Updated Cowichan-Koksilah River Flood Mapping Project
Final Report

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Cowichan Valley Regional District
Duncan, BC

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Staff from the Nanaimo WSC branch provided historical data and information for key hydrometric stations in the study area.

Appreciation is extended to the CVRD and other stakeholders including the MNC, CT and City of Duncan for providing valuable input and feedback over the course of the work program.

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EXECUTIVE SUMMARY

The Cowichan Valley Regional District (CVRD), in partnership with Cowichan Tribes, the City of Duncan and the Municipality of North Cowichan (MNC) retained Northwest Hydraulic Consultants (NHC) to update existing floodplain mapping for the lower Cowichan watershed. The project area encompasses the floodplains of the lower Cowichan and Koksilah River, portions of Somenos Creek and Somenos Lake. The project was funded by the National Disaster Mitigation Program and Emergency Management British Columbia.

The main outputs from the study include:

- Development of a comprehensive two dimensional hydraulic model (HEC-RAS 5.0.7) of the main rivers and floodplain that can simulate flooding for a range of climate scenarios (river flows and ocean levels) and can be used to assess flood management alternatives and mitigation measures. An assessment of coastal wave conditions in Cowichan Bay and Saanich Inlet was made using SWAN, a two dimensional wave model developed at Deft University.
- Production of updated 1:5,000 floodplain maps representing a 200 year flood condition in the year 2100, incorporating effects of climate change and sea level rise. The maps were developed using current guidelines and mapping standards issues by EGBC and Natural Resources Canada.
- Preparation of digital raster mapping output for various designated flood scenarios, including baseline conditions, dike breaching and the year 2100 flood scenario.

The 2019 LiDAR for the project was originally going to be supplied by GeoBC to the CVRD in August 2019. Due to delays, the data was not available to NHC until near the end of April 2020. Interim modelling and mapping was conducted using available LiDAR from 2016. This present report describes results using the updated 2019 LiDAR and supersedes all previous interim investigations.

The project was split into three phases: data collection, hydraulic modelling and flood mapping. Each phase involved stakeholder consultation which allowed for a collaborative approach to address study objectives.

The initial project phase involved compiling existing bathymetric, topographic and hydrometric data for the Cowichan and Koksilah Rivers. Data gaps were assessed and supplemented with newly gathered topographic and bathymetric surveys. The hydraulic modelling phase of this project required simulations of both the riverine and coastal environments. Several types of hydraulic modelling software were reviewed and the 2D (two dimensional) HEC-RAS 5.0.7 software was adopted for this study. The coastal wave modelling was completed using SWAN, a 2D wave model developed by Delft in the Netherlands.

The second phase, hydraulic modelling, required an assessment of river flows and ocean levels along with a climate change analysis. Results of this assessment were used as input for the hydraulic model.

The hydraulic model was calibrated on 5 recent storm events and was able to reproduce water levels within ±0.20 m of observed data. Various flood scenarios were assessed including existing dikes (base case) and 13 different potential dike breach scenarios. The dike breach locations were selected to represent the worst-case flooding that would result from potential failures and do not represent locations of present overtopping or where breaching is expected to occur in the future. This approach is conservative but is consistent with present floodplain guidelines. A series of 1:5,000 flood maps were generated for the 2100 climate change scenario to illustrate the depth and extent of floodplain inundation. The resulting inundation mapping represents a worst case scenario from the simulated base case and dike breaches.

Two flood mitigation options were reviewed, namely construction of a new south Cowichan-Koksilah dike and effects of sediment excavation of flood levels. Assessment of a south Cowichan-Koksilah dike indicated that this option was only effective at eliminating spills if a portion of Highway 1 was also raised (or temporarily closed by a flood barrier). This section of Highway 1 is currently below the 200-year flood level and has overtopped during a previous flood in 2007.

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1 INTRODUCTION

1.1 Background

This draft final report presents flood modelling and flood mapping results for the Cowichan Valley Regional District's (CVRD) Cowichan-Koksilah River Floodplain Mapping project. The results presented in this report and all maps, digital data and model output supersede results that were contained in NHC's interim report of May 2020 (NHC, 2020). The updated results incorporate new LiDAR that was supplied to the CVRD by GeoBC in April 2020.

The limits of the study were defined in the CVRD's request for proposal. The study area includes the floodplain of the lower Cowichan River, lower Koksilah River, Somenos Creek and Somenos Lake as well as a portion of Bings[1] (Holmes) Creek and Cowichan Bay (Figure 1-1). The total area of floodplain is approximately 21 km^2.

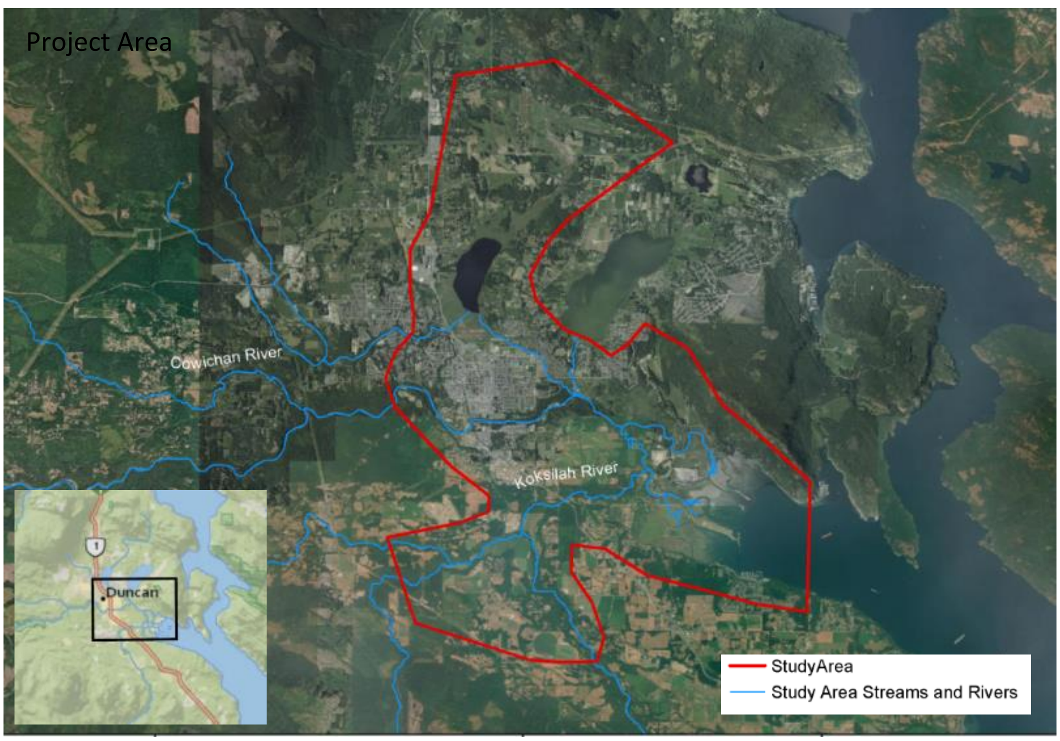


Figure 1-1: Major streams within the study area

[1] Bings Creek is the official name for this stream but is locally referred to as Holmes Creek. For the purposes of this report the official name has been used.

The upstream boundary of the Cowichan River is located 0.6 km upstream of the Allenby Bridge, Duncan where the river exits from a confined canyon. The upstream boundary of the Koksilah River is located near Cowichan Station near the Water Survey of Canada gauge “Koksilah River near Cowichan Station.

1.2 Outline of Report

This main report provides a high level summary of the flood management issues in the region, a description of the hydrological and oceanic conditions that govern flooding, an overview of the available data that were used in the study and a description of the river and coastal modelling investigations that were carried out. This material has been selected and condensed from a series of technical appendices which are located at the end of this report. These appendices are as follows:

Appendix A Surveys: including the bathymetric data used to support the hydraulic modelling work, as well as details on the project datum and coordinate system used for the mapping.

Appendix B Hydrology: review and analysis of existing hydrometric data in the region, frequency analysis of flood events, assumed climate change scenario, adopted hydrologic boundary conditions and inflow hydrographs for flood modelling.

Appendix C Coastal Assessment and Wave Modelling: regional analysis of observed tide levels near Cowichan Bay, review of sea level rise projections, analysis of winds and development of a SWAN wave model to predict wave heights in Cowichan Bay, an analysis of wave runup and estimation of coastal Flood Construction Levels along the shoreline in the study area.

Appendix D Joint Probability Analysis: reviews methods to assess the joint occurrence of river floods and extreme ocean levels using various statistical approaches, assesses available data for conducting the analysis, estimates the dependence of the two variables presents results of the joint probability analysis, and summarizes two flood scenarios that were used for the final modelling and flood mapping.

