and buildings, rented or leased from others 11	$868,740,725	19.15%	18.62%
Tractors under 60 hp 12	$27,695,080	4.34%	4.22%
Tractors from 60 to 149 hp 12	$30,433,030		
Tractors over 149 hp 12	$18,907,968		
Pick-ups, cargo vans, cars and other passenger vehicles used in the farm business	$28,442,198		
Grain combines and swathers	$1,970,000		
Forage harvesters, balers, mower-conditioners, etc.	$13,254,450		
Tillage, cultivation, seeding and planting equipment	$10,238,650		
Irrigation equipment	$13,851,291		
All other farm machinery and equipment	$52,081,126		
Value of livestock and poultry	$129,767,481	0.00%	2.78%
TOTAL FARM CAPITAL	**$4,666,759,796**	**100.00%**	**100.00%**

The above percentages are then applied to the unit farm capital values ($/ha) developed for each NAICS code to determine the proportion of the capital assets that fall under equipment (i.e., farm capital excluding buildings, land and livestock) and livestock.

Table 8: Distribution of Farm Capital by NAICS Code.

NAICS Code	NAICS Description	Total Farm Capital ($/ha)	Farm Capital, Excluding Buildings, Land, Livestock ($/ha)	Capital of Livestock and Poultry ($/ha)
111200	Vegetable & Melon	$114,470.54	$4,967.22	$ -
111300	Fruit & Tree Nut	$250,076.38	$10,851.57	$ -
111100_112100	Oilseed, Grain, & Cattle	$171,371.96	$7,229.57	$4,765.30
112300	Poultry & Egg	$568,565.99	$23,985.75	$15,809.98
112900_111400_111900_112200_112400	Greenhouse, Nursery, Floriculture, Hog & Pig, Sheep & Goat, Other crop and animal production	$207,383.01	$8,748.74	$5,766.65

Replacement Value of Destroyed Trees

The replacement value of destroyed trees is assessed using the numbers reported in the "Cost of Producing Fresh and Processing Blueberries in the Fraser Valley of British Columbia" published by the Ministry of Agriculture, Government of BC (Spring 2016). Based on this, the cumulative operating margin for blueberry production at the 10-year mark (after planting) is $ -6,278.79/acre (-$2,536.31/ha). Taking into account the loss of full-scale production from the original established plants for the 10 years, ($1,329/acre/year times 11 years) is $14,619/acre ($5,906/ha). Therefore, the total financial cost for destroyed blueberry production is $20,898.80/acre ($8,443/ha).

Other Considerations

Other considerations/decisions that were made in the process include:

- Due to the inability to run time-series assessment for the flood, a duration of flooding cannot be obtained for this assessment. Therefore, all perennials are assumed to be flooded for a period of 24 hours.

Assumptions and Limitations

The following list key assumptions and limitations of this analysis:

- Based on conventional agricultural methods (i.e., no organic, regenerative method, etc.)
- The assessment is considered conservative and is generally the 'worst-cast' scenario, as the flooding is assumed to occur immediately prior to harvest/slaughter; however, in reality harvest/slaughter will occur throughout the year depending on the crop/animal type.

Submission

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Statement of Limitations

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Revision History

Revision #	Date	Status	Revision Description	Author
0	May 31, 2020	Final		YS/PKB

OQM CERTIFIED

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consulting engineers

Appendix F

Transportation and Business Economic Loss Analysis

Nooksack River Overflow Flood Mitigation Plan Task 2B: Flood Damage Assessment for Flood Scenarios Under Current Climate Conditions

Transportation Economic Impacts

Final Report February 14, 2020

Davies Transportation Consulting Inc.

Food Flows in Metro Vancouver

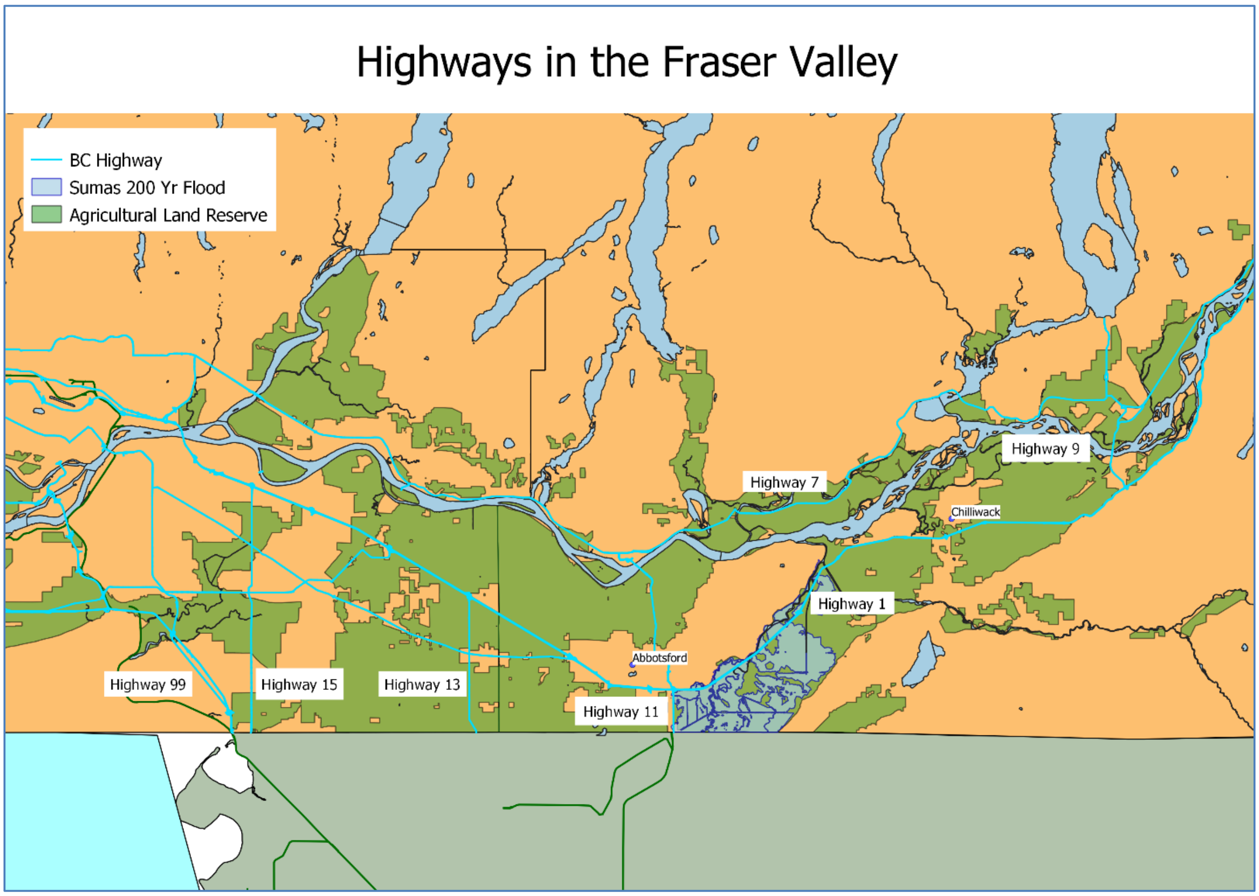
Table of Figures

1 Highway Economic Impacts

1.1 Highway Infrastructure in the Fraser Valley

Major highways in the Fraser Valley are depicted below. Those likely to be affected under the scenarios analysed include Highway 1 (the TransCanada Highway) between Abbotsford and Chilliwack and Highway 11 at the Sumas Border crossing.

Figure 1-1 Highways in the Fraser Valley



1.2 Impact of the 1990 Flood

A report on the 1990 flooding of West Sumas Prairie was prepared by Klohn Leonof Ltd. for BC Environment Water Management in 1991.[1] The 1990 flood took place from November 9 to November 12.

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[1] Flooding of West Sumas Prairie November 9-12 1990 Klohn Leonof Ltd. for BC Environment Water Management April 1991.

The 1990 flood resulted in flooding and closure of the TransCanada highway at Whatcom Road just east of Abbotsford for 26 hours. The Sumas Border crossing (Highway 11) was also closed due to flooding in Sumas.

Figure 1-2 TransCanada Highway Flooding November 11, 1990[2]

PHOTO 3 Trans Canada Highway from Whatcom Road Bridge, Looking West
1100 hrs. November 11, 1990

Figure 1-3 Sumas Flooding November 10, 1990[3]

PHOTO 5 Looking South Across Border Towards the City of Sumas
November 10, 1990

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[2] Klohn Leonoff p. 57.

[3] Klohn Leonoff p. 58.

1.3 Economic Impacts of Flood Scenarios – Highways

The five current climate conditions flood scenarios modelled include:

- Scenario 1: November 1990 flood (includes embankment breaching);
- Scenario 2A: 100-yr flood with Nooksack Overflow (includes embankment breaching as in 1990 flood);
- Scenario 2B: 100-yr flood with Nooksack Overflow assuming no embankment breaching.
- Scenario 2C: 100-yr flood without Nookscak Overflows assuming no embankment Breaching;
- Scenario 3: 200-yr flood with Nooksack overflow (includes embankment breaching as in 1990 flood).

The two embankments are the Southern Railway railroad embankment and the Whatcom/Highway 1 interchange.

Based on the hydraulic models the longest duration for flooding of the TransCanada Highway is 4.8 days in the vicinity of the Whatcom road interchange, approximately 4 km east of the Highway 1/Highway 11 interchange at Abbotsford.

1.3.1 TransCanada Highway

The economic impact of closure of the TransCanada Highway has been estimated using current parameters for highway user costs from the BC Ministry of Transportation and Infrastructure ShortBEN High Level Benefit Cost Tool[4] including value of travellers' time, fuel prices, and other operating costs. Fuel consumption data is based on fleet wide averages.[5] The values of these parameters used in the analysis are shown below.

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[4] https://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/transportation-planning/benefit-cost-analysis

[5] Average fuel consumption for cars is based on the value reported in Table RO4: Canadian Vehicle Use Study Light Vehicle Statistics, Annual Averages Per Vehicle, 2015 Transportation Statistical Addendum 2018 Transport Canada p. 101; truck fuel consumption is based on "The State of Fuel Economy in Trucking" https://www.geotab.com/truck-mpg-benchmark/

Figure 1-4 Cost Parameters Used for Estimating Traveller Impacts of Highway Closures

Cost Parameters for Highway Closure Economic Impact Analysis	
Costing Paramater	**Value**
Value of Time Auto Occupants $/hour	$19.13
Truck Driver Payroll Cost $/hr	$31.25
Fuel Price Auto $/litre	$1.01
Fuel Price Truck $/litre	$0.94
Other Car Costs $/km	$0.14
Truck Time $/hr	$14.65
Truck Distance $/km	$0.26
Avg Fuel Cons Cars (l/100km)	12.2
Avg Fuel Cons trucks (l/100km)	52.0

Annual Average Daily Traffic (AADT) on the TransCanada Highway between Chilliwack and Abbotsford has been estimated based on BC MOTI traffic count data. The closest data collection point is the Yale road interchange. Data is collected periodically at the site under MOTI's "Short Count" program, and the latest data available from this site is 2009. This site lies between two permanent count stations which constantly monitor traffic levels and vehicle classification: Lorenzetta (East of Chilliwack) and Bradner (west of Abbotsford). To estimate current (2018) traffic levels at Yale road, a growth rate of 2.1% per year (the average of the growth rates for Lorenzetta and Bradner) has been applied to the 2009 traffic count. Based on the Lorenzetta and Bradner vehicle classifications, it is estimated that trucks account for 15% of traffic at Yale Road.

Figure 1-5 Estimated Annual Average Daily Traffic Highway 1 Yale Road

Yale Road Estimated Annual Average Daily Traffic 2009 - 2018											
Count Site	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**AAGR**
Lorenzetta	16,858	17,584	14,817	17,016	17,503	17,902	18,875	19,597	19,595	20,488	2.2%
Bradner	68,074	69,489	69,294	68,989	70,538	72,547	75,951	79,262	78,449	81,645	2.0%
Yale Road	48,408	49,425	50,462	51,522	52,604	53,709	54,837	55,988	57,164	58,365	2.1%

It is assumed that traffic will detour around the closure via the Highway 9 bridge at Bridal Falls and Highway 7 to Mission before returning to Highway 1 via Highway 11 at Abbotsford. According to Google Maps, this would increase the travel time by 47 minutes (1 hour 14 minutes vs 27 minutes) and 38.5 km (83.7km vs 45.2 km).

The table below shows the estimated daily incremental costs to travellers of detouring around the flooded area of the TransCanada Highway between Abbotsford and Chilliwack.

Figure 1-6 Daily Incremental Traveller Costs of Highway 1 Detour

Daily Incremental Traveller Costs Due to Highway 1 Detour	
Average daily cars	49,610
Average daily trucks	8,755
Total Traffic	58,365
Auto Occupancy Persons	1.2
Additional Hours/vehicle	0.6
Additional km/Vehicle	38.5
Additional Fuel Cons per Car litres	4.7
Additional Fuel Cons per Truck litres	20.0
Additional hours cars	28,278
Additional km cars	1,909,978
Additional hours truck	4,990
Additional km truck	337,055
Additional Hours Cost Car	$627,423
Additional Hours Cost Truck	$229,049
Additional km Cost Car	$257,847
Additional km Cost Truck	$1,282
Additional Fuel Cost Car	$236,280
Additional Fuel Cost Truck	$165,103
Total Additional Cost Cars	$1,121,550
Total Additional Costs Trucks	$395,434
Grand Total	$1,516,984

Incremental traveller costs would total approximately $7.3 million for the maximum closure of 4.8 days.

This estimate does not take into account delays due to the impact of congestion resulting from the diversion of the full volume of Highway 1 traffic (a limited-access 4-lane divided highway) to Highway 11 (a 2-lane secondary highway). Under the assumption that travel time on the detour route would increase by 50% due to congestion (i.e. from 47 minutes to 70.5 minutes), the daily impact would increase to $2,503,874 and the total cost for a closure of 4.8 days would be approximately $12.0 million.

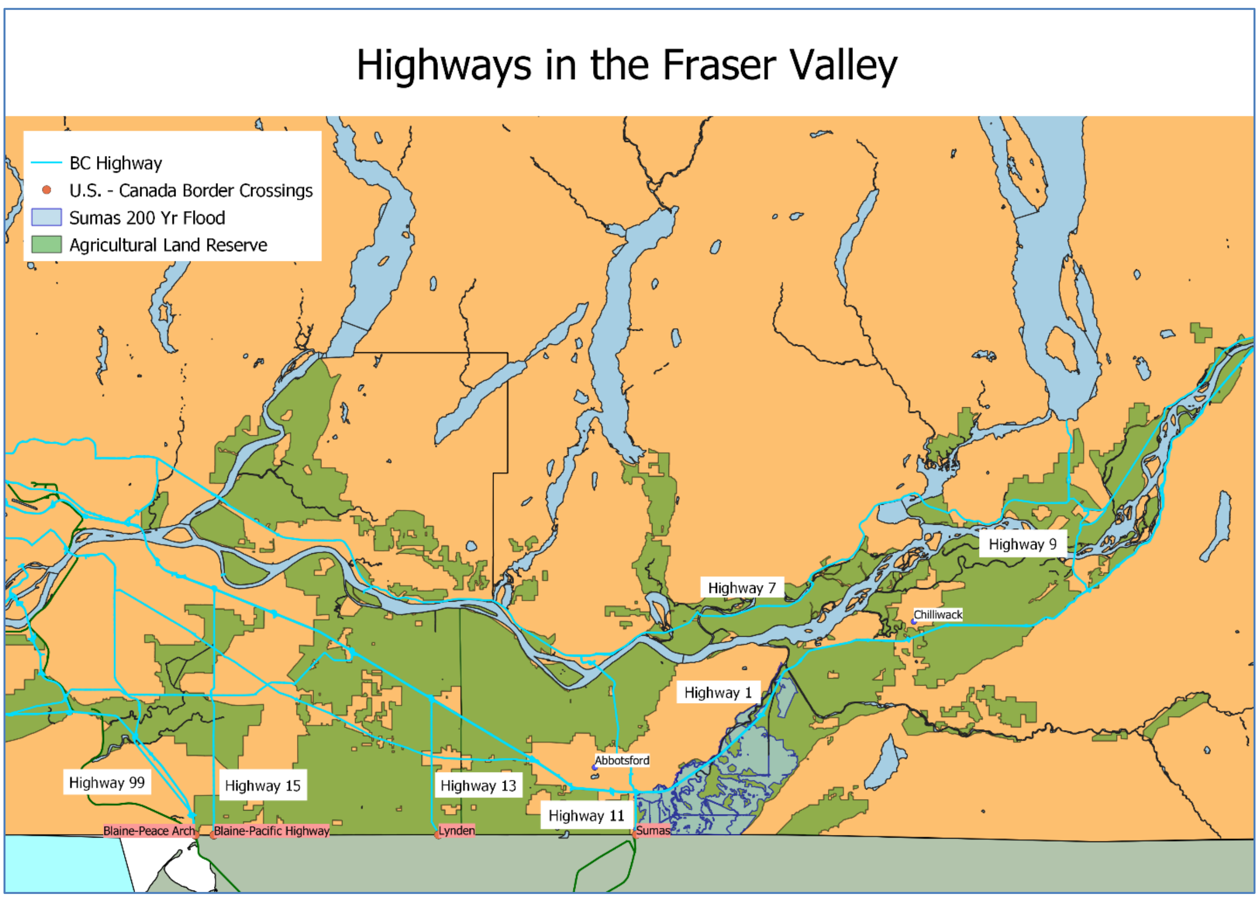
1.3.2 Highway 11 Sumas Border Crossing

Under all scenarios flooding and closure of the Sumas Border Crossing is likely. Average daily southbound car and truck traffic is shown below.[6]

Sumas Border Crossing Southbound Average Daily Traffic 2015 - 2018				
Measure Per Day	**2015**	**2016**	**2017**	**2018**
Personal Vehicle Passengers	4347	3975	3977	4446
Personal Vehicles	2519	2307	2299	2543
Trucks	420	434	437	428

Southbound traffic to the U.S. would have to divert to one of the other three Canada-U.S. Border Crossings: Aldergrove/Lynden, Pacific Highway, or Peace Arch.

Figure 1-7 Highways and Border Crossings in the Fraser Valley



[6] Source: U.S. Bureau of Transportation Statistics Border Crossing Data https://www.bts.gov/content/border-crossingentry-data

For purposes of estimating incremental travel costs, it is assumed the car traffic diverts to the closest border crossing – Aldergrove/ Linden. According to Google Maps this would result in additional travel time of 15 minutes per car (24 minutes vs 9 minutes assuming an origin of the Highway 1/Highway 11 interchange) and additional travel distance of 18.5 km (22.4 km vs 3.9 km).

Trucks are assumed to divert to the Pacific Highway border crossing, because full commercial Customs services are not available at Lynden. this would result in additional travel time of 35 minutes per car (44 minutes vs 9 minutes) additional travel distance of 37.5 km (41.4 km vs 3.9 km).

The table below shows the estimated daily incremental costs to travellers of diverting to alternative border crossings due to flooding of the Sumas border crossing.

Figure 1-8 Daily Incremental SB Traveller Costs Due to Sumas Border Closure

Daily Incremental SB Traveller Costs Due to Sumas Border Crossing Closure	
Average daily cars	2,543
Average daily trucks	428
Total Traffic	2,971
Auto Occupancy Persons	1.7
Additional Hours/car	0.3
Additional Hours/truck	0.6
Additional km/car	18.5
Additional km/truck	37.5
Additional Fuel Cons per Car litres	2.3
Additional Fuel Cons per Truck litres	9.6
Additional hours cars	636
Additional km cars	47,054
Additional hours truck	248
Additional km truck	16,036
Additional Hours Cost Car	$19,771
Additional Hours Cost Truck	$11,384
Additional km Cost Car	$6,352
Additional km Cost Truck	$64
Additional Fuel Cost Car	$5,821
Additional Fuel Cost Truck	$3,875
Total Additional Cost Cars	$31,944
Total Additional Costs Trucks	$15,323
Grand Total	$47,267

2 Railway Economic Impacts

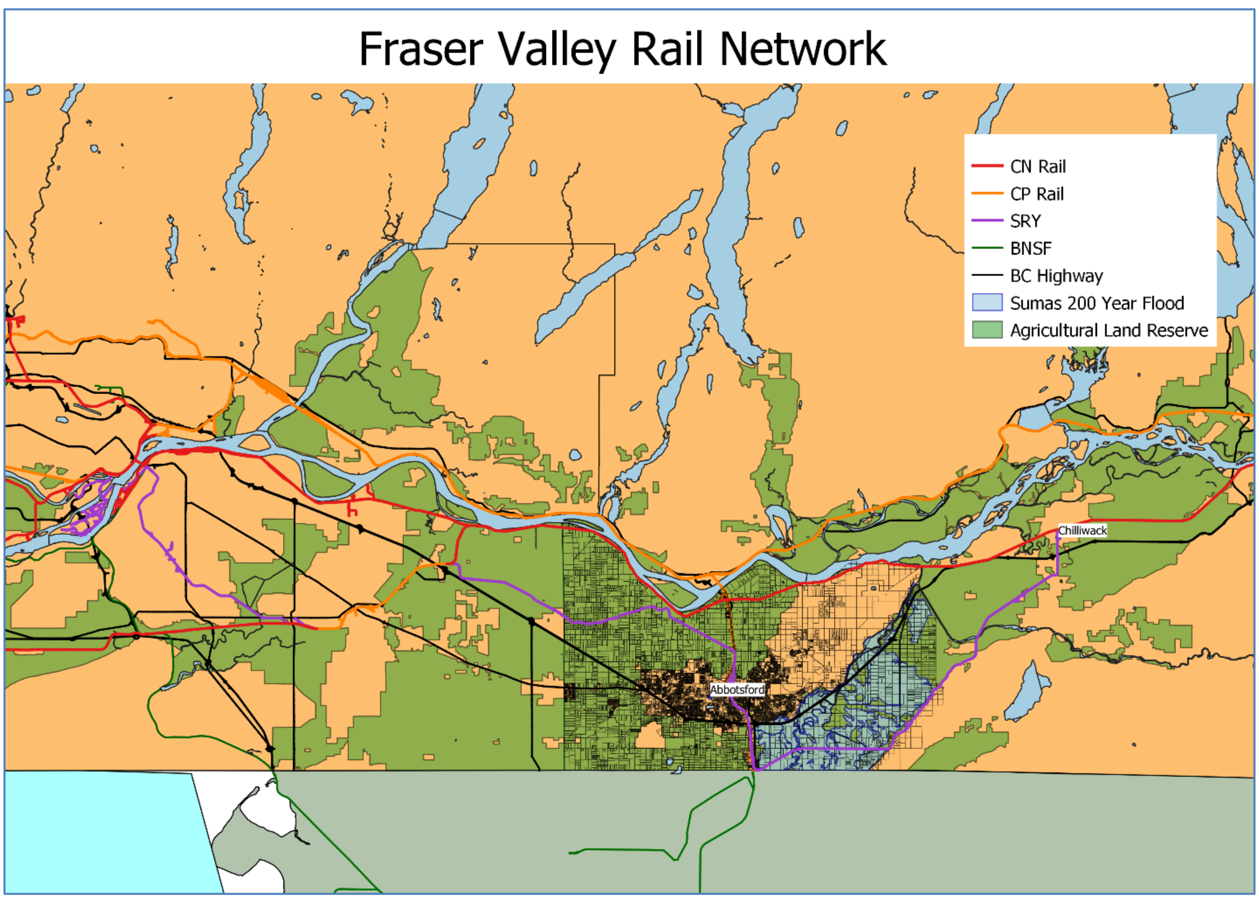
2.1 Fraser Valley Rail Infrastructure

Rail infrastructure in the Fraser Valley includes the Class 1 railways (Canadian Pacific and Canadian National) mainlines connecting Metro Vancouver to the rest of Canada via the Fraser Canyon; and Southern Railway of BC (SRY) lines serving local customers. The Burlington Northern Santa Fe (BNSF) railway connects to SRY at the Sumas border crossing.

2.1.1 Class 1 Railways

The Canadian Pacific (CP) Mainline north of the Fraser River line to Port Moody was completed in 1885. Construction of the Canadian National (CN) mainline south of the Fraser River was undertaken by the Canadian Northern Railway starting in 1910. In 1911, work was started on a new townsite named Port Mann on the Fraser River that would accommodate the new car shops and from where lines would extend to Vancouver and to the delta of the Fraser River.

Figure 2-1 Fraser Valley Rail Network



CN and CP implemented a co-production agreement for directional running in the Fraser Canyon between Boston Bar/North Bend and Matsqui in 1999. Under the agreement all CNR and CPR westbound trains use the CNR mainline tracks on the south side of the Fraser river, and all eastbound CNR and CPR trains use the CPR mainline tracks. This significantly increases line capacity by increasing the total number of trains that can be operated through the Fraser Canyon sections of each rail line.

Neither of the Class 1 railways' operations was affected by the 1990 flood. The CP line is on the other side of the Fraser River; the CN line crosses the Sumas River where it joins the Fraser River but there is no record of any issues related to flooding of the Sumas River.

2.1.2 Southern Railway of BC (SRY)

SRY's line between Chilliwack and Abbotsford (Sumas) is most vulnerable to disruptions due to flooding of the Sumas River.

SRY was originally part of the BC Electric Railway (BCER), which was incorporated in 1897 to unite the separate interurban and street railway systems in Vancouver, Victoria and New Westminster. The BCER operated the largest system of interurban railways in Canada, shuttling passengers and express trains in the Lower Mainland for 40 years. Since 1950 the line has been a shortline freight railway.

The BCER was taken over by the provincial government in 1961, as the Rail Division of British Columbia Hydro and Power Authority. BC Hydro Railway, as it was called, continued to operate the railway until 1988, when the operation was sold to Itel Rail Corp. At that time, the railway was renamed the Southern Railway of British Columbia (SRY). Ownership of the right-of-way and air rights on all BC Hydro Railway tracks was retained by the Province. In 1994, SRY became a part of the Rail Link System of the Washington Companies. The Pratt-Livingstone trackage was sold by SRY to CPR in 1998, but SRY retained the exclusive right to serve rail customers adjacent to the track.

SRY is a short line railway which serves local customers by interchanging cars with the Class 1 railways (CN, CP and BNSF) for long haul transport. SRY interchanges cars with CN Rail at Chilliwack and New Westminster; with CP Rail at Abbotsford; and with BNSF at the Sumas border crossing.