Appendix E Hydraulic Modelling: describes the HEC-RAS model software, model development details, model calibration and validation, designated flood base runs, dike breach modelling and modelling of two mitigation options.

A separate Model Operating Manual, describing details of the HEC-RAS river model, including model mesh, digital elevation model (DEM), input files and output results has been prepared.

1.3 Meetings and Stakeholder Consultation

Developing robust modelling tools and flood mapping for this study has been a collaborative process involving key stakeholder groups. The stakeholder groups consist of members from the following organizations: Cowichan Tribes, The City of Duncan, the Municipality of North Cowichan and the CVRD. Over the course of this work program NHC submitted memos outlining the methods and recommendations for key milestone decisions as listed in Table 1-1. The content of each memo was subsequentially presented to the stakeholder group in order to further discuss study methods and create opportunities for input and feedback. Feedback was recorded via meeting minutes and circulated.

Table 1-1: **Summary of memos and presentations NHC completed for this study.**

Memos and Reporting		Presentations and Meetings	
Date	**Document**	**Date**	**Topic**
Aug. 7, 2019	No. 1: Hydraulic model selection	Aug. 7, 2019	Presented memo 1 & 2
Aug. 7, 2019	No. 2: Data management and data collection	Nov. 19, 2019	Presented memo 3 & 4
Sep. 27, 2019	No. 3: LiDAR data quality	Jan. 7, 2020	Presented memo 5 and 6
Oct. 28, 2019	No. 4: Boundary conditions	Feb. 13, 2020	Presented memo 6 & 7
Dec. 13, 2019	No. 5: Flood mapping template	Apr. 23, 2020	Presented preliminary model results
Jan. 31, 2020	No. 6: Dike breach analysis	Jun. 23, 2020	LiDAR update meeting
Feb. 6, 2020	No. 7: Flood mitigation concepts		
Jun. 1, 2020	Interim Report	Sep. 1, 2020	Project update
Sep. 9, 2020	Memo-LiDAR assessment	Sep 29, 2020	LiDAR with GeoBC
Dec 21, 2020	Draft Final Report	Dec 8, 2020	Updated model/mapping
Feb 5, 2021	Final Report	Feb 11, 2021	Final presentation

2 PROJECT SNAPSHOT

Name: Updated Cowichan-Koksilah Flood Mapping Project

Location: Duncan, Vancouver Island, British Columbia

Agency: Cowichan Valley Regional District (CVRD)

Funding: National Disaster Mitigation Program, Emergency Management British Columbia, CVRD and Community Emergency Preparedness Funding, UBCM.

Goals: Develop up-to-date flood mapping for the lower Cowichan and Koksilah watersheds. Provide modelling tools to guide river management planning using a science based approach.

Objectives:

1. Develop a comprehensive hydraulic modelling tool that can be used to evaluate flood mitigation measures.
2. Develop updated 200-year Designated Floodplain maps for the lower Cowichan and Koksilah watersheds.
3. Develop flood mitigation concepts that can provide integrated water management planning along the river system.
4. Undertake consultation with stakeholder groups.

Approach: Collaborative, multi-phase approach, including stakeholder consultation.

Timeline: July 2019 – March 2020 (Interim study using 2016 LiDAR)
July 2020 – January 2021 (Finalization using 2019 LiDAR)

Project Outputs:

1. Updated hydraulic model (HEC-RAS 2D) capable of assessing flood levels for a wide range of flood scenarios in the study area for assessing the effectiveness of various structural flood mitigation projects.
2. Updated flood maps for a designated 200 year flood condition, representing a flood climate change scenario in the year 2100. The climate change scenario includes an increase in river discharge to account for projected increases in precipitation and an increase in ocean level to account for global sea level rise.
3. Raster mapping outputs in GIS format representing flood depths for designated present and future flood scenarios.
4. Hydraulic assessment of flood mitigation measure concepts.

3 THE COWICHAN WATERSHED

3.1 Setting

The Cowichan River watershed drains an area of approximately 939 km^2 and flows 47 km from near its headwaters at Cowichan Lake to the estuary at Cowichan Bay in the Straight of Georgia. Cowichan Lake has a surface area of 62 km^2 and has a significant effect on moderating flood flows on the lower Cowichan River.

The floodplain planning region covers an area of 21^2 includes portions of the City of Duncan, Municipality of North Cowichan, Cowichan Tribes lands, and the Cowichan Valley Regional District. Major tributaries of the lower Cowichan River are Somenos Creek and the Koksilah River. The Koksilah River joins the south branch of the Cowichan River near Clem Clem, before flowing into Cowichan Bay in the Strait of Georgia.

The average slope of the Cowichan River from Highway-1 to the estuary is 0.2 percent. The average slope of the Koksilah river is 0.1 percent, approximately half of the Cowichan River gradient. Due to its lower gradient, backwater effects from the ocean extend further up the Koksilah River than the Cowichan River.

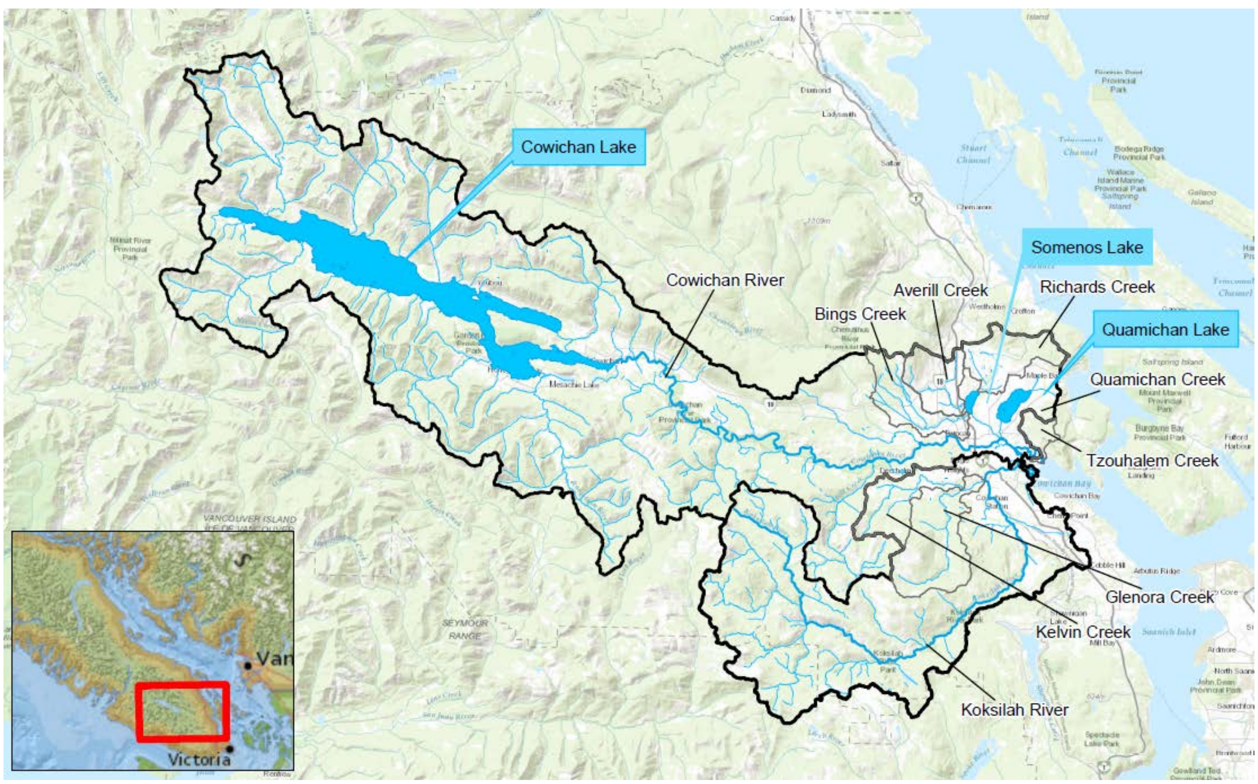


Figure 3-1: Overview of Cowichan Watershed.

3.2 Flood Generation Mechanisms

There are several distinct types of flood mechanisms on the Lower Cowichan/Koksilah River floodplain, including:

- Flooding on the mainstem rivers due to overtopping of banks and floodplain spills;
- Backwater controlled flooding on tributaries such as Somenos Creek;
- Flooding governed by high tides/storm surge in Cowichan Bay;
- Erosion, sedimentation and debris jamming which may lead to dike failures, bank breaching or major channel shifting (avulsions).