2.2 Impact of the 1990 Flood on SRY

The Nooksack River overflowed at Emerson on the afternoon of November 9 and the flood reached the Canada-U.S. border (Boundary Line Road) at 6:50 on the Morning of November 10. The flow over Boundary Line road was collected by a number of ditches and was conveyed by culverts to a low point in the embankment of the SRY track. The culverts had inadequate capacity to convey the flow and the water ponded behind the embankment which eventually overtopped and washed out at about 13:00 hours on November 10. There were two washed-out sections, one about 90 m wide and one about 60 m wide.[7] SRY Made an insurance claim of $110,600 for damage to the embankment and track following the 1990 flood.

The photo below shows the breaches in the railway embankment looking south from Vye Road.

Figure 2-2 Breaches in SRY Embankment November 1990[8]

PHOTO 6 Looking South Across Vye Road Towards Breaches in Railway Embankment - November 10, 1990

The flooding also caused closure of the Abbotsford-Sumas border crossing.

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[7] Klohn Leonof p.7.

[8] Klohn Leonoff p. 58.

2.3 Economic Impacts of Flood Scenarios – SRY

For the current study, duration of flooding of the SRY track has been estimated from the hydraulic models:

- Scenario 2A: 100-yr w/ Nooksack Overflow and Breach of railway = 3.3 days (at the breach west of Kenny Road).
- Scenario 2B: 100-yr w/ Nooksack Overflow - No Breach of railway= 1.4 days (at Kenny Road). Under this scenario the embankment is not breached but the water overtops the track.
- Scenario 2C: 100-yr w/o Nooksack Overflow = 0 days.
- Scenario 3: 200-yr w/ Nooksack and Breach of railway = 4.9 days (at the breach west of Kenny Road).

Breach values represent the duration of flow through the breach, not overtopping of the crest of the railway embankment.

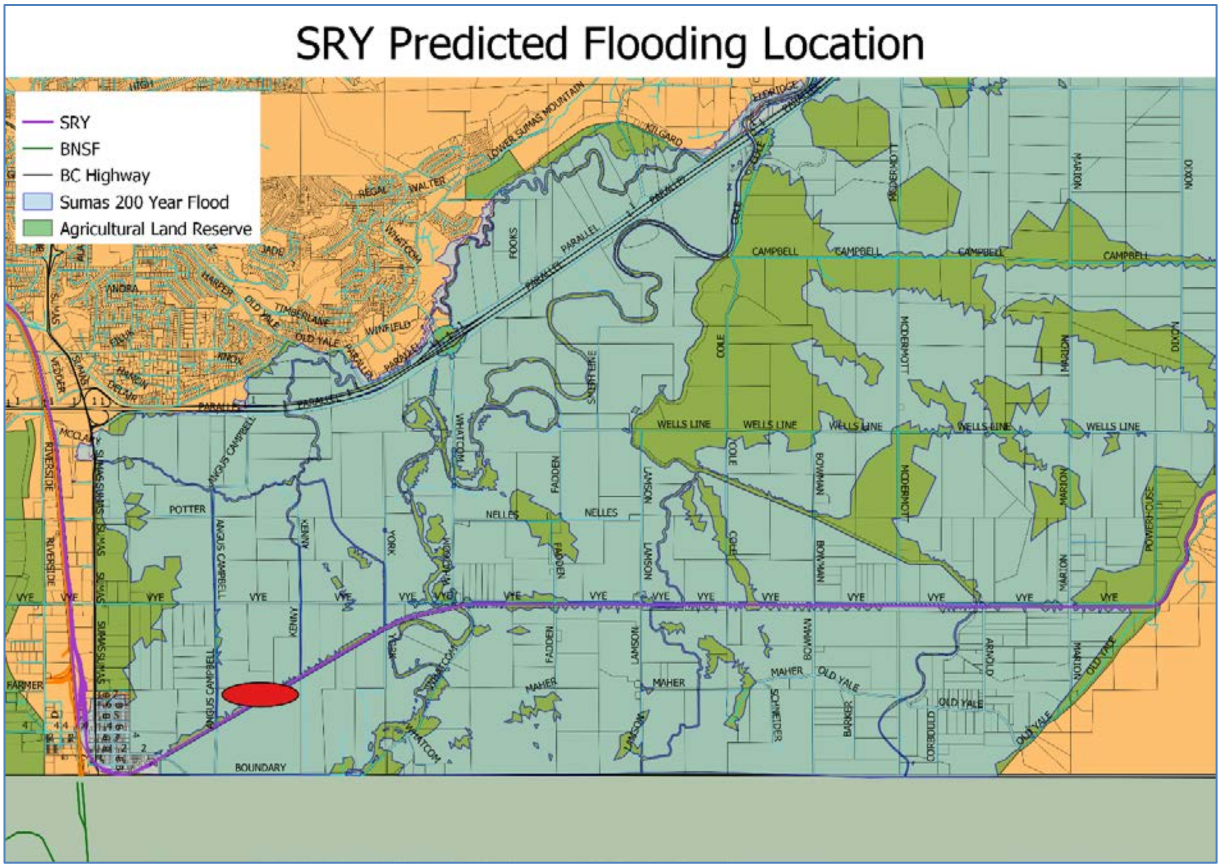
According to SRY, traffic would be disrupted by additional delays until the track could be inspected and repaired. For Scenario 2A resumption of rail operations would be delayed approximately five to six days based on a 60m breach. For Scenarios 2B and 2C, the flooding would be monitored and no traffic would be delayed until the water receded below the rails and the track and embankment could be inspected. Scenario 3 would require six to seven days to repair based on a 90m breach.

Based on present cost of Riprap, Track material and labor the cost of repairing damage similar to the 1990 flood would be approximately $290,000 compared to the 1990 cost of $110,000.

2.3.1 SRY Abbotsford-Chilliwack Line

The predicted approximate flooding location of SRY track is shown below.

Figure 2-3 SRY Predicted Flooding Location



SRY confirms the location identified in the modelling is the most vulnerable location, and the area did see high water levels as a result of recent flooding south of the border (February 2020). The Sumas River to the east by Whatcom Road could also flood its banks as it overflowed in some locations during the recent flooding.

Current traffic on the SRY line between Abbotsford and Chilliwack is approximately 15,000 carloads per year. SRY runs 5 trains per week in each direction on the line, for an average train length of 29 cars. All traffic likely to be affected by a flooding event is through traffic i.e. there are no SRY customers in the flood zone. The primary traffic on the line consists of forest products, feed grains and asphalt.

Normally railcars are interchanged with CN at Chilliwack. In the event of closure of the Abbotsford-Chilliwack line, cars could be diverted and interchanged in New Westminster and transferred to destination from the west rather than the east. Additional costs for this would be minimal. Customers in the Chilliwack area would be unaffected.

2.3.2 Sumas Border Crossing Rail Impact

Under all scenarios flooding and closure of the Sumas Border Crossing is likely. SRY interchanges railcars with BNSF at the Sumas Border crossing. Average southbound crossborder rail traffic at the Sumas border crossing is shown below. [9]

Figure 2-4 Sumas Border Crossing Southbound Average Daily Traffic 2015 – 2018

Sumas Border Crossing Southbound Average Daily Traffic 2015 - 2018				
Rail Traffic	**2015**	**2016**	**2017**	**2018**
Rail Containers Empty	7	7	7	10
Rail Containers Full	2	3	3	3
Trains	0.4	0.5	0.5	0.5

Based on this data, train frequency is approximately one train every two days with an average of 26 railcars per train. Traffic consists primarily of forest products and asphalt southbound and feed corn northbound.

Railcars which are enroute when the border crossing is closed would have to be stored on sidings or rail yards until the crossing reopens; for cargo which has not been loaded, a delay in loading at the origin may occur. A portion of the southbound traffic at Sumas consists of forest products transloaded from truck to rail just north of the border, and these shipments can easily be timed to access the border when the flooding clears.

It is not uncommon for railcars to be delayed in transit for operational reasons; for example, the Class 1 railways will often hold railcars in a yard until they have accumulated the minimum traffic for an efficient train size. Direct costs to both shippers and railways due to delays at the Sumas border crossing would be minimal.

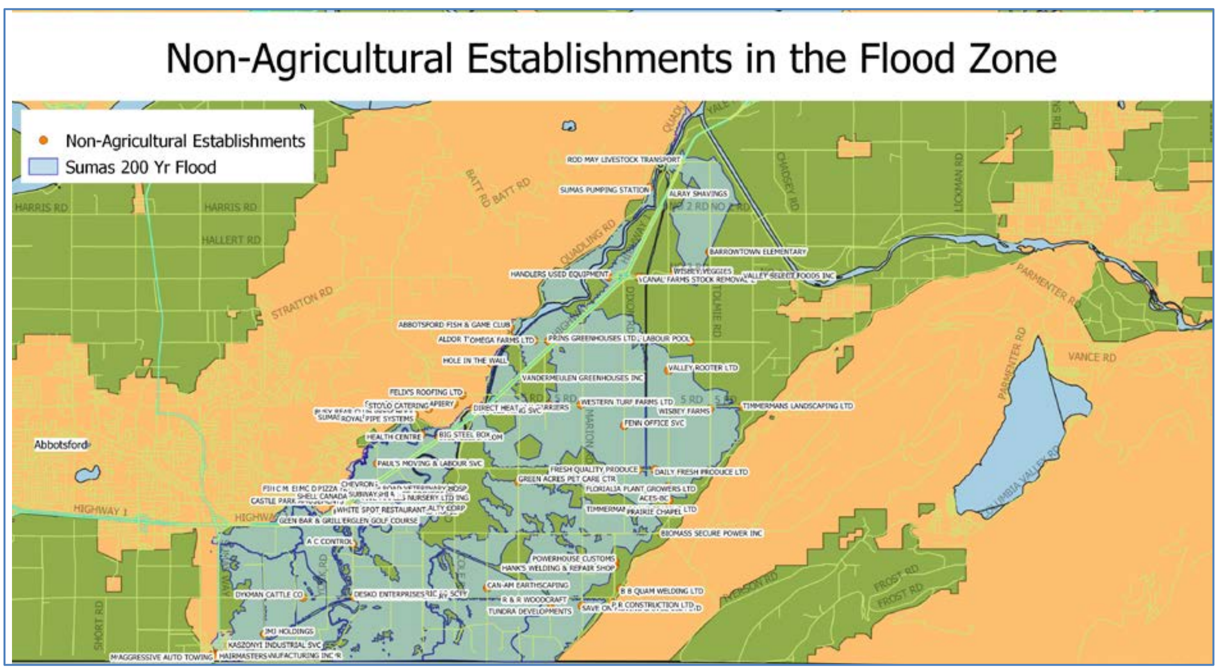
[9] Source: U.S. Bureau of Transportation Statistics Border Crossing Data
https://www.bts.gov/content/border-crossingentry-data

3 Non-Agricultural Business Losses

Potential agricultural losses are analyzed in a previous section of the report. However, there are non-agricultural businesses within or close to the flood zone which would be affected and may experience financial losses. These losses may be categorized as business interruption losses: "The term business interruption usually describes the disruption of typical operations as a result of a definable event that is beyond the entity's control. In legal contracts and insurance policies, business interruption means the financial impact of such a disruption over a period of time."[10] Note that while these impacts may cause serious hardship for affected businesses, they may not result in any significant economic impact at the regional level as goods and services are likely to continue to be produced and consumed elsewhere in the region.

Locations of non-agricultural establishments in the flood zone are depicted below, based on the 2016 Pitney Bowes Business Points database for BC .

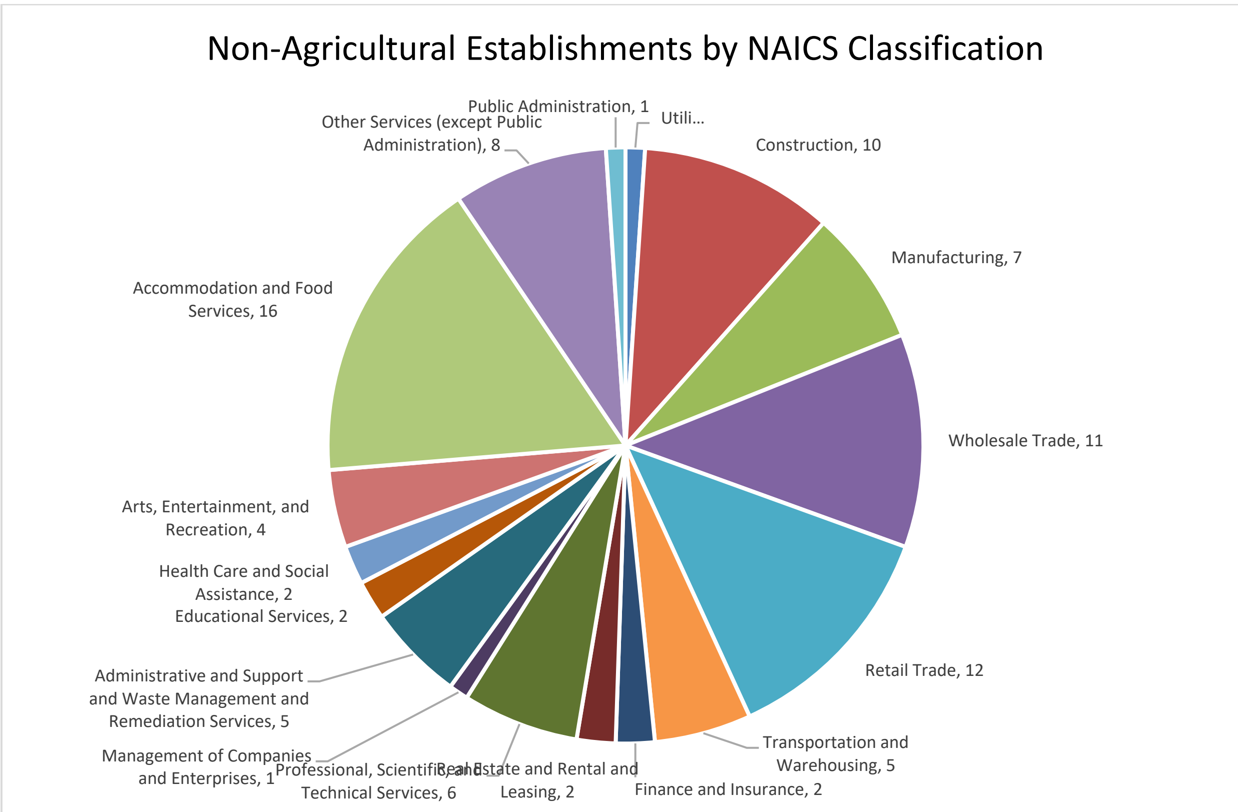
Figure 3-1 Non-Agricultural Establishments in the Flood Zone



[10] A Formula for Determining Business Interruption Loss https://www.irmi.com/articles/expert-commentary/the-essential-equation-a-formula-for-determining-business-interruption-loss

Based on 2016 data, there are 95 non-agricultural establishments in the flood region. The figure below shows the classification of these by 2-digit North American Industrial Classification System (NAICS) codes.