This study addresses each of these factors. The study does not assess flooding by local storm drainage, flooding from groundwater seepage or other mechanisms such as debris flows, landslide generated waves or tsunamis.

Flooding in the Cowichan region typically occurs from November to March. Multiple days of heavy rain and rain-on-snow events are the primary driving mechanism of riverine flooding. These intense winter storms are called atmospheric rivers and are sometimes referred to locally as 'pineapple express storms'. Atmospheric rivers consist of narrow bands of enhanced water vapor transport. Moist sub-tropical air from the Pacific Ocean is transported towards BC, bringing intense rain and warmer air temperatures. The extent of flooding brought by these winter time atmospheric rivers depends on antecedent conditions of the Cowichan watershed during the month leading up to the storm.

Previous experience has shown that the highest observed flood levels along the river does not necessarily coincide with the highest meteorological events due to the effects of sedimentation and flow obstruction from log jams. Past hydrometric monitoring has demonstrated that a moderately severe meteorological event combined with local sedimentation, flow obstruction and log jams can produce higher water levels than a more extreme meteorological event that occurs when the channel is unobstructed. This introduces an additional level of uncertainty in defining future flood levels, although the potential flood level rise can be mitigated partially by ongoing sediment and debris management.

Coastal flooding can occur along low-lying areas of the Cowichan Bay shoreline and occur when high astronomical tides coincide with relatively short-duration storm surges that are generated from cyclonic depressions passing over the Strait of Georgia. Low pressure systems are associated with wetter and windier conditions. During the winter months, easterly winds are most common for the region however the occasional northerly outflow wind can occur. North outflow winds are likely to generate waves in Cowichan Bay during winter flood conditions. North outflow winds flow out of the Fraser Valley, cross over the Gulf Islands and then typically split, with part of the system flowing towards Salt Spring Island. This results in southerly or easterly winds near Cowichan Bay.

4 FLOOD MANAGEMENT ISSUES AND CHALLENGES

A timeline of flooding and flood management activities that have taken place in the Cowichan watershed is presented in Figure 4-1.

4.1 Flood Management Prior to 2004

The Province (BCMOE) issued floodplain maps on the lower Cowichan-Koksilah River starting in the late-1970s and updated them again in 1997 (MOE, 1997). The Province also constructed the Cowichan South Side Dike and Cowichan Dike in the early 1980s (Figure 4-2). The dikes were regularly inspected and maintained by the Province until 2004. These engineered structures are classified as Primary Dikes in this report.

Many of the older historic dikes on the Cowichan-Koksilah floodplain are constructed on lands of the Cowichan Tribes where they are not subject to provincial regulations. It is our understanding the dikes were originally funded by Indian and Northern Affairs Canada (INAC) in the 1990s. These dikes include Koksilah Village Dike, South Side Spur Dike, Quamichan Dike, Hatchery Dike, Clem Clem Dike and Tooshley Island Dike. Other private dikes built in MNC and CVRD including Dinsdale Farm Dike, Rodenbush Dike and Blackley Farm Dike have limited ability to function as flood control structures, since they are either very low or have openings that will allow flood water to enter. There is no information on the design or construction practices for these structures. The dikes have generally not been maintained and some have experienced frequent overtopping and breaching. These non-standard structures are classified as Secondary Dikes in this report.

Flooding and Flood Management Activities

1960

1961
January 15
Several days of rain brought caused flooding. Flood event with approximately a 25-year return period. Fifty families in the Duncan North Cowichan area were evacuated. Large quantities of logs were transported in the rivers.

1968
January 19
Heavy rain brought flooding to the Cowichan Valley. Flood event with approximately a 16-year return period.

1970

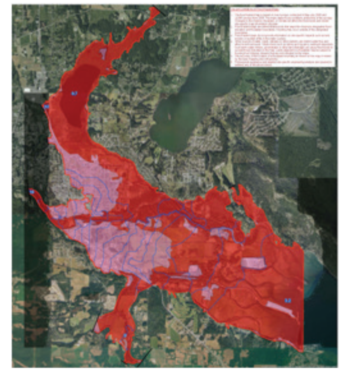
1972
December 25–26
Beverly Street was flooded, more than 50 families were forced to leave their homes. High tides damaged the docks. The Cowichan Bay area and the Reserve lands were flooded. Flood event with approximately a 13-year return period.

1980

1983
Construction of Cowichan South Side Dike

1987
Construction of Cowichan River Dike

2009
November 16–21
Flood event with approximately a 7-year return period. Flooded Lakes Road and JUB Sewage Treatment Plant, flooded the Cowichan Tribes Reserve. Three hundred homes were evacuated and $810k was required for long-term support for 121 families. Extensive flooding caused partially by accumulated gravel deposits and log jams.



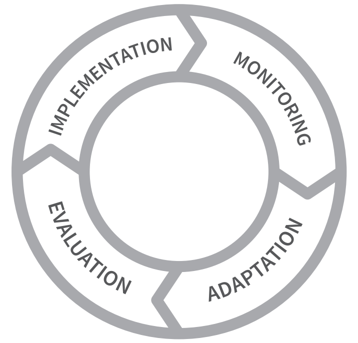
2009
March
Integrated Flood Management Plan completed for the lower Cowichan Watershed. Updated 200-year flood levels and outlined actions needed to reduce flood risk.

2010

2010
Memorandum of Understanding adopting integrated flood management plan, signed by Cowichan Tribes, City of Duncan, CVRD and District of North Cowichan

2011
Construction of JUB Lagoon Dike

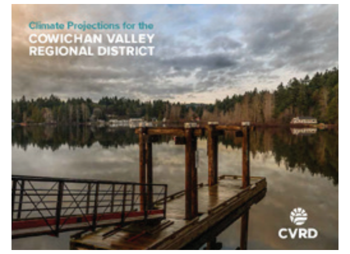
2012–PRESENT
Sediment and debris management program initiated. The purpose of this program is to identify management sites based on effectiveness to mitigate flood or erosion hazards.



2014
Cowichan Phase 1 dike construction: dike protection for the Cowichan River and Somenos Creek

2015
Cowichan Phase 2 dike construction: flood protection upstream of Hwy 1

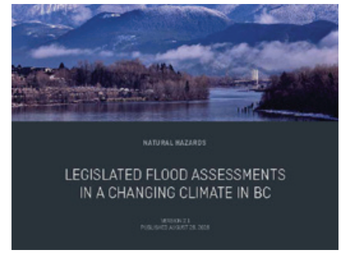
2015
Engineering and Geoscience BC releases flood mapping guidelines for British Columbia



2017
CVRD New Normal Cowichan – Phase 1 Report released "Climate projections for the Cowichan Valley Regional District".

2018
January 29
Heavy rainfall over 2-days flooded several areas of the Cowichan Valley. Several main roads were closed including Canada Avenue. Flood event with an approximate 11-year return period.

2018
Removal of log jam on Lower Koksilah



2018
August
Engineering and Geoscience BC releases flood assessment guidelines that incorporate climate change.

2020

2020
February 1
Record peak flows on Koksilah-Cowichan River causing evacuation of Cowichan Tribes members. Flooding closed Sahilton Rd, Cowichan Bay Rd and Canada Ave.