Figure 3-2 Non-Agricultural Establishments by NAICS Classification



These establishments can be further classified based on the type of operation (commercial or non-commercial) and vulnerability of operations to interruption due to flooding. The enterprises have been classified based on analysis of individual businesses as shown below. Points to note include:

- The single establishment in the Utilities category does not have operating facilities in the area.
- Construction firms are excluded due to the nature of the work i.e. work will be carried out at a job site rather than at the registered location and these sites are likely to be outside the flood region.

Figure 3-3 Non-Agricultural Establishments Classification for Business Interruption Analysis

Non-Agricultural Enterprises Classification for Business Interruption Analysis					
NAICS 2 Digit	Description	Total	Commercial	Vulnerability	Included
22	Utilities	1	Yes	No	No
23	Construction	10	Yes	No	No
32-33	Manufacturing	7	Yes	Yes	Yes
42	Wholesale Trade	11	Yes	Yes	Yes
44	Retail Trade	12	Yes	Yes	Yes
48	Transportation and Warehousing	5	Yes	Yes	Yes
52	Finance and Insurance	2	Yes	No	No
53	Real Estate and Rental and Leasing	2	Yes	No	No
54	Professional, Scientific, and Technical Services	6	Yes	Yes	Yes
55	Management of Companies and Enterprises	1	Yes	No	No
56	Admin. & Support & Waste Mgmt Services	5	Yes	Yes	Yes
61	Educational Services	2	No	Yes	Yes
62	Health Care and Social Assistance	2	No	Yes	Yes
71	Arts, Entertainment, and Recreation	4	Yes	Yes	Yes
72	Accommodation and Food Services	16	Yes	Yes	Yes
81	Other Services (except Public Administration)	8	No	Yes	Yes
92	Public Administration	1	No	No	No
	Total	95			78

Establishments were further classified based on specific activities. Wholesale and retail firms selling agricultural produce were excluded to avoid double counting with agricultural losses.

Base Case Scenario

Estimates of business impacts for the Base Case scenario were developed from Business Points data by identifying firms located within the flood zone for the 200-year flood event. The resulting list of firms identified as vulnerable to business losses included 43 firms. The Business Points data reports firm revenue by range; for estimation purposes, it was assumed that each firm's revenue equals the midpoint of the range. On this basis, estimated total revenue for the selected firms is $120.0 million per year and average daily revenue is estimated at $ $328,630. The cost of a 10- day disruption due to flooding would be approximately $3.7 million.

Scenario M1-1 Mitigation #1: Marshall Creek Sump Floodway with Sumas Mountain Tunnel - 100-year flood

Estimates of the business impacts under this scenario are identical to the Base Case.

Scenario M1-2 Mitigation #1: Marshall Creek Sump Floodway with Sumas Mountain Tunnel - 200-year flood under climate change conditions

Estimates of the business impacts under this scenario are identical to the Base Case.

Scenario M2-1 Mitigation #2: dike raise and floodproofing - 100-year flood

Under this scenario, the number of businesses affected was reduced from 43 in the Base Case to 35. Annual revenue of the affected businesses is estimated at $108.3 million, and daily revenue is estimated at $296,575. The cost of a 10- day disruption due to flooding would be approximately $3.0 million.

Scenario M2-2 Mitigation #2: dike raise and floodproofing - 200-year flood under climate change conditions

Estimates of the business impacts under this scenario are identical to Scenario M2-1. Annual revenue of the affected businesses is estimated at $108.3 million, and daily revenue is estimated at $296,575. The cost of a 10- day disruption due to flooding would be approximately $3.0 million.

Scenario M3-1 Mitigation #3: eliminate Nooksack overflow - 100-year flood

Under this scenario, the number of businesses affected was reduced from 43 in the Base Case to 36. Annual revenue of the affected businesses is estimated at $108.5 million, and daily revenue is estimated at $ $297,260. The cost of a 10- day disruption due to flooding would be approximately $3.0 million.

Scenario M3-2 Mitigation #3: eliminate Nooksack overflow - 200-year flood under climate change conditions

Under this scenario, the number of businesses affected was reduced from 43 in the Base Case to 38. Annual revenue of the affected businesses is estimated at $110.5 million, and daily revenue is estimated at $ $302,603. The cost of a 10- day disruption due to flooding would be approximately $3.0 million.

Scenario 3 (200-year under existing climate conditions) – with Sumas dike breach

Under this scenario, the number of businesses affected was increased from 43 in the Base Case to 44. Annual revenue of the affected businesses is estimated at $127.4 million, and daily revenue is estimated at $ $349,178. The cost of a 10- day disruption due to flooding would be approximately $3.5 million.

Scenario CC-3 (200-year under climate change conditions) – with Sumas dike breach

Estimates of the business impacts under this scenario are identical to Scenario 3. The number of businesses affected increases from 43 in the Base Case to 44. Annual revenue of the affected businesses is estimated at $127.4 million, and daily revenue is estimated at $ $349,178. The cost of a 10- day disruption due to flooding would be approximately $3.5 million.

A summary of estimated Business Impacts for the scenarios modelled is shown below.

Figure 3-4 Business Impact Summary – All Scenarios

Estimated Business Impacts - Nooksack River Flooding Scenarios									
Measure	**Rev Base Case**	**Scenario M1-1**	**Scenario M1-2**	**Scenario M2-1**	**Scenario M2-2**	**Scenario M3-1**	**Scenario M3-2**	**Scenario 3**	**Scenario CC-3**
Businesses Affected	43	43	43	35	35	36	38	44	44
Annual Revenue $ Millions	$120.0	$120.0	$120.0	$108.3	$108.3	$108.5	$110.5	$127.5	$127.5
Daily Revenue (Impact)	$328,630	$328,630	$328,630	$296,575	$296,575	$297,260	$302,603	$349,178	$349,178

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Appendix G

Summary Table of Flood Mitigation Options

Table G-1: Summary of Flood Mitigation Options

Option	Benefits	Drawbacks	Include Option for Flood Mitigation and Damage Assessment?
Option 1 – Increasing the Capacity at Barrowtown Dam			
Option 1A: Increase Floodbox Capacity	• Increases flows through Barrowtown Dam, reducing Saar-Arnold flooding	• Provides reduced benefit when Vedder and Fraser levels are high • Minimal impact on Sumas water levels • Only relieves Saar-Arnold flooding	No – not as a stand-alone option. Has minimal impact and provides no relief when Vedder and Fraser levels are high. Could be used to greater benefit in combination with downstream channel modifications (Option 2).
Option 1B: Increase Pump Station Capacity	• Increases flows through Barrowtown Dam, reducing Saar-Arnold flooding • Can operate when Vedder and Fraser levels are high	• Would require significant pump upgrades • Only relieves Saar-Arnold flooding • Requires ongoing operation and maintenance for intermittent to rare use	No – would require impractical pump capacity for 200-year climate change flows. Based on initial modelling, it was estimated that a 250 m^3/s pump capacity would be needed to prevent breaching of the Sumas Dike during the 200-year climate change flood. Lower pump rates would have minimal impact on damages during this flood event.
Option 2 – River Modifications Downstream of Barrowtown Dam			
Option 2A: Channel Improvements to Sumas River	• Reduces water levels at Barrowtown Dam, reducing Saar-Arnold flooding	• Requires significant dredging that would need to be maintained. • Provides reduced benefit when Fraser River levels are high. • Requires acquiring and modifying DND lands. • Poses ongoing fish habitat disturbances • Only relieves Saar-Arnold flooding	No – maintaining an invert of -1.0 m would be impractical.
Option 2B(a): Dedicated Sumas River Channel Along Left Bank	• Reduces water levels at Barrowtown Dam, reducing Saar-Arnold flooding	• Requires relocation of Sumas Cemetery IR 12 (Leq'á:mel First Nation) • Requires a new railway bridge and a 2 km displacement of railway tracks • Only relieves Saar-Arnold flooding	No – unacceptable impact to Sumas Cemetery IR 12.
Option 2B(b): Relocate Vedder River through DND Lands	• Reduces water levels at Barrowtown Dam, reducing Saar-Arnold flooding	• Requires additional armouring of Chilliwack dikes • Requires acquiring and modifying a large area of DND lands. • Would require a new railway bridge • Poses fish habitat disturbances • Only relieves Saar-Arnold flooding	No – less desirable river separation option because of high impacts to lands, existing flood protection and fish habitat.
Option 2B(c): Dedicated Sumas River Channel Along Right Bank	• Reduces water levels at Barrowtown Dam, reducing Saar-Arnold flooding	• Challenges associated with construction and maintenance of inverted siphon • Requires acquiring and modifying DND lands. • Requires a new railway bridge • Only relieves Saar-Arnold flooding	No – poses more drawbacks than tunnel option.
Option 2B(d): Tunnel Sumas River through Sumas Mountain	• Reduces water levels at Barrowtown Dam, reducing Saar-Arnold flooding • Does not require channel modifications along the Sumas and Vedder downstream of Barrowtown Dam	• Expected to be more expensive than other river separation options. • May require new railway bridge • Only relieves Saar-Arnold flooding • Requires minimal maintenance and operation once constructed	**Yes – in combination with upstream measures** – while costly, this is the most desirable and practical option for relieving flow restrictions at Barrowtown Dam.

Table G-1: Summary of Flood Mitigation Options

Option	Benefits	Drawbacks	Include Option for Flood Mitigation and Damage Assessment?
Option 3 – Floodway Alternatives			
Option 3A: Sumas River (right bank) Floodway	• Reduces Marshall flooding	• Requires multiple new low-head bridges or fords for road crossings • Requires new viaduct for railway • Requires border dike and channel improvements in US to Johnson Creek and Sumas River • Requires new dike and floodbox for Arnold Slough • Increases Saar-Arnold flooding	No – this floodway option requires significant efforts by the US to redirect all flows to the right bank of the Sumas River. The floodway would also need to be much larger than originally anticipated in previous studies to accommodate peak 200-year plus climate change flows.
Option 3B: Marshall Creek Sump (left bank) Floodway	• Reduces Marshall flooding • Does not require a border dike or channel improvements in the US	• Requires a new ford for the Whatcom Road crossing • Does not prevent flood damages along overflow path from border • Increases Saar-Arnold flooding	**Yes – in combination with downstream measures** – this floodway option has the smallest footprint and does not require a border dike or channel improvements in the US, although it only provides partial conveyance of flood flows.
Option 4 – Improvements to Interceptor Dike and Sumas River Dike			
Option 4A: Construct Relief Spillways	• Prevents breaching of dikes • Allows for overtopping to be controlled	• Does not reduce overall flooding	No – not applicable for reducing overall flooding.
Option 4B: Raise Interceptor Dike and Sumas River Dike	• Prevents overtopping to Old Sumas Lake Bottom	• Increases flooding outside of Old Sumas Lake Bottom	**Yes – in combination with other measures outside of the Old Sumas Lake Bottom.**
Option 5 – Improvements to Railway Embankment			
Option 5A: Reinforce Railway Embankment	• Prevents breaching and slightly relieves Marshall flooding	• Flood relief benefits for Marshall sump are minimal • Slightly increases Saar-Arnold flooding	No – impacts on flooding and damages are expected to be minimal
Option 5B: Raise Railway Embankment	• Prevents overtopping to Marshall sump • Benefits operation of the railway during flood events	• Sumas River does not have capacity to convey the additional flows • Increases Saar-Arnold flooding	No – this option does not significantly reduce flood damages
Option 6 – Floodproofing			
Option 6: Floodproofing	• Protects all structures	• Does not protect agricultural land	**Yes – either as a standalone option or in combination with other measures that do not provide full protection of structures.**
Option 7 – Measures in Washington State			
Option 7A: Block Overflow at Everson	• Provide largest flood reduction benefit for Sumas Prairie	• May not be accepted by US agencies since overflow is naturally occurring • Increases flooding along Nooksack River downstream of Everson.	**Yes – this is expected to be the most effective option for preventing impacts from the overflow flood** - this option has benefits both for Washington and BC, though this project will only evaluate the benefits North of the border.
Option 7B: Restore Gravel Mining	• Reduces potential for overflow	• Requires ongoing work in US	No – unknown whether US would continue this operation.
Option 7C: Johnson Creek Channel Improvements and Dike	• Redirect location of overflows from US	• Does not reduce overall flows	No – only beneficial to Sumas Prairie if part of larger floodway option.