LEGEND

- EVENTS
- MITIGATION ACTIVITIES
- POLICY & GUIDELINES

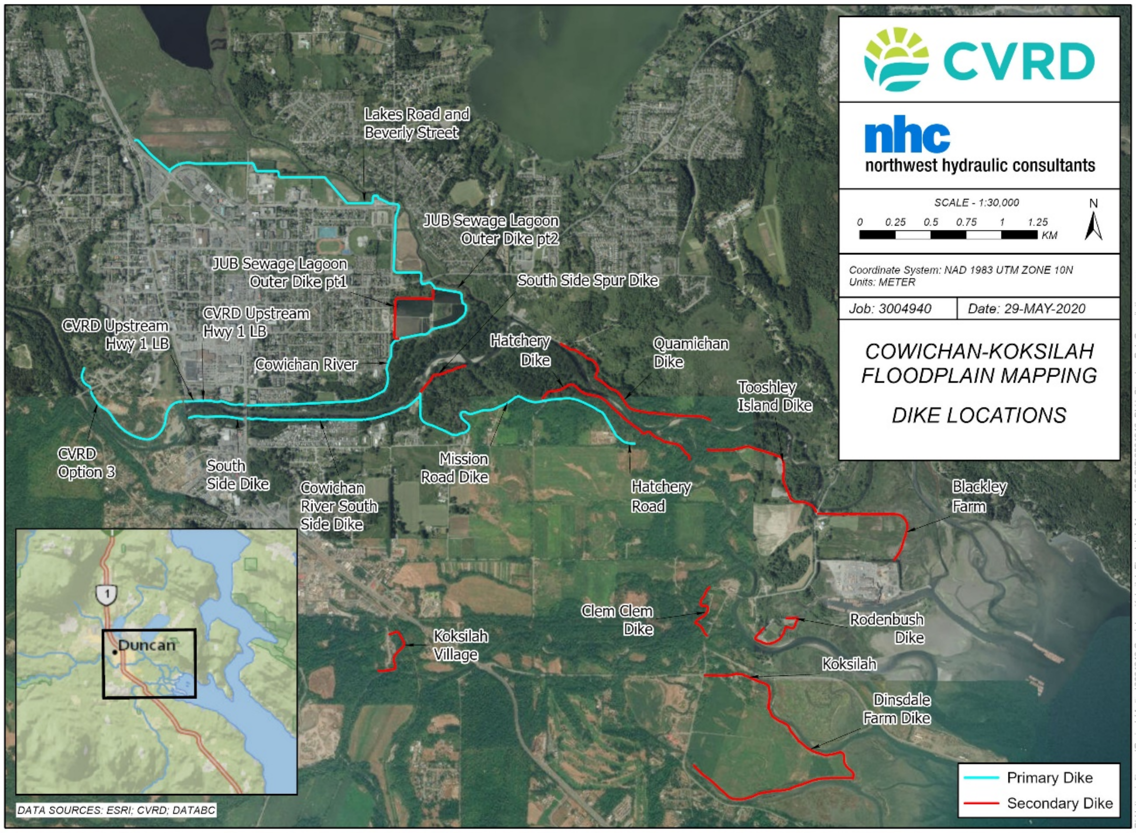


Figure 4-2: Location of flood dikes.

4.2 Flood Management After 2004

4.2.1 Legislative Changes

Since legislative changes in 2003 and 2004 the Province transferred many flood management responsibilities to local governments, giving them the authority to:

- Develop flood hazard area bylaws, including establish minimum setbacks from watercourses and dikes and to specify minimum flood levels for habitable dwellings (FBC, 2008).;
- Grant flood hazard area land development exemptions, provided that the exemptions are consistent with provincial guidelines or certified by a suitably qualified professional;

- Establish the requirements for subdivision in flood prone areas, which includes engineering reports assessing flood hazards and restrictive covenants[2] .

The responsibility to update and maintain the flood maps was also delegated to local authorities.

4.2.2 2006-2009: Update of Flood Mapping and Integrated Flood Management Plan

CVRD and its partners carried out a multi-disciplinary study, completed in 2008 and reviewed in 2009 post-flood to develop an integrated flood management plan (IFMP) for the lower Cowichan-Koksilah Rivers (Figure 4-1). Hydraulic modelling studies identified that large portions of the floodplain were vulnerable to flooding and that many of the existing dikes did not have adequate freeboard or would overtop during high flows. A portfolio of non-structural and structural flood mitigation measures were developed as part of the plan. In total, 20 projects that promoted the Plan's guiding principles and incorporated habitat enhancement as important project components were outlined. The types of projects included:

- Dike upgrades or new dike construction, with the focus on set-back dikes to minimize raising water levels due to confinement effects
- Channel maintenance and improvement programs for sediment management and log jam removal.
- Upstream sediment and debris control
- Bridge and road upgrades to reduce flow obstruction and backwater effects
- Recommended habitat compensation projects to promote a more naturalized floodplain and channel system.

This 2021 mapping program is an update to that base information and provides updated tools for ongoing flood management.

4.2.3 Flooding 2007 – 2009

In 2007 three powerful storms hit Vancouver Island over a period of five days in December. The flood peak on the Koksilah River was the highest on record, causing Highway 1 to be overtopped and widespread flooding around Cowichan Bay Road.

In 2009 a series of frontal systems hit coastal British Columbia generating flood damage on both the Koksilah River (2007) and Cowichan River (2007-2009). The worst flooding occurred in the Cowichan Valley on Friday, November 20, 2009. Following more than a week of rain, the Cowichan and Koksilah Rivers and several creeks overflowed their banks. Highway 1 was closed north of Duncan due to high levels in Somenos Lake. Over 50 home were flooded in North Cowichan, the City of Duncan and on Cowichan Tribes land. Residents were evacuated, roads and schools were flooded and closed, and property damage was extensive (Photo 1 and Photo 2). Between November 15 and 26, the MNC raised

[2] www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/flood-hazard-land-use-management

dikes and filled gaps and low spots in certain critical areas near the flooded areas around Lakes Road. Emergency measures were also carried out at the JUB sewage lagoons to prevent a breach of the lagoon dikes after sections were overtopped.

A post-flood assessment of the flood conditions (NHC, 2010) showed that the hydro-meteorological conditions were not exceptional; the peak discharge on the Water Survey of Canada's gauge near Duncan (0HA011) had an estimated return period of 7 years. The peak discharge on the Koksilah River was less than a 2 year event. Large log jams on the Cowichan River near the JUB outfall, Somenos Creek confluence, North Branch of the Cowichan near Tooshley Island and lower Koksilah River all contributed to the high flood levels during the event. Log jams and sediment aggradation were a significant factor to the high flood levels (representative examples of log jams are shown in Photos 3 to Photo 5).

4.2.4 Flood Mitigation Actions Since 2009

2010-2015: Flood Protection Upgrades

Beginning in 2010 a substantial effort was made to upgrade the system of flood dikes along the Cowichan River (Figure 4-1). Funding for the work was primarily through Emergency Management BC (EMBC) and the local governments in the region. The work included:

- Raising and strengthening the JUB sewage lagoon dike.
- Replacing the existing low berm along Lakes Road and Beverly Street with a new set-back primary flood dike and pump stations up to Highway 1.
- Erosion protection at Quamichan village road.
- Raising and strengthening the existing Mission Road Dike and Hatchery Dike to form a new set-back primary flood dike along the south side of the Cowichan River.
- Re-building a new section of the South Side Spur Dike to connect the Mission Road Dike and Cowichan South Side Dike.
- Constructing new dikes on both banks of the Cowichan River upstream of Highway 1.
- Constructing a flood wall on the south side of the Cowichan River upstream of the rail bridge.

2012: Sediment Management Strategy

In 2012, CVRD initiated a three year project to design and implement a longterm sediment and large woody debris (LWD) management strategy for the Cowichan and Koksilah Rivers. The objective was to develop a 20-year program with regulatory input that would allow ongoing sediment management programs in key locations to reduce flood impacts and to maintain safe operation of the diking system. The objectives of the program included both flood mitigation and habitat restoration. A sediment management plan was published in 2012 and several sites for systematic removals were identified (NHC, 2012). Sediment and log jam removals were carried out in 2012 and 2013, and post-construction monitoring continued until 2015. The goal of the strategy was to maintain a stable design flood profile to ensure that flood levels will not continue to rise over time due to sedimentation and debris accumulation. A network of real-time hydrometric monitoring stations was installed in 2015 to detect high water and impacts of log jams and debris on flood levels.

Cowichan Tribes took on the sediment management program in 2016 and has continued to expand the scope and scale of the work since then (Figure 4-3). A major log jam removal project was carried out on the Koksilah River in 2018 as shown in Photo 3.

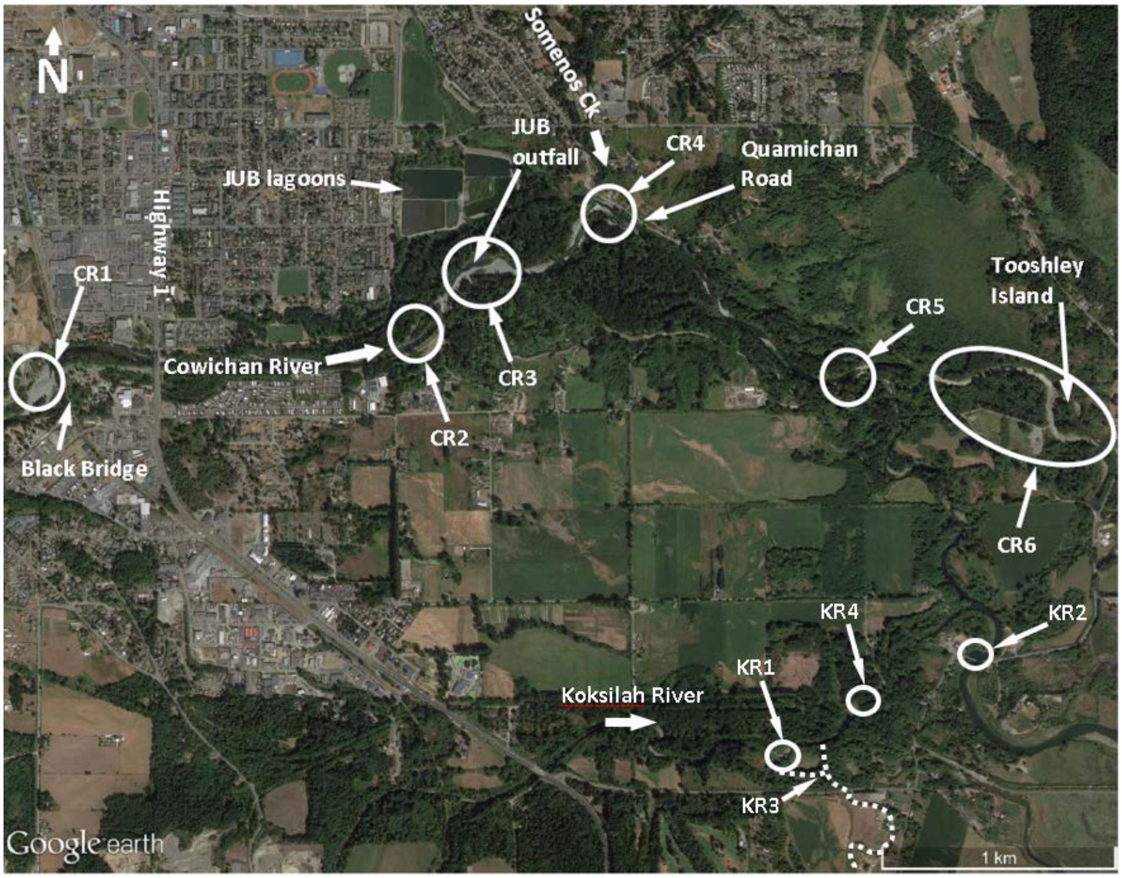


Figure 4-3: Sediment and logjam management sites on Cowichan-Koksilah Rivers

2010 Partners Memorandum of Understanding

Given the complexity of managing flood infrastructure and ongoing flood reduction programs across four distinct local governments, a joint understanding of objectives and process was necessary to ensure that the flood impacts are addressed systemically across the floodplain. Consequently a Memorandum of Understanding was developed between the CVRD, MNC, CT and City of Duncan. Highlights of the approach are as follows:

Approach: It was stated that the Parties will be guided by a long term, sustainable and achievable lower Cowichan/Koksilah Integrated Flood Management Plan. The Plan will be a living document subject to revision from time to time as required and based on the most up to date information available including local, traditional and scientific knowledge.

Goals: The main goals included:

1) Flood risk to all communities on the floodplain will be reduced, while protecting aquatic and riparian habitat and acknowledging the cultural values of the rivers.

2) Innovative methods of flood hazard management that contribute to short and long-term economic, environmental and social benefits and minimize negative economic, environmental and social impacts will be promoted.

3) Integrated flood management will be valued and sustained by all communities and stakeholders over the long term.

Strategies: The following strategies were adapted from the IFMP (2009):

1) Return the rivers and their tributaries to a more natural state considering economic, environmental and social values.

2) Strive to sustain the natural state of the existing floodplain.

3) Redevelopment in existing developed areas will be supported if flood-proofed to 200 year levels and provided the developments

4) do not increase flood hazards to other areas.

5) Site future development in areas with low flood hazard and low habitat sensitivity and work together to solve the challenges of land availability for development (areas protected from 200 year flooding are considered to be low flood hazard areas).

6) Ensure new or upgraded flood protection structures do not adversely increase the overall flood hazard.

7) Decrease flood related vulnerability to people, areas of development and habitat.

8) Mitigate impacts of high flows on the main-stem of the river by facilitating flow through off-channel habitat.

9) Work together to develop long-term mechanisms to share the benefits of maintaining a functioning flood-plain (e.g. leasing lands to buffer effects of high flood conditions).

10) Establish and maintain accessible and sustainable tools for flood management (e.g. computer modeling; Geographic Information Systems (GIS), in-river flow meters, early flood alert systems).

11) Promote integrated planning initiatives for the lower Cowichan/Koksilah Rivers and floodplain.

12) Monitor and maintain flood management projects.

2015: Establishment of Cowichan Flood Management Function

A watershed based CVRD function was approved at referendum to provide the CVRD with the legal ability to partake in flood management activities, primarily to coordinate ongoing flood management activities, maintain the flood maps and consider other flood management activities in the watershed. This function supports activities in the Cowichan Watershed.

Flood Management Working Committee

This is a joint committee with membership of the CVRD, MNC, Cowichan Tribes and the City of Duncan which provides an ongoing mechanism to coordinated flood management activities across the Cowichan Koksilah Floodplain. CVRD informed NHC that key activities anticipated for 2021-2026 will be as follows:

- 2021/2022: Ongoing discussions on joint investments and a formal structure for sediment management.
- 2021/2022: Development of an integrated asset management strategy for flood infrastructure.
- 2021: Joint agreement and inspections and maintenance
- 2022 – 2028: Additional flood management/reduction activities proposed under Federal Disaster Mitigation and Adaptation Fund (DMAF).

4.3 Future Flood Management Issues-Climate Change

4.3.1 Increased Frequency of Floods and Higher Discharges

The Pacific Climate Impacts Consortium (PCIC) worked with the CVRD and a multi-stakeholder team to produce high-resolution regional projections to understand how the climate in the region may change in two future time intervals; 2050s (average of 2041-2070) and 2080s (average of 2071-2100) (CVRD, 2017). The report presents information on temperature, precipitation, and other related extreme indicators to illustrate how the region's climate is expected to change over time. The analysis was conducted for three Green House Gas (GHG) emission scenarios, RCP[3]2.6, RCP4.5 and RCP 8.5. Results of the "business as usual" scenario (RCP8.5) were reported in detail, while results for the other scenarios are available as a download. An ensemble of 12 climate models were chosen for that study to represent the range of projected change in each climate parameter. For each parameter, both the mean and the 10^{th} to 90^{th} percentile range are reported. Results of predictions of changes to extreme precipitation values are summarized below in Table 4-1. The "Water Supply Watersheds" included the headwaters of the Cowichan River (upstream of Cowichan Lake) and upper Koksilah River. The "Developed Watersheds" included the lower portions of the two rivers and areas draining into Somenos Lake.

[3] RCP refers to Representation Concentration Pathway, which is a greenhouse gas concentration trajectory adopted by the International Panel on Climate Change.

Table 4-1: Projections of increased intensity of storm rainfall in the region (CVRD 2017).

Precipitation Parameter	Water Supply Watersheds 2050s	2080s	Developed Watersheds 2050s	2080s
5-day Maximum Precipitation	11% (2%-20%)	23% (8%-32%)	10% (4%-21%)	24% (6%-34%)
1-day Maximum Precipitation	18% (3%-5%)	30% (10%-44%)	16% (3%-31%)	30% (10%-46%)
1:20 Year wettest day precipitation	32% (9%-50%)	42% (23%-59%)	24% (8%-43%)	36% (14%-55%)

1. Note: Mean changes from the baseline (1971-2000) are shown. 10th and 90th percentile values are included in parenthesis.
2. 5-day maximum precipitation: the largest amount of rain that falls over a period of 5 consecutive days in the year.
3. 1-day maximum precipitation: the largest amount of rain that falls on any single day in the year.
4. 1:20 year wettest day precipitation: the day so wet that is has only a 1-in-20 chance of occurring in any given year.

The model scenarios show 1-day maximum precipitation increases of 18% in the 2050s time period in the Water Supply Watersheds and 16% increases in the Developed Watersheds. In the 2080s time period, the precipitation values are projected to increase by 30%. It should be noted that the range in projections is very large, reflecting the uncertainty in the estimates. For example, the projected increases in 1-day maximum precipitation by the year 2080 for water supply watersheds ranges from 10% to 44%, while the average value is 30%. There are considerable differences between 1-day, 5-day and 1:20 year wettest day projections, making it difficult to interpret the potential changes to extreme events and effects on flood generation. However, it should be noted that floods on large, lake regulated watersheds such as the Cowichan are governed by precipitation events that last 3 to 5 days duration rather than a 1-day event.