Table G-1: Summary of Flood Mitigation Options

Option	Benefits	Drawbacks	Include Option for Flood Mitigation and Damage Assessment?
Option 7D: Flood Warning Systems	• Helps plan for evacuation, emergency services and preventative shutdowns where needed	• Does not reduce flooding	No – does not reduce flood damages but provides other benefits such as reduced risk to life.
Option 8 – Flood Mitigation Options Not Previously Studied			
Option 8A: Sumas River Corridor Floodway	• Protects Huntingdon, Marshall and Saar-Arnold areas • Avoids or eliminates border dike and channel improvements in US • Backwater effects at Barrowtown Dam have less impact on Saar-Arnold levels	• Increases water levels within floodway and along Sumas River dike • Requires multiple new low-head bridges or fords for road crossings. • Requires new viaduct for railway • Requires floodboxes and pumps for Marshall Creek and Saar Creek • Full containment of overflows requires tying the right bank of the floodway into high ground on the US side	No – this floodway option incorporates significant complexity from multiple elements and thus has very high construction and coordination costs to implement. This option was not developed and reviewed by the Nooksack River International Task Force prior to this project.
Option 8B: Local Huntingdon Area Dike	• Protects Huntingdon area • Very high structure damage reduction for cost • Dike height would be minimal • Unlikely to increase water levels outside of dike	• Only protects Huntingdon	**Yes – in combination with other measures to provide additional flood protection**. This dike protection would be in lieu of floodproofing, as floodproofing individual structures at this density would not be practical.
Option 8C: Local Arnold Area Dike	• Protects Arnold area • High structure damage reduction for cost	• Only protects Arnold • May have some impact on water levels outside of dike	**Yes – in combination with other measures to provide additional flood protection.** This dike protection would be in lieu of floodproofing, as floodproofing individual structures at this density would not be practical.

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Appendix H

Class D Cost Estimates for Flood Mitigation Options

Flood Mitigation Option #1 - Marshall Creek Sump Floodway with Sumas Mountain Tunnel
Class 'D'

Item	Description	Unit	Estimated Quantity	Unit Rate	TOTAL PRICE $	Comment
1	**General**					
1.01	Mobilization and Demobilization	L.S.	1	18,424,000	18,424,000	Assumed 5% of total cost.
			SUBTOTAL FOR ITEM 1		**18,424,000**	
2	**Marshall Creek Sump Floodway**					
2.01	Floodway Excavation	m^3	200,000	25	5,000,000	Assumed 2 m deep excavation of 2 km long and 50 m wide floodway. Geotechnical conditions are unknown.
2.02	Material Disposal for Reuse Onsite	m^3	200,000	10	2,000,000	Assumed all excavated material will be reused nearby. Assumed no contaminated material or archaeological sites.
2.03	Allowance for New Bridge at Roscoe Road Above Floodway	L.S.	1	3,000,000	3,000,000	Assumed 50 m span and 11 m width. Bridge cost based on similar bridge construction costs in BC.
2.04	New Whatcom Road Ford	L.S.	1	323,000	323,000	Assumed 2 m deep excavation for 50 m length and 100 m approaches on both ends, including road replacement.
2.05	Watermain Replacement	m	200	500	100,000	Watermain replacement assumed for along the full length of the new Whatcom Road ford.
2.06	Allowance for Resurfacing/Landscaping of Fraserglen Golf Course	L.S.	1	1,000,000	1,000,000	Resurfacing and landscaping costs for the golf course cannot be accurately estimated at this time.
			SUBTOTAL FOR ITEM 2		**11,423,000**	
3	**Tunnel Through Sumas Mountain**					
3.01	Tunnel Boring Machine (6.8 m diameter)	L.S.	1	70,000,000	70,000,000	Cost based on other tunnel boring machines purchased in Canada/USA.
3.02	Tunnel Boring	m	3000	90,000	270,000,000	Assumed mix of soft and hard material. Geotechnical conditions are unknown.
3.03	Concrete Lining	m^3	6410	2,500	16,025,000	Assumed 100 mm thick concrete lining using slipform construction.
3.04	Concrete Weir to Block Low Flows from Entering Tunnel	m^3	10	2,500	25,000	Assumed 16 m long weir surrounding entrance to tunnel.
3.05	Outlet Works Allowance	L.S.	1	1,000,000	1,000,000	Includes installation of gate to prevent Fraser River backflows and temporary cofferdam.
			SUBTOTAL FOR ITEM 3		**357,050,000**	
	CONSTRUCTION COST SUBTOTAL				**386,897,000**	
	Engineering & Construction Management	20%			77,379,400	
	Contingencies	30%			116,069,100	
	TOTAL AMOUNT (excl. GST)				**580,346,000**	

Note: Estimates have been prepared with little or no site information and as such indicates the approximate magnitude of the cost of the capital tasks, for project planning purposes only. The estimate has been derived from unit costs for similar projects.

CITY OF ABBOTSFORD
Nooksack River Overflow Flood Mitigation Plan
Class D Cost Estimate
November 30, 2020

Flood Mitigation Option #2 - Dike Raise and Floodproofing

Class 'D'

Item	Description	Unit	Estimated Quantity	Unit Rate	TOTAL PRICE $	Comment
1	**General**					
1.01	Mobilization and Demobilization	L.S.	1	10,762,000	10,762,000	Assumed 5% of total cost.
				SUBTOTAL FOR ITEM 1	**10,762,000**	
2	**Raise Sumas River Dike & Interceptor Dike**					
2.01	Dike Raise (2.5 m height)	m	13,080	3,750	49,050,000	Includes dike fill, grubbing, clearing, stripping, crest surfacing, topsoil and seeding with 4 m crest width.
2.02	Dike Raise (2.5 m height) - Narrow Space Constraints	m	3,670	4,200	15,414,000	Dike segments with narrow space constraints assumed to have a higher unit cost.
2.03	Utilities	L.S.	1	390,000	390,000	Includes watermain, gas pipelines, oil piplines & streetlights.
2.04	Access and Roads	m^2	9660	100	966,000	Includes 5% grade tie-ins to existing roads and assumes all roads are paved.
2.05	Turnouts	m^3	6,100	60	366,000	Turnouts assumed to be 6 m wide for 20 m with 15 m tapers on either side.
2.06	Drainage	L.S.	1	705,000	705,000	Includes replacement of drainage pipes/culverts and small floodboxes.
2.07	Bank Protection	m^3	157,000	75	11,775,000	Assumed bank protection needed for locations with less than 10 m setback (assumed 1.5 m thick revetment).
2.08	Land Acquisition	m^2	411,000	25	10,275,000	Unit cost provided by City of Abbotsford. Includes 5 m on each side of dike.
2.09	Habitat Management and Compensation Allowance	L.S.	1	3,934,000	3,934,000	Estimated as 5% of total cost of items 2.01 to 2.07.
2.10	Seismic Performance Improvements	m^3	4,148,000	17	70,516,000	Assumed 10 m strips of ground densification on each side of the dike to 12.5 m depth.
				SUBTOTAL FOR ITEM 2	**163,391,000**	
3	**Huntingdon Area Dike**					
3.01	Dike Fill	m^3	8,000	50	400,000	Assumed 1000 m length, 1 m height, 3H:1V side slopes and 5 m crest width.
3.02	Grubbing, Clearing and Stripping	m^2	11,000	11	121,000	Assumed for 11 m dike cooridor.
3.03	Dike Crest Surfacing	m^3	800	130	104,000	Assumed for 5 m crest width with 150 mm material thickness.
3.04	Topsoil and Hydroseeding	m^2	7,000	12	84,000	Assumed for both side slopes.
3.05	Watermain Replacement	m	40	500	20,000	Assumed 40 m watermain replacement for crossing at 2nd Avenue.
3.06	Sanitary Sewer Replacement	m	50	500	25,000	Assumed 50 m total sanitary sewer replacement for crossings at 2nd Avenue and end of B Street.
3.07	Sheet Pile Flood Wall	m^2	2960	550	1,628,000	Assumed 740 m length, 1m height and an embedment height of 3 times the exposed height (total sheet pile height of 4 m).
3.08	Land Acquisition	m^2	29,000	25	725,000	Unit cost provided by City of Abbotsford. Includes 5 m on each side of dike.
3.09	Passive Self-Deploying Road Flood Gate (FloodBreak)	each	1	200,000	200,000	Roadway gate for 2nd Avenue (1 m height).
3.10	Flap Gate for Existing Stormwater Outfall	each	2	40,000	80,000	Flap gates for outfalls located at northeast corner and southeast corner.
				SUBTOTAL FOR ITEM 3	**3,387,000**	

Item	Description	Unit	Estimated Quantity	Unit Rate	TOTAL PRICE $	Comment
4	Arnold Area Dike					
4.01	Dike Fill	m^3	96,000	50	4,800,000	Assumed 2270 m length, 3 m height, 3H:1V side slopes and 5 m crest width.
4.02	Grubbing, Clearing and Stripping	m^2	53,000	11	583,000	Assumed for 23 m dike cooridor.
4.03	Dike Crest Surfacing	m^3	1,800	130	234,000	Assumed for 5 m crest width with 150 mm material thickness.
4.04	Topsoil and Hydroseeding	m^2	22,000	12	264,000	Assumed for land-side side slopes.
4.05	Turnouts	m^3	700	60	42,000	Turnouts assumed to be 6 m wide for 20 m with 15 m tapers on either side.
4.06	Turnarounds	m^3	400	60	24,000	Turnaround assumed to be 12.5 m wide for 6 m with 4 m tapers on either side.
4.07	Bank Protection	m^3	20,000	75	1,500,000	Assumed bank protection needed for entire length (assumed 1.5 m thick revetment).
4.08	Watermain Replacement	m	100	400	40,000	Assumed 100 m total watermain replacement for crossings at Old Yale Road and Vye Road/Arnold Road.
4.09	Flood Box for Local Drainage Channels	each	3	300,000	900,000	For channel along Southern Railway, channel from Corbould Road and channel downstream of Arnold Road sewer system.
4.10	Sheet Pile Flood Wall	m^2	12240	550	6,732,000	Assumed 1020 m length, 3 m height and an embedment height of 3 times the exposed height (total sheet pile height of 12 m).
4.11	Land Acquisition	m^2	86,000	25	2,150,000	Unit cost provided by City of Abbotsford. Includes 5 m on each side of dike.
4.12	Habitat Management and Compensation Allowance	L.S.	1	420,000	420,000	Estimated as 5% of total cost of items 4.01 to 4.09.
4.13	Seismic Performance Improvements	m^3	568,000	17	9,656,000	Assumed 10 m strips of ground densification on each side of the dike to 12.5 m depth. Geotechnical conditions are unknown.
4.14	Allowance to Replace Southern Railway Bridge	each	1	3,000,000	3,000,000	New railway bridge includes a span and clearance that is able to contain the new flood wall, Arnold Road and Arnold Slough.
4.15	Manual Roadway Flood Gate	each	1	300,000	300,000	Roadway gate for Old Yale Road (3 m height).
	SUBTOTAL FOR ITEM 4				**30,645,000**	
5	Floodproofing					
5.01	Dike Fill for Private Structure Ring Dike	m^3	356,000	50	17,800,000	Assumed 400 m of dike per structure, 1 m height, 3H:1V side slopes and 2 m crest width
	SUBTOTAL FOR ITEM 5				**17,800,000**	
	CONSTRUCTION COST SUBTOTAL				**225,985,000**	
	Engineering & Construction Management	20%			45,197,000	
	Contingencies	30%			67,795,500	
	TOTAL AMOUNT (excl. GST)				**338,978,000**	

Note: Estimates have been prepared with little or no site information and as such indicates the approximate magnitude of the cost of the capital tasks, for project planning purposes only. The estimate has been derived from unit costs for similar projects.

CITY OF ABBOTSFORD
Nooksack River Overflow Flood Mitigation Plan
Class D Cost Estimate
November 30, 2020

Flood Mitigation Option #3 - Eliminate Nooksack Overflows
Class 'D'

Item	Description	Unit	Estimated Quantity	Unit Rate	TOTAL PRICE $	Comment
1	General					
1.01	Mobilization and Demobilization	L.S.	1	951,000	951,000	Assumed 5% of total cost.
				SUBTOTAL FOR ITEM 1	951,000	
2	Everson Levee Extension - Raise Existing Roads by 1 m					
2.01	Dike Fill	m^3	12,000	50	600,000	Assumed 1860 m length, 1 m height, 3H:1V side slopes and 11 m crest width to accommodate roads. Subtracted road fill.
2.02	Grubbing, Clearing and Stripping	m^2	21,000	11	231,000	Assumed for 23 m dike cooridor.
2.03	Road Replacement	m	1,860	1,000	1,860,000	Includes 600 mm of road fill and 75 mm thick asphalt surface.
2.04	Topsoil and Hydroseeding	m^2	12,000	12	144,000	Assumed for land side side-slopes and 3 m height.
2.05	Bank Protection	m^3	27,000	75	2,025,000	Assumed bank protection needed for entire length and 3 m height (assumed 1.5 m thick revetment).
2.06	Seismic Performance Improvements	m^3	465,000	17	7,905,000	Assumed 10 m strips of ground densification on each side of the dike to 12.5 m depth. Geotechnical conditions are unknown.
				SUBTOTAL FOR ITEM 2	12,765,000	
3	Everson Levee Extension - New 3 m High Levee					
3.01	Dike Fill	m^3	29,000	50	1,450,000	Assumed 690 m length, 3 m height, 3H:1V side slopes and 5 m crest width.
3.02	Grubbing, Clearing and Stripping	m^2	16,000	11	176,000	Assumed for 23 m dike cooridor.
3.03	Dike Crest Surfacing	m^3	500	130	65,000	Assumed for 5 m crest width with 150 mm material thickness.
3.04	Topsoil and Hydroseeding	m^2	10,000	12	120,000	Assumed for land side side-slopes.
3.05	Turnarounds	m^3	700	60	42,000	Turnaround assumed to be 8.6 m wide for 15.2 m with 8.5 m tapers on either side (based on USACE guidelines).
3.06	Bank Protection	m^3	10,000	75	750,000	Assumed bank protection needed for entire length (assumed 1.5 m thick revetment).
3.07	Land Acquisition	m^2	23,000	25	575,000	Assumued same unit cost as used for Abbotsford. Includes 5 m on each side of dike.
3.08	Habitat Management and Compensation Allowance	L.S.	1	131,000	131,000	Estimated as 5% of total cost of items 3.01 to 3.06.
3.09	Seismic Performance Improvements	m^3	173,000	17	2,941,000	Assumed 10 m strips of ground densification on each side of the dike to 12.5 m depth. Geotechnical conditions are unknown.
				SUBTOTAL FOR ITEM 3	6,250,000	
	CONSTRUCTION COST SUBTOTAL				19,966,000	
	Engineering & Construction Management	20%			3,993,200	
	Contingencies	30%			5,989,800	
	TOTAL AMOUNT (excl. GST)				29,949,000	

Note: Estimates have been prepared with little or no site information and as such indicates the approximate magnitude of the cost of the capital tasks, for project planning purposes only. The estimate has been derived from unit costs for similar projects.