The available climate projections do not directly represent runoff generation or the resulting changes to discharges in the rivers. Additional hydrological modelling could potentially improve the estimates of future peak river discharges during floods. This would be a major task and is outside the scope of this current study. Furthermore, given the lack of actual hydro-meteorological data in the watersheds, it may not necessarily provide more definitive answers on how extreme events (200-year floods) will respond to climate change. The underlying projections of climate change are subject to large and unquantifiable uncertainty, including:

- Unknown future emissions of greenhouse gases
- Uncertain response of the global climate system to increases in greenhouse gas concentrations
- Incomplete understanding of regional and local manifestations that will result from global changes

The analysis by (Kundzewicz et al., 2014) which is based on a substantial body of literature including the IPCC SREX[4] report on climate extremes, concluded:

[4] IPCC SREX refers to the Intergovernmental Panel on Climate Change Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.

"presently we have only low confidence in numerical projections of changes in flood magnitude or frequency resulting from climate change".

This leaves floodplain mapping practitioners and local governments in the difficult position of making decisions under a high degree of uncertainty.

EGBC guidelines indicate peak flows should be increased by a minimum 10% to account for climate change when no other climate information or climate modelling is available for guidance and 20% if data is available indicating a trend to increasing runoff over time. Therefore, following this guidance the designated 200 year discharge was increased by a factor of 20% to represent Year 2100 flood conditions.

4.3.2 Sea Level Rise and Increased Coastal Flooding

Research on sea level rise has been ongoing and intensive since the provincial guidelines were first issued (Ausenco-Sandwell, 2011b). The most recent comprehensive study relevant to this project was published by the National Oceanographic and Atmospheric Administration (NOAA) in 2017 (Sweet et al. 2017). The report includes recent observations and modelling literature related to potential rapid ice melt in Greenland and Antarctica. The projections, and results presented in several peer-reviewed publications, support a plausible global mean SLR in the range of 2.0 to 2.7 m and recent observations regarding Antarctic ice-sheet instability indicate that such outcomes may be more likely than previously thought. As a result, Sweet et al. (2017) recommended a revised "extreme" upper bound scenario of 2.5 m by the year 2100 (0.5 m higher than the upper bound estimate published in 2012 (Parris. A., et al., 2012), which was adopted previously in the third US National Climate Assessment.

Figure 4-4 (lower set of curves) plots the range of the (Sweet et al., 2017) projections. The RCP 8.5 5% (lower bound) and RCP 8.5 95% (upper bound) confidence levels that were used in the provincial coastal floodplain mapping guidelines (MFLNRO, 2011, Ausenco-Sandwell, 2011b) are shown in the top graph for reference. The two lines used in the 2011 guidelines follow closely to the "Low" and "Intermediate" Sweet et al. (2017) curves.

For the purposes of the floodplain mapping, a global sea level rise of 1 m was included for the floodplain mapping investigations. Estimates of local sea level rise are made by adjusting the global rate to account for local tectonic and iso-static effects (the rising of the land due to geological uplift or post-glacial re-bound). On the east coast of Vancouver Island most areas continue to slowly rise by 1 to 2 mm/year, slightly offset global sea level rise by approximately 0.1 m to 0.2 m/century. However, portions of the delta in Cowichan Bay may be subsiding due to compaction of the sediments that form the tidal flats, offsetting tectonic uplift. Long-term natural subsidence rates of 1 to 2 mm/year on the Fraser delta have been reported (Mazzotti et al, 20009; Ertolahti, 2014) with locally higher rates adjacent to structures that have induced consolidation of the fine-grained sediments. However, the sediments in the Cowichan tidal flats/delta are substantially coarser (gravel and sand) than the Fraser and may not exhibit comparable rates. Given these uncertainties, it was assumed that local sea level rise was the same as global sea level rise and a value of 1.0 m was adopted for the study. This is a conservative assumption in terms of flood mapping, since most of the area where habitable development is possible are more likely to be experiencing uplift than subsidence.

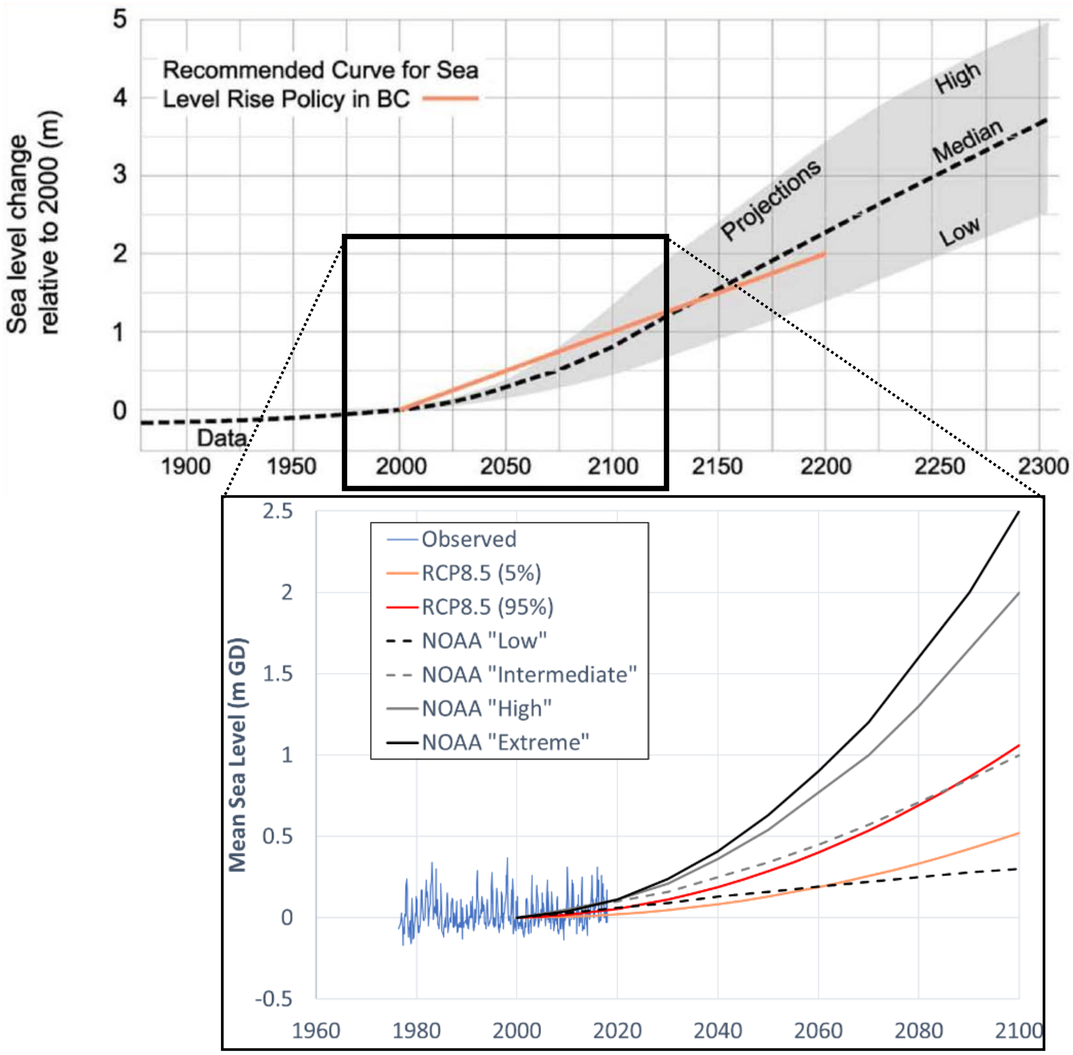


Figure 4-4: Global SLR from (Ausenco-Sandwell, 2011) (top plot) and updated predicted global SLR scenarios (Sweet et al., 2017) with observed ocean levels at Patricia Bay added in blue (bottom plot).

4.4 Summary of Future Flood Management Challenges

This section summarizes the key flood management challenges will need to be addressed to reduce and mitigate flood damages in the region over the coming decades:

- The lower floodplain is a broad, low gradient alluvial fan that coalesces into a coastal plain. Over the last century increasing sediment supply from the watershed, re-alignments of the rivers for roads, rail lines and bridges, and channelization works have increased the risk of local channel shifting and avulsions. ***Long term sediment and debris management are now essential for maintaining the stability of the river system and ensuring that dikes will function during critical time periods.***

- Much of the densely populated portion of the floodplain is now ringed by dikes. So long as they are regularly inspected, maintained and upgraded (if necessary) in response to climate change, these structures can provide security against most flood events. However, dike breaching could lead to flow spills and ponding of water on the floodplain. Therefore, monitoring and dike maintenance are essential components of the flood management planning in the region.
- High ocean levels contribute to flooding in the lower coastal portion of the floodplain particularly along portions of lower Tzouhalem Road and Cowichan Bay Road near Clem Clem. Impacts from coastal flooding and backwater from high ocean levels will extend inland further over time in response to sea level rise.
- The intensity and frequency of river flooding is anticipated to increase over time in response to climate change. This will lead to a need for a dynamic, adaptive planning approach to manage the changing nature of the flood hazard over time.