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Appendix I

Additional Benefit-Cost Analysis for Huntingdon and Arnold Area Dikes

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Greater Vancouver
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Technical Memorandum

DATE: November 30, 2020

TO: Stella Chiu, M. Eng., P.Eng., Senior Drainage and Wastewater Engineer, City of Abbotsford

FROM: Laurel Morgan, M.Sc., P.Eng., Project Manager
Jeffrey Marvin, M.A.Sc. P.Eng., Project Engineer

RE: **Nooksack River Overflow Flood Mitigation Plan**
Additional Benefit-Cost Analysis for Huntingdon and Arnold Area Dikes
Our File 510.184-300

1. Introduction

This memorandum provides an additional benefit-cost analysis of the local Huntingdon and Arnold area dike options described in the *Nooksack River Overflow Flood Mitigation Plan* report (the report) as part of "Mitigation Option #2: Dike Raise and Floodproofing". While the report evaluates Mitigation Option #2 as a complete project that also includes floodproofing of individual properties and raising the Interceptor and Sumas River dikes, this assessment investigates the benefit-cost of the Huntingdon and Arnold dikes as standalone projects.

2. Description of Area Dike Options

A full description of the Huntingdon and Arnold area dike options is provided in the report. In summary, the Huntingdon dike is expected to be 1.7 km in length and have an average height of 1 m, whereas the Arnold dike is expected to be 3.3 km in length and have an average height of 3 m. Both dikes include space-constrained sections where vertical flood walls such as sheet piles would be required in lieu of earth-filled dikes. While both dikes would require land acquisition, building relocation was not evaluated. The dikes were sized based on the 200-year flood under climate change conditions, assuming the remaining flood mitigation measures included in Mitigation Option #2 (floodproofing and dike raising) are also carried out.

3. Flood Analysis

No additional hydraulic modelling was carried out for the Huntingdon and Arnold area dike options, as the flood volumes prevented by the dikes would not be large enough to significantly impact the overall flood levels in the Sumas Prairie. The flood depths associated with unmitigated conditions were therefore assumed to remain the same outside of the two diked areas. Further modelling should be carried out to estimate water levels in the Sumas Prairie if the area dike options are further advanced. In particular, the Arnold dike would have a larger impact on water levels outside of the protected area due to its larger area and higher depth of flooding (flood water displacement caused by the protection works).

4. Flood Damage Assessment

Flood damages and losses were estimated for the Huntingdon and Arnold area dike options by excluding the areas protected by the dikes from the structure, content and agricultural damage assessment results. This was carried out for the four unmitigated scenarios that were used to develop benefit-cost analysis curve. The area dikes were assumed to have no impact on the business and transportation economic losses, as major road corridors would still be closed and changes to the number of opened businesses would be minor.

As described in the report, the four unmitigated flood scenarios used to develop the benefit-cost analysis curves were as follows:

- **Scenario 1**: November 1990 flood (35-year return period)
- **Scenario 2A**: 100-year flood
- **Scenario 3**: 200-year flood
- **Scenario CC-3**: 200-year flood under climate change conditions

Damages and losses estimated for the area dike options are summarized in Table 1 for each of the corresponding unmitigated flood scenarios (1, 2A, 3 and CC-3).

Table 1: Residual Damages for Huntingdon & Arnold Area Dike Mitigation Scenarios

Mitigation Option	Flood Scenario	Damages ($ million)				
		Structure Damages	Content Damages	Agricultural Damages	Economic Losses	Total
(no mitigation)	1	$65	$40	$41	$4	**$150**
	2A	$188	$127	$136	$10	**$462**
	3	$315	$236	$271	$14	**$836**
	CC-3	$365	$277	$304	$14	**$960**
Huntingdon Area Dike	1	$34	$26	$41	$4	**$105**
	2A	$140	$104	$136	$10	**$390**
	3	$262	$210	$271	$14	**$757**
	CC-3	$311	$250	$304	$14	**$879**
Arnold Area Dike	1	$63	$39	$40	$4	**$146**
	2A	$165	$111	$129	$10	**$414**
	3	$290	$219	$263	$14	**$786**
	CC-3	$339	$259	$296	$14	**$908**

5. Mitigation Works Cost Estimation

Class D capital cost estimates and annual operation and maintenance (O&M) costs for the Huntingdon and Arnold area dikes are summarized in Table 2 in 2019 dollars. Further details on the costing of the dikes are provided in the report, as no additional costing was carried out for this memorandum. It is reiterated that the Class D cost estimates were prepared with little or no site information based on unit costs from similar projects and as such are considered indicative for planning purposes only. Planning, conceptual design, and investigation would be required to more accurately determine costs for these projects. Due to the high level of uncertainties for costing, a 30% contingency was added to the estimated costs.

Table 2: Capital and O&M Class D Costs for Huntingdon & Arnold Area Dike Mitigation Options

Mitigation Option	Item	Capital Cost ($ million)	Annual Operation and Maintenance Cost ($)
Huntingdon Area Dike	Subtotal Costs	$3.6	**$10,000 / year**
	Engineering & Construction Management (20%)	$0.7	
	Contingencies (30%)	$1.1	
	Total (excl. GST)	**$5.3**	
Arnold Area Dike	Subtotal Costs	$32	**$130,000 / year**
	Engineering & Construction Management (20%)	$6	
	Contingencies (30%)	$10	
	Total (excl. GST)	**$48**	

6. Benefit-Cost Analysis

A benefit-cost analysis was carried out for the Huntingdon and Arnold area dike options for existing and future climate change conditions following the same methodology and assumptions provided in the report. However, unlike the three mitigation options evaluated in the report, the 1990 flood (Scenario 1) and the 200-year flood under existing climate conditions (Scenario 3) were able to be incorporated into the calculation of annualized damages, as no additional modelling was needed for the area dike mitigation options.

The benefit-cost analysis results are provided in Table 3 for existing and future climate change conditions. Damage curves depicting the estimated residual flood damages for given return periods when separately implementing each of the mitigation options are provided in Figure 1 and Figure 2 for existing and future climate change conditions, respectively.

As shown in Table 3, the Huntingdon area dike option was found to have favourable (> 1.0) benefit-cost ratios when assuming both a 2% and 8% discount rate, whereas the Arnold area dike option was found to have a favourable benefit-cost ratio when assuming a 2% discount rate and a non-favourable benefit-cost ratio when assuming an 8% discount rate. These findings hold true for both existing and climate change conditions. The notably higher benefit-cost ratios of the Huntingdon dike option were expected are due to its lower cost and the higher value of the land that it would protect. It should be noted that while the cost of mitigation is less than the cost of the mitigated damages for both dike options, additional mitigation is still needed for remaining properties within the Sumas Prairie that are at risk of flooding, as presented in the report.

Table 3: Benefit-Cost Ratios Summary for Huntingdon & Arnold Area Dike Mitigation Options

Mitigation Option	Annualized Damages ($ million)	Discount Rate of 2%			Discount Rate of 8%		
		Damages Avoided Over Lifespan [present value] ($ million)	Life Cycle Cost [present value] ($ million)	Benefit-Cost Ratio	Damages Avoided Over Lifespan [present value] ($ million)	Life Cycle Cost [present value] ($ million)	Benefit-Cost Ratio
Existing Climate Conditions							
(no mitigation)	$26	-	-	-	-	-	-
Huntingdon Area Dike	$21	$235	$6	41	$68	$5	13
Arnold Area Dike	$25	$52	$54	1.0	$15	$50	0.3
Climate Change Conditions							
(no mitigation)	$41	-	-	-	-	-	-
Huntingdon Area Dike	$33	$374	$6	65	$108	$5	20
Arnold Area Dike	$40	$74	$54	1.4	$21	$50	0.4

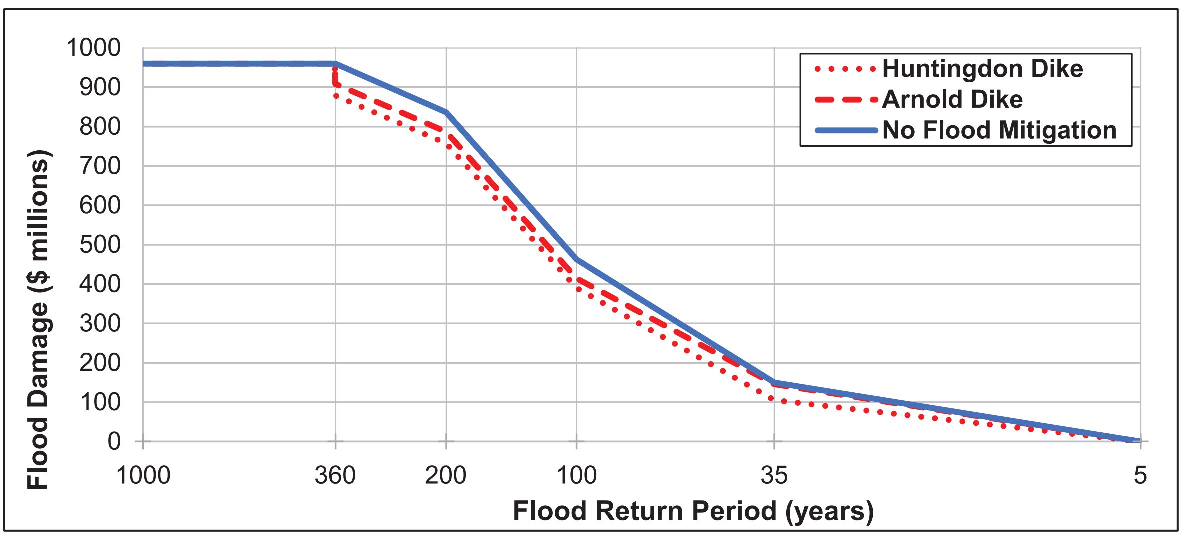

Figure 1: Mitigation Option Damage vs. Return Period Curves for Existing Climate Conditions

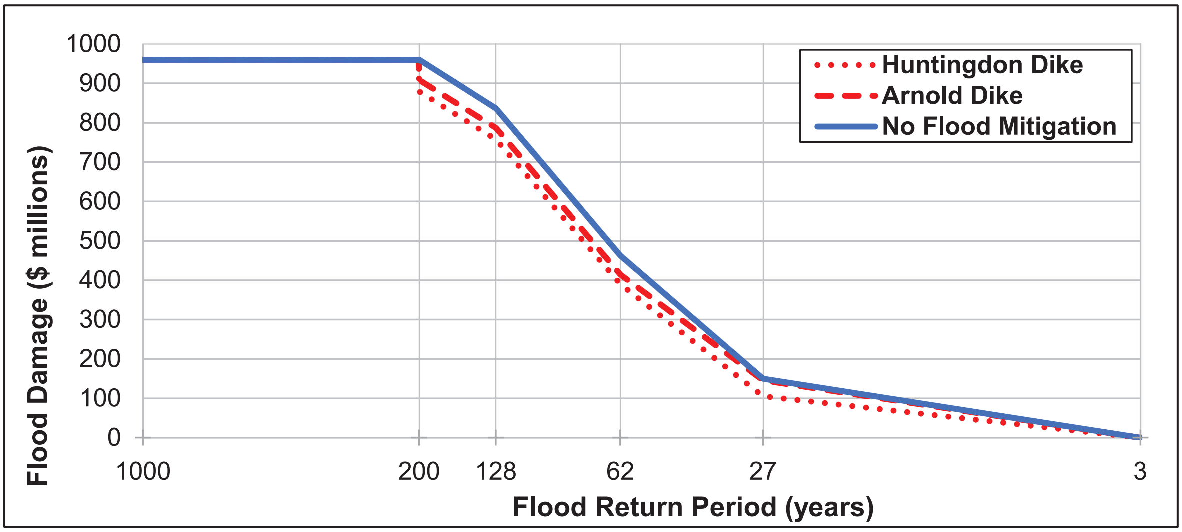

Figure 2: Mitigation Option Damage vs. Return Period Curves for Climate Change Conditions

7. Conclusions

Both the Huntingdon and Arnold area dike options are favourable from a benefit-cost analysis at a lower end discount rate of 2%, whereas only the Huntingdon area dike option was favourable at a higher end discount rate of 8%. The Huntingdon area dike has a much higher benefit-cost ratio due to it being an inexpensive option with a smaller footprint that protects a higher density development. It is therefore recommended to prioritize the Huntingdon area dike as a first low-cost mitigation option, whereas the feasibility of the Arnold dike should undergo further investigation.

In addition to the recommendations for future work provided in the report, further recommendations related to the Huntingdon and Arnold area dike options are as follows:

- More detailed modelling of the Huntingdon and Arnold areas with higher resolution terrain data should be carried out to improve the estimation of impacted areas and flood depths. In particular, local topographic features within the Huntingdon area that were not included in the current model resolution may be found to hold back a portion of the floodwaters within for the community, as flood depths estimated for the Huntingdon area were relatively low.
- Dike crest elevations will need to consider the other flood mitigation measures planned for the Sumas Prairie. The area dikes were sized assuming the remaining flood mitigation measures included in Mitigation Option #2 (individual properties and raising the Interceptor and Sumas River dikes) are also carried out. Should these other flood mitigation measures not be further pursued, the required crest elevations for these area dikes, particularly the Arnold dike, would be slightly lower.
- Dike fill volumes should be better estimated based on the local topography along the dike alignment, as dike heights were approximated for this analysis based on average ground elevations.
- The feasibility of the Arnold dike needs further investigation, as the dike requires significant land acquisition and is currently assumed to transition into vertical flood walls around existing buildings where space constraints exist. Its feasibility should also consider the needs for a riparian buffer next to Arnold Slough.

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:

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Revision History

Revision #	Date	Status	Revision Description	Author
0	November 30, 2020	Final		JTM

OQM CERTIFIED

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Appendix J

Additional Benefit-Cost Analysis for US/Canada Border Dike

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Technical Memorandum

DATE: November 30, 2020

TO: Stella Chiu, M. Eng., P.Eng., Senior Drainage and Wastewater Engineer
City of Abbotsford

FROM: Laurel Morgan, M.Sc., P.Eng., Project Manager
Jeffrey Marvin, M.A.Sc., P.Eng., Project Engineer

RE: **Nooksack River Overflow Flood Mitigation Plan**
Additional Benefit-Cost Analysis for US/Canada Border Dike
Our File 510.184-300

1. Introduction

This memorandum investigates an additional flood mitigation option of constructing a dike along the US/Canada border on the Canada side to control flows into Canada such that all Nooksack River overflows are stored within the US. This option was excluded during the option selection process described in the *Nooksack River Overflow Flood Mitigation Plan* report (the report) due to the various challenges and high costs it would pose. Most notably, the option would require significant flood protection work in the US to provide storage for the Nooksack overflows such that flooding is not exacerbated within the City of Sumas and the nearby communities south of the border. A benefit-cost analysis of the border dike is provided below from the Canadian perspective, excluding flood damages and additional flood protection works within the US.

2. Description of Border Dike Option

2.1 Border Dike Crest Elevation

The crest elevation required for a US/Canada border dike was estimated by assuming all Nooksack overflows would be stored on the US side of the dike while allowing for Sumas River flows to pass through. The design flood selected for the crest elevation was assumed to be the 200-year flood under climate change conditions. During this flood, the peak water level in the Sumas Prairie at the US/Canada border was estimated to be at 9.5 m Canadian Geodetic Vertical Datum 1928 (CGVD28) if Nooksack overflows are excluded, and the volume of Nooksack River overflows was estimated to be 70 million m^3. Based on the existing Washington State lidar data[1], the addition of 70 million m^3 above elevation 9.5 m CGVD28 would result in a water level of 15.5 m CGVD28, creating a ponded area of approximately 25 km^2. Including 0.6 m for freeboard, the design dike crest elevation was estimated to be at 16.1 m CGVD28.

[1] North Puget USGS 2006 lidar data processed at a 6 ft x 6 ft gridded resolution in North American Vertical Datum 1988 (NAVD88), provided by Whatcom County. NAVD88 was approximated to be 1.2 m above CGVD28 based on an analysis of the North Puget lidar and the Abbotsford lidar.

The above dike crest elevation was estimated without any additional modelling. A model simulation of the Nooksack overflow within Washington State and in British Columbia with inclusion of the border dike would be needed to better estimate this level. The estimated dike crest elevation also assumes no flood protection works would be carried out in the US, and that significant flooding would occur within the City of Sumas and the nearby communities. Flood protection works on the US side would displace flood waters and raise the water level on the south side of the dike, requiring a higher crest.

2.2 Border Dike Alignment

The US/Canada border dike would span approximately 9 km across the Sumas Prairie (see Figure 1). The dike would consist of a 6.3 km long earth-fill dike along the border on the east side of the Sumas River with an average height of 9 m, whereas Boundary Road would be raised to form a new 1.8 km long earth-fill dike on the west side of the Sumas River with an average height of 6 m. The dike would require significant land acquisition to accommodate its footprint, and five properties along the dike alignment contain structures that would need to be relocated.

It was assumed that the natural gas and oil distribution facilities located approximately half a kilometer east of the Sumas River that operate on both sides of the border would not be relocated or modified to accommodate the dike. Instead, it was assumed that these facilities would implement their own flood protection works (costs not included in this analysis), and that the border dike would be routed along the north side of the facilities. Driveway access for the facilities would need to be maintained through the dike, likely using roadway flood gates.

Approximately 0.6 km of sheet pile flood walls and 0.2 km of road and railway gates was assumed for the remaining flood protection to the west of where Boundary Road turns toward the north. Insufficient space is available along this part of the alignment for an earth-fill dike due to the existing developments, roads and railways. Manually operated flood gates would be placed along the road and railway border crossings, closing border access when Nooksack River overflows are present. These gates would need to be up to 5 m high.

2.3 Flow Control Structures

Flow control structures would be needed crossing the Sumas River, Saar Creek and Arnold Slough to regulate the release of the stored Nooksack River overflows across the border. Flow structures would consist of mechanical gates programmed to adjust based on Sumas River upstream flows (e.g. based on the return period of rainfall event or a flow gauge on the Sumas River that is outside of the Nooksack River overflow influence).

While the Saar Creek and Arnold Slough control structures would be relatively small structures likely consisting of flood boxes with automated gates, the Sumas River control structure would need to be large enough to allow for the 200-year Sumas River flow under climate change conditions of 82 m^3/s to pass through while holding back excess Nooksack River overflows. Such a structure would likely be in the order of 30 m wide and contain multiple automated slide or weir gates. Some realignment of the Sumas River and Boundary Road near the border would be needed to accommodate the control structure and dike system, as the Sumas River currently turns east immediately after crossing the border, limiting the space available for the flood protection works.

Flow control throughout the duration of flood events would need to be carried out such that the shape of the hydrograph which excludes Nooksack River overflows is maintained as much as possible during an overflow event. Maintaining the hydrograph is important for flood management in the Sumas Prairie, as much of the flooding is driven by flood volumes in addition to peak flows. The stored Nooksack River overflows would then be released through the control structures when it is deemed safe to allow them to pass through Canada towards the Fraser River.

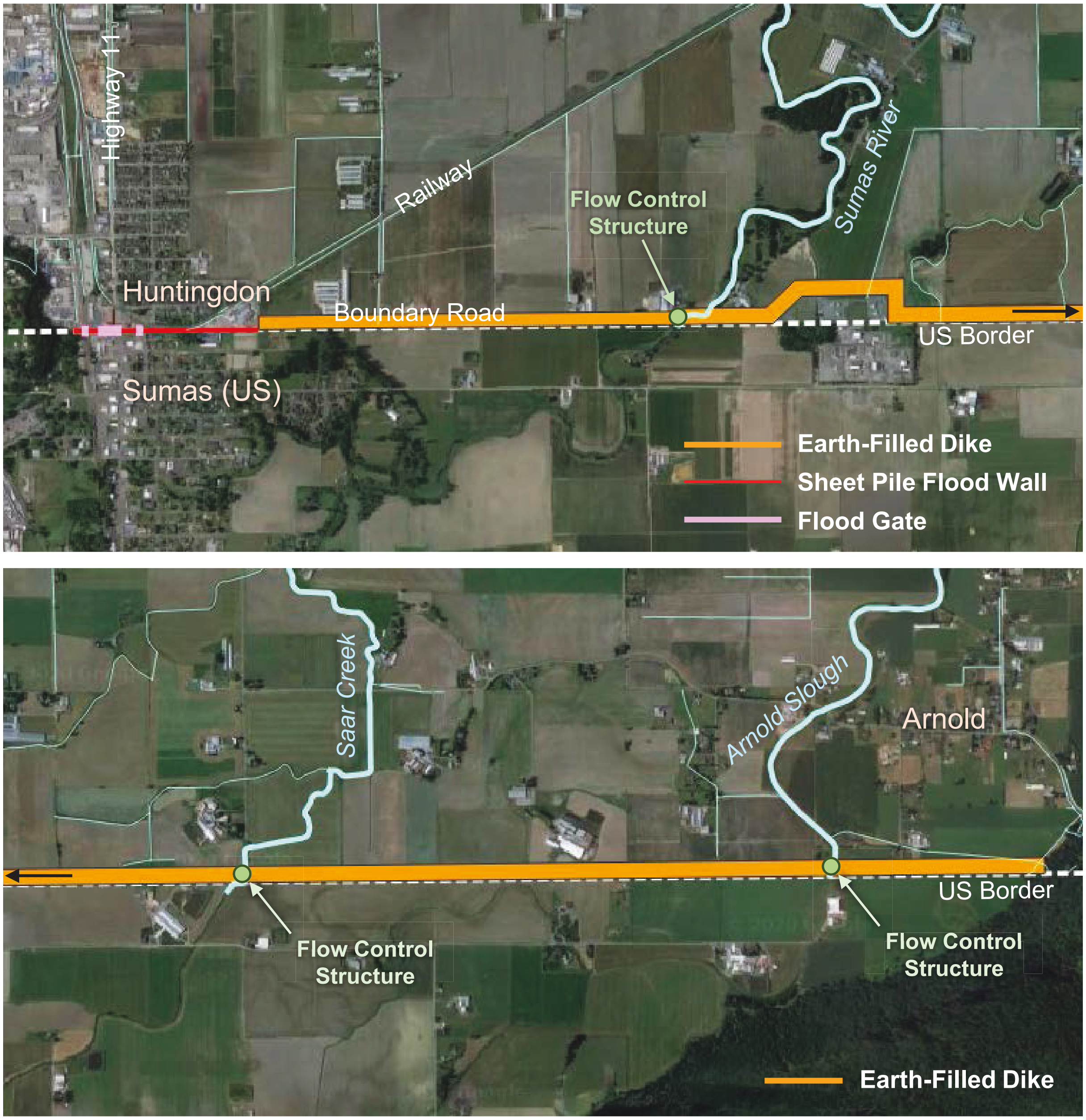

Figure 1: Schematic Showing Location and Structures for US/Canada Border Dike Option

3. Flood Analysis

No additional hydraulic modelling was carried out for the US/Canada border dike option, as model simulations were already performed for Sumas River flood scenarios that exclude Nooksack River overflows (see "Mitigation Option #3: Eliminate Nooksack Overflows" in the report). The results for these scenarios were assumed to be applicable to the US/Canada border dike option.

4. Flood Damage Assessment

No additional flood damage assessments were carried out for the US/Canada border dike option, as flood damages were already estimated for the Sumas River flood scenarios that exclude Nooksack River overflows. A summary of the damages and losses for the border dike option based on Mitigation Option #3 from the report and for the corresponding unmitigated flood scenarios is provided in Table 1. As described in the report, the two unmitigated flood scenarios used as baseline conditions for the flood mitigation scenarios were as follows:

- **Scenario 2A**: 100-year flood under existing climate conditions
- **Scenario CC-3**: 200-year flood under climate change conditions

Table 1: Residual Damages for US/Canada Border Dike Mitigation Scenarios

Mitigation Option	Flood Scenario	Damages ($ million)				
		Structure Damages	Content Damages	Agricultural Damages	Economic Losses	Total
(no mitigation)	2A	$188	$127	$136	$10	**$462**
	CC-3	$365	$277	$304	$14	**$960**
Border Dike	2A	$70	$52	$84	$7	**$213**
	CC-3	$152	$108	$170	$16	**$445**

5. Mitigation Works Cost Estimation

A Class D cost estimate was carried out for the US/Canada border dike option and is provided in the attached table in 2019 dollars. A summary of the Class D cost estimate, including annual operation and maintenance (O&M) costs, is presented in Table 2. The costs are broken down for the east and west sides of the Sumas River, as the earth-fill dike on the east side of the river would consist of a much greater amount of material due to lower ground elevations, whereas the earth-fill dike on the west side of the river would include raising Boundary Road.

The Class D cost estimate was prepared with little or no site information based on unit costs from similar projects, and as such are considered indicative for planning purposes only. Planning, conceptual design, and investigation would be required to more accurately determine costs for this option. Due to the high level of uncertainties for costing, a 30% contingency was added to the estimated costs. Annual operation and maintenance costs were estimated following the same methodology and assumptions provided in the report.