5 OVERVIEW OF FLOODPLAIN MAPPING STUDY

5.1 Study Extent

The flood mapping project covers the floodplain of the Lower Cowichan and Koksilah Rivers

5.2 Study Approach

There are several reasons for updating and extending the previous work:

1) Additional information on climate change and sea level rise is available now and has been incorporated into floodplain mapping guidelines and practice. This information was not available at the time of previous investigations.

2) New flood dikes and other infrastructure has been constructed since the time of the previous studies which will affect hydraulic conditions on the rivers.

3) Better topographic information (Lidar and bathymetric surveys of the channels) is available for conducting the hydraulic modelling and for preparing flood maps.

4) New guidelines and standards have been published on flood mapping (listed below).

This study builds on the past flood management plans and initiatives that have been carried out in the region (Section 0). The study has been divided into three phases: 1. Data collection; 2. Hydraulic and Wave modelling; 3. Flood mapping.

5.3 Flood Mapping Guidelines

The following guidelines were considered in the development of this document:

- Flood Mapping in BC – Professional Practice Guidelines (APEGBC, 2017).
- Legislated Flood Assessments in a Changing Climate in BC – Professional Practice Guidelines (EGBC, 2018).
- Flood Hazard Area Land Use Management Guidelines (FLNRORD, 2018).
- Coastal Floodplain Mapping – Guidelines and Specifications (MFLNRO, 2011)
- Guidelines for Management of Coastal Flood Hazard Land Use (Ausenco-Sandwell, 2011)
- The Canadian Federal Flood Mapping Guidelines Series (currently under development). There are several documents already published in this series. Of particular relevance to mapping standards are the Geomatics Guidelines for Flood Mapping (Natural Resources Canada, 2019).

5.4 Hydraulic Modelling Tools

5.4.1 River Model

A two-dimensional hydraulic model is a key tool for simulating flood levels and improving the understanding of flood hazards, risks, and mitigation options. Results from the model will help estimate flood extents, depths and velocities under different flood and dike breach scenarios; evaluate the effectiveness of different flood mitigation options; and inform a range of decision-makers and stakeholders.

NHC undertook preliminary evaluation of several modelling software packages, narrowing the selection to RAS2D and TELEMAC2D. NHC used a previously developed TELEMAC2D model of the Cowichan-Koksilah floodplain and developed a test RAS2D model using files exported from the TELEMAC2D model. A 200-year flood event was simulated with both models. Slight differences in the flood extents were attributed to differences in the mesh.

The RAS2D software was selected due to a number of significant technical advantages over the TELEMAC2D software, namely:

- Superior graphic user interface.
- the ability to model the effects of pressure and overtopping flow at bridges and culverts.
- RAS2D's modelling technique of combining a large cell with underlying terrain allows for readily simulating the interaction of overland flow with topographic controls on the floodplain such as roads or dikes.

A detailed memo summarizing selection of hydraulic modelling software was submitted to the CVRD in August 2019.

5.4.2 Coastal Model

A wave model (Simulating Waves Nearshore or SWAN) of the Strait of Georgia, Saanich Inlet, and Cowichan Bay was developed to model wave generation and propagation from deep water into coastal areas and shorelines. SWAN is a third-generation wave model, developed at Delft University of Technology in the Netherlands, that computes random, short-crested wind-generated waves in coastal regions and inland waters. SWAN incorporates physical processes such as wave propagation, wave generation by wind, white-capping, shoaling, wave breaking, bottom friction, sub-sea obstacles, wave setup and wave-wave interactions in its computations. SWAN version 41.20 was used for this study.

5.5 Field Investigations and Survey Data

5.5.1 Available Data From Previous Studies

Topography

NHC has completed numerous studies in the project area over the past 10 years. Previous NHC studies entailed collecting bathymetric and hydrometric data along with completing bridge surveys. Previous NHC bathymetric surveys on the Cowichan and Koksilah Rivers were compiled for the period 2008 to 2018. In reaches where gravel management projects have been implemented, several years of repeat bathymetric surveys were available from previous NHC studies. These studies included estimating the volumes of sediment removed from various project sites.

Hydrometric Monitoring Stations

Several organizations including CVRD, Municipality of North Cowichan, Cowichan Tribes and FLNRO operate water level monitoring stations in the study area. This data was used to calibrate and validate the hydraulic model. Further detailed technical information on existing data and surveys can be found in Appendix A.

5.5.2 Additional Surveys and Field Investigations

Existing bathymetry provided adequate data for the study channels with the exception of a section of the Somenos Creek and Koksilah River. To address this gap, sections of the Somenos and Koksilah channels were surveyed under the current work program.

A series of terrestrial surveys were completed to support development of the hydraulic model. Hydrometric benchmark surveys were undertaken to complete datum shifts and high water mark surveys from photo documentation were used to support model calibration. All elevations were referenced to Canadian Geodetic Vertical Datum (CGVD) 2013. Details of the survey coordinate system adopted for the project are provided in Appendix A.

5.5.3 LiDAR Data

LiDAR data was collected by the province for the flood mapping project between 12 June and 24 July 2019. Due to delays by GeoBC in processing and delivering the LiDAR, this data was not available until

April 2020. Therefore, LiDAR from November 2016 was used for initial model development and interim reporting (NHC, 2020). The interim results have been superseded by the updated work described in this report.

The completed 2019 LiDAR data covers the Cowichan and Koksilah floodplains. Additional ground surveys were carried out by NHC to confirm the vertical accuracy of the data; the root mean square error was estimated to be 0.03 m. The bare earth point density (DSM) was 8 pts/m^2, which complies with the Federal Guidelines for the high flood risk category (Federal Flood Mapping Framework (Natural Resources Canada, 2018); and Federal LiDAR Acquisition Guidelines (Natural Resources Canada and Public Safety Canada, 2020)).

NHC developed a Digital Elevation Model (DEM), combining the LiDAR and bathymetric surveys for the study area. The finalized DEM was used to develop the Cowichan-Koksilah 2D hydraulic model.

6 HYDROLOGY

6.1 Overview of hydrologic analysis

An updated hydrologic analysis was completed for the Cowichan and Koksilah watersheds. The hydrologic analysis provides the required discharge data for the flood model at points of inflow as shown in Figure 6-1. A brief overview of the hydrologic assessment is provided below. Further detailed technical information regarding the hydrologic analysis can be found in Appendix B.

Statistical frequency analysis was completed on Water Survey of Canada (WSC) gauges listed in Table 6-1. The resulting frequency analysis values adopted for model inflows are presented in Table 6-2. The frequency analysis results for Bings Creek were transferred to tributary model reaches using area-based scaling according to methods outlined in Eaton et al. (2003). The design flow values for the river systems have increased since the last flood study by NHC (NHC, 2009). Several large floods have occurred since 2007 (Figure 4-1) that have shifted the frequency analysis. A review of guidelines and best management practices for incorporating climate change into boundary conditions was completed and results were presented to the CVRD along with a technical memorandum. A climate change factor of a 20 percent increase in peak flows was approved by the CVRD and project partners and adopted for the designated flood scenarios. The designated future (Year 2100) 200-year flood discharges on the Cowichan and Koksilah River (896 m^3/s and 601 m^3/s) correspond to a return period of approximately 1,000 years under present conditions.

For model simulations, synthetic flood hydrographs were developed with the assumption that the flood hydrograph shape follows that of a recorded WSC hydrograph shape. Flood hydrographs from February 2020 and January 2018 were large single peak floods (versus double peak) and therefore were selected as representative flood hydrograph shapes for scaling.

For design simulations it was assumed that the Cowichan and Koksilah Rivers peaked at the same time. This assumption appears to be reasonable given review of the calibration floods for this study indicate the two rivers peaked within hours of each other for all calibration flood events (see Appendix E Hydraulic Modelling).