Table 2: Capital and O&M Class D Costs for US/Canada Border Dike Mitigation Option

Item	Capital Cost ($ million)
Flood Protection East of Sumas River	$152
Flood Protection West of Sumas River	$45
Flow Control Structures	$10
Engineering & Construction Management (20%)	$41
Contingencies (30%)	$62
Total (excl. GST)	**$310**
Annual Operation and Maintenance	**$900,000 / year**

6. Benefit-Cost Analysis

A benefit-cost analysis was carried out for the US/Canada border dike option for existing and future climate change conditions following the same methodology and assumptions provided in the report. The benefit-cost analysis results are provided in Table 3 for existing and future climate change conditions. Damage curves depicting the estimated residual flood damages for given return periods for the border dike option is provided in Figure 2 and Figure 3 for existing and future climate change conditions, respectively. These damage curves are the same as Mitigation Option #3 in the report.

As shown in Table 3, the border dike was found to have a favourable (> 1.0) benefit-cost ratio when assuming a 2% discount rate and a non-favourable (< 1.0) benefit-cost ratio when assuming a 8% discount rate. This finding holds true for both existing and future climate change conditions.

It should be noted that this benefit-cost analysis assumes no change to the current development of the Sumas Prairie throughout the lifespan of the border dike, and it may be found that future development or changes to land use in the floodplain increases the benefit-cost ratio above 1.0 at the higher discount rates. However, the estimated benefit-cost ratios do not account for additional flood mitigation work in the US to manage the stored Nooksack River overflow volumes, nor do they account for damages within the US. For this reason, additional analysis of flood management options and damages in the US are needed to provide the overall benefit-cost ratio for the US/Canada border dike option.

Table 3: Benefit-Cost Ratios Summary for US/Canada Border Dike Mitigation Option

Mitigation Option	Annualized Damages ($ million)	Discount Rate of 2%			Discount Rate of 8%		
		Damages Avoided Over Lifespan [present value] ($ million)	Life Cycle Cost [present value] ($ million)	Benefit-Cost Ratio	Damages Avoided Over Lifespan [present value] ($ million)	Life Cycle Cost [present value] ($ million)	Benefit-Cost Ratio
Existing Climate Conditions							
(no mitigation)	$26	-	-	-	-	-	-
Border Dike	$14	$552	$349	**1.6**	$160	$322	**0.5**
Climate Change Conditions							
(no mitigation)	$41	-	-	-	-	-	-
Border Dike	$22	$848	$349	**2.4**	$246	$322	**0.8**

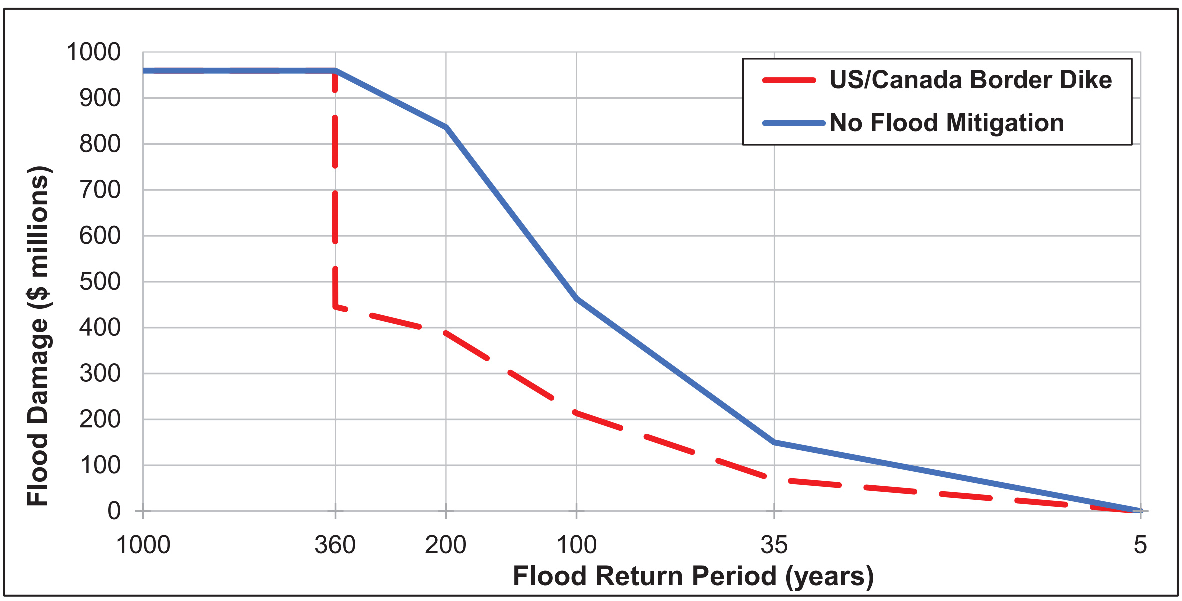

Figure 2: Mitigation Option Damage vs. Return Period Curves for Existing Climate Conditions

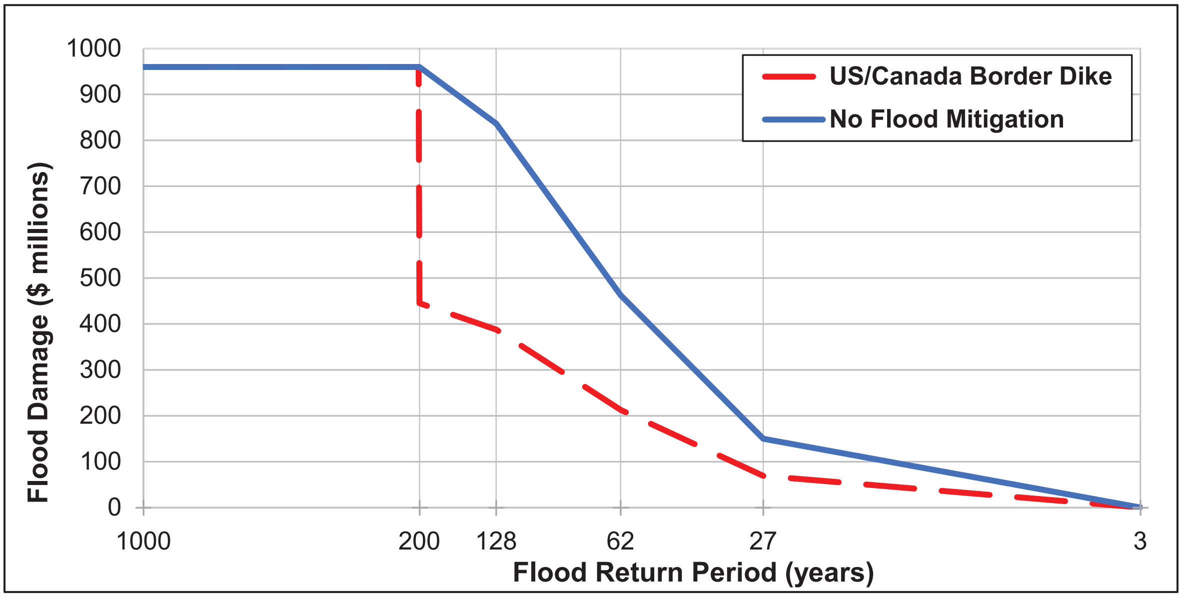

Figure 3: Mitigation Option Damage vs. Return Period Curves for Climate Change Conditions

7. Conclusions

The cost of the US/Canada border dike option is similar to the cost of annual damages that it would prevent, depending on the assumed discount rate. The benefit-cost ratio of the border dike is > 1.0 for a lower end discount rate of 2% and is < 1.0 for an upper end discount rate of 8%, for both existing and future climate change conditions. Future development and changes in land use were not included in this analysis. The benefit-cost ratios are from a Canadian perspective only, as they do not include flood mitigation measures and damages within the US.

In addition to the recommendations for future work provided in the report, further recommendations related to the US/Canada border dike option are as follows:

- The US hydraulic model should be updated to simulate the impacts of the border dike and of additional flood mitigation measures in the US. The cost of the additional flood mitigation measures and the associated damage results should then be used to complete an overall benefit-cost analysis that includes the Canadian results. The US model should also be used to provide a better estimation of the design crest elevation for the border dike.
- Dike volumes should be better estimated based on the local topography along the dike alignment, as dike heights were approximated for this analysis based on average ground elevations.
- The feasibility of the border dike option needs further investigation, as the dike requires significant land acquisition, building relocation and road realignment. The dike would also pose challenges related to installing flood gates at the road and railway border crossings, and challenges related to the natural gas and oil distribution facilities located on both sides of the border. Most notably, the border dike would result in very high water levels and a large area of flooding within the US during Nooksack River overflow events. These additional flood volumes in the US would require significant flood management work to mitigate, and the feasibility of such options would need to be assessed. Moreover, a joint flood management plan would be needed between the US and Canada.

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Encl: Class D Cost Estimate for Flood Mitigation Option: US/Canada Border Dike and Control Structure to Prevent Nooksack River Overflows

Statement of Limitations

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Revision History

Revision #	Date	Status	Revision Description	Author
0	November 30, 2020	Final		JTM

OQM CERTIFIED

Flood Mitigation Option - US/Canada Border Dike and Control Structure to Prevent Nooksack River Overflows
Class 'D'

Item	Description	Unit	Estimated Quantity	Unit Rate	TOTAL PRICE $	Comment
1	**General**					
1.01	Mobilization and Demobilization	L.S.	1	9,854,000	9,854,000	Assumed 5% of total cost.
			SUBTOTAL FOR ITEM 1		**9,854,000**	
2	**New Flood Protection East of Sumas River**					
2.01	Dike Fill	m^3	1,821,000	50	91,050,000	Assumed 6150 m length, 9 m height, 3H:1V side slopes and 5 m crest width.
2.02	Grubbing, Clearing and Stripping	m^2	373,000	11	4,103,000	Assumed for 59 m dike cooridor.
2.03	Dike Crest Surfacing	m^3	4,800	130	624,000	Assumed for 5 m crest width with 150 mm material thickness.
2.04	Topsoil and Hydroseeding	m^2	361,000	12	4,332,000	Assumed for both side slopes.
2.05	Turnouts	m^3	22,700	60	1,362,000	Turnouts assumed to be 6 m wide for 20 m with 15 m tapers on either side.
2.06	Turnarounds	m^3	1,200	60	72,000	Turnaround assumed to be 12.5 m wide for 6 m with 4 m tapers on either side.
2.07	Land Acquisition	m^2	437,000	25	10,925,000	Unit cost provided by City of Abbotsford. Includes 5 m on each side of dike.
2.08	Building Relocation	each	1	234,000	234,000	Assumed total building assessment values of impacted properties.
2.09	Habitat Management and Compensation Allowance	L.S.	1	5,078,000	5,078,000	Estimated as 5% of total cost of items 2.01 to 2.06.
2.10	Seismic Performance Improvements	m^3	1,580,000	17	26,860,000	Assumed 10 m strips of ground densification on each side of the dike to 12.5 m depth. Geotechnical conditions are unknown.
			SUBTOTAL FOR ITEM 3		**144,640,000**	
3	**New Flood Protection West of Sumas River**					
3.01	Dike Fill	m^3	297,000	50	14,850,000	Assumed 1770 m length, 6m height, 3H:1V side slopes and 11 m crest width to accommodate roads. Subtracted road fill.
3.02	Grubbing, Clearing and Stripping	m^2	84,000	11	924,000	Assumed for 47 m dike cooridor.
3.03	Road Replacement	m	1,780	1,000	1,780,000	Includes 600 mm of road fill and 75 mm thick asphalt surface.
3.04	Road Approaches	m^2	2640	100	264,000	Includes 5% grade tie-ins to Boundary Road and Whatcom Road
3.05	Topsoil and Hydroseeding	m^2	68,000	12	816,000	Assumed for both side slopes.
3.06	Sheet Pile Flood Wall	m^2	12600	550	6,930,000	Assumed 500 m length, 5 m height and an embedment height of 3 times the exposed height (total sheet pile height of 20 m).
3.07	Land Acquisition	m^2	66,000	25	1,650,000	Unit cost provided by City of Abbotsford. Includes 5 m on each side of dike.
3.08	Building Relocation	each	1	4,080,000	4,080,000	Assumed total building assessment values of impacted properties.
3.09	Habitat Management and Compensation Allowance	L.S.	1	932,000	932,000	Estimated as 5% of total cost of items 3.01 to 3.05.
3.10	Seismic Performance Improvements	m^3	445,000	17	7,565,000	Assumed 10 m strips of ground densification on each side of the dike to 12.5 m depth. Geotechnical conditions are unknown.
3.11	Manual Roadway Flood Gates	m	160	19,000	3,040,000	Gates for Sumas Ave., border crossing (Cherry St./Sumas Way and commercial road), and railway. Assumed 5 m height.
			SUBTOTAL FOR ITEM 2		**42,831,000**	
4	**Flood Control Structures**					
4.01	Flow Control Structure for Sumas River	each	1	8,500,000	8,500,000	Assumed 30 m wide concrete structure with five automated flood gates.
4.02	Flood Box for Saar Creek	each	1	700,000	700,000	Assumed 3 m high x 4 m wide opening with automatic gate.
4.03	Flood Box for Arnold Slough	each	1	400,000	400,000	Assumed 2 m high x 3 m wide opening with automatic gate.
			SUBTOTAL FOR ITEM 2		**9,600,000**	
	CONSTRUCTION COST SUBTOTAL				**206,925,000**	
	Engineering & Construction Management	20%			41,385,000	
	Contingencies	30%			62,077,500	
	TOTAL AMOUNT (excl. GST)				**310,388,000**	

Note: Estimates have been prepared with little or no site information and as such indicates the approximate magnitude of the cost of the capital tasks, for project planning purposes only.
The estimate has been derived from unit costs for similar projects.