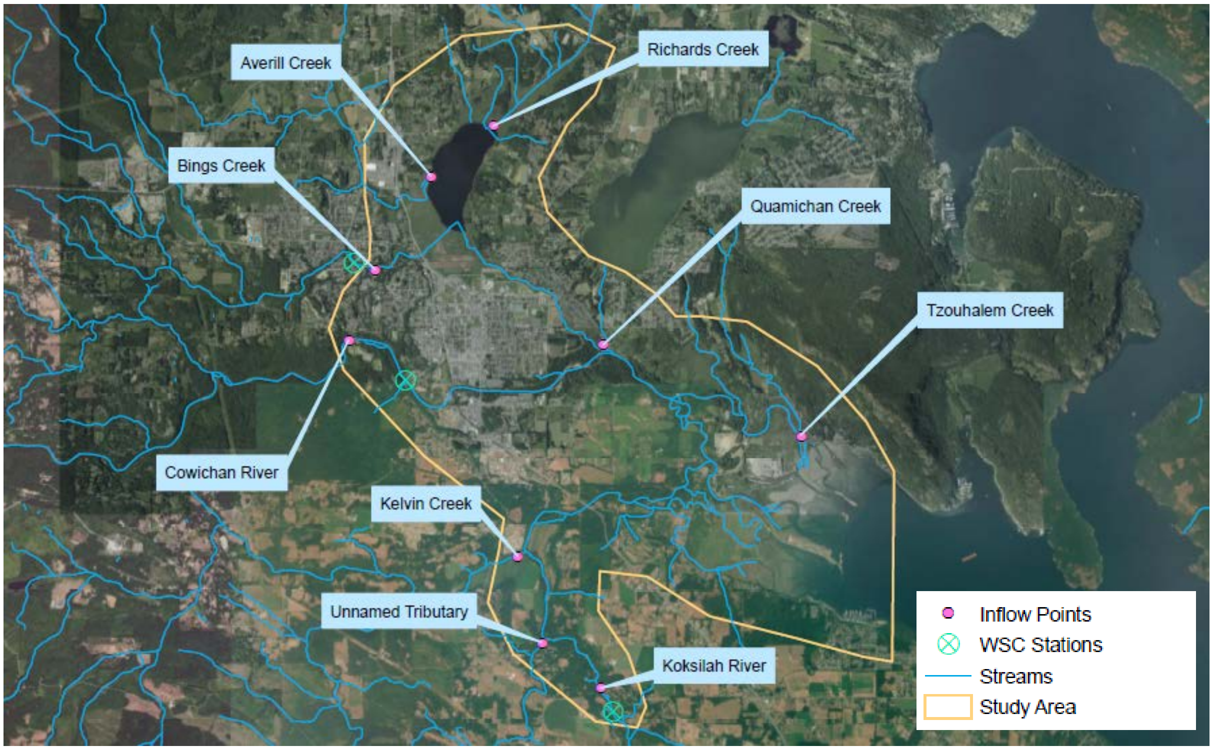


Figure 6-1: Points of inflow for the hydraulic model.

Table 6-1: Water Survey of Canada stations used for design inflows.

River	WSC gauge	Record	Regulated	QPI Record	QPD Record	Basin Area (km^2)
Cowichan River at Lake Cowichan	08HA002	1913-1919, 1940-present	Y	1940-present	1914-1918, 1940-present	594
Cowichan River near Duncan	08HA011	1960-present	Y	1977-present	1960-present	826
Koksilah River at Cowichan Station	08HA003	1914-1917, 1954-present	N	1990-present	1915-1916, 1960-present	209
Bings Creek near the mouth	08HA016	1961-present	N	1994-present	1962-present	15.5

Table 6-2: Summary of adopted design flows for this study.

Return Period (years)	Cowichan River near Duncan (08HA011)	Cowichan River near Lake Cowichan (08HA002)	Koksilah River near Cowichan Station (08HA003)	Bings Creek near the mouth (08HA016)
	QPI (gum)	QPI (pe3)	QPI (Gev)	QPI (gev)
	1960-2020	1957-2020 post weir	1990-2020	1994-2020
10	468	260	311	19
20	534	283	352	21
25	555	290	366	22
50	619	309	409	24
100	683	328	454	26
200	747	344	501	27
250	767	350	517	28
500	830	365	566	30

6.2 Uncertainty Associated with Hydrometric Data

The rating curve for 08HA011, Cowichan River near Duncan, is presented in Figure 6-2. The actual measured discharge values completed by WSC are indicated by large blue circles. The hourly published water level and discharge data obtained from WSC for years 2015-2020 is also plotted. Review of the rating curve shows that only two high flow measurements have been made since 2009, with the highest measurement reported being 202 m^3/s in 2010. The only high flow measurements in the entire period of record were made in 2007 (401 m^3/s) and 2009 (407 m^3/s). The published winter flood discharges since 2015 appear to have been estimated using several different assumed rating curves, and the resulting estimated discharges and corresponding water levels often don't fit the available high flow measurements even though these points are the only reliable information for estimating peak flows.

This difference is most pronounced for discharges above 250 m^3/s. The published discharge and water level records from 2019 and 2020 appear to fit the actual measured rating curves best, while the published values from 2015 through 2018 all plot systematically below the actual observations (often by 0.3 to 0.4 m). This suggests the published peak flows from 2015 to 2018 may be overestimated. Model calibration scenarios simulate Cowichan River flows that ranged from 307 to 564 m^3/s for flood events between 2015-2020. The uncertainty associated with WSC's discharge data will be translated into uncertainty in the subsequent modelled flood levels. This is further discussed in Appendix E and Section 8.1.

A similar review was carried out on the published peak flows on the Koksilah River at Cowichan Station (8HA003). The situation on the Koksilah River is even more problematic. The highest observed flow measurement was 223 m^3/s in March 1997 and the second highest measurement was 134 m^3/s in 2015. The published peak discharge from 2020 was 382 m^3/s, far beyond the range of the actual discharge measurements and the general trend of the values plotting far off the trend of the measurements.

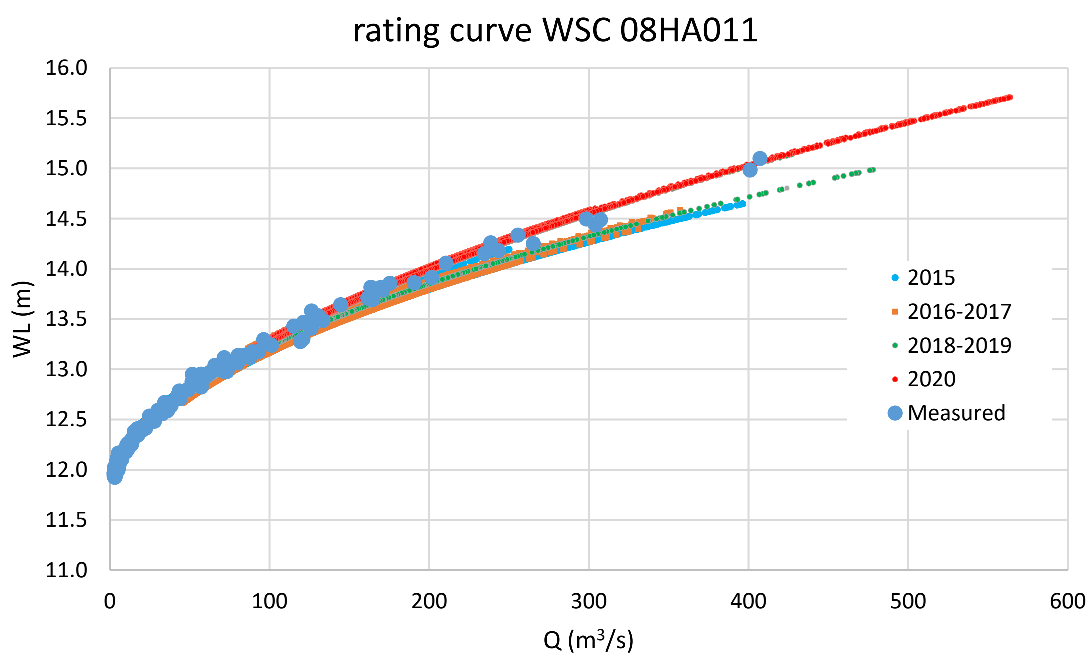


Figure 6-2: Rating curve for WSC 08HA011, Cowichan River near Duncan.

7 DESIGNATED FLOOD SCENARIOS

7.1 Timing of River and Coastal Flood Events

In the lower reaches of Cowichan and Koksilah Rivers, the water levels are governed by the complex interaction of river flows, the astronomical tide level and the magnitude of any storm surge. The highest water levels at any location do not necessarily correspond to the highest inflow discharge or highest ocean level. The available guidelines for floodplain mapping in British Columbia do not provide useful guidance on how to quantify the risk of flooding in tidally-affected rivers and estuaries. It has been common practice in BC to assume the 200 year river flood discharge coincides with the 200 year maximum ocean level (including astronomical tide, surge and local wind set-up). However, in many cases the probability of these two events occurring simultaneously may be very low. For example, during this study, a significant flood occurred during February 2020 (Figure 7-1). Peak ocean levels did not coincide with peak discharge. Additionally, the flow of the Cowichan River was approximately a 30-year flood while the ocean level return period was less than a 1.5-year event.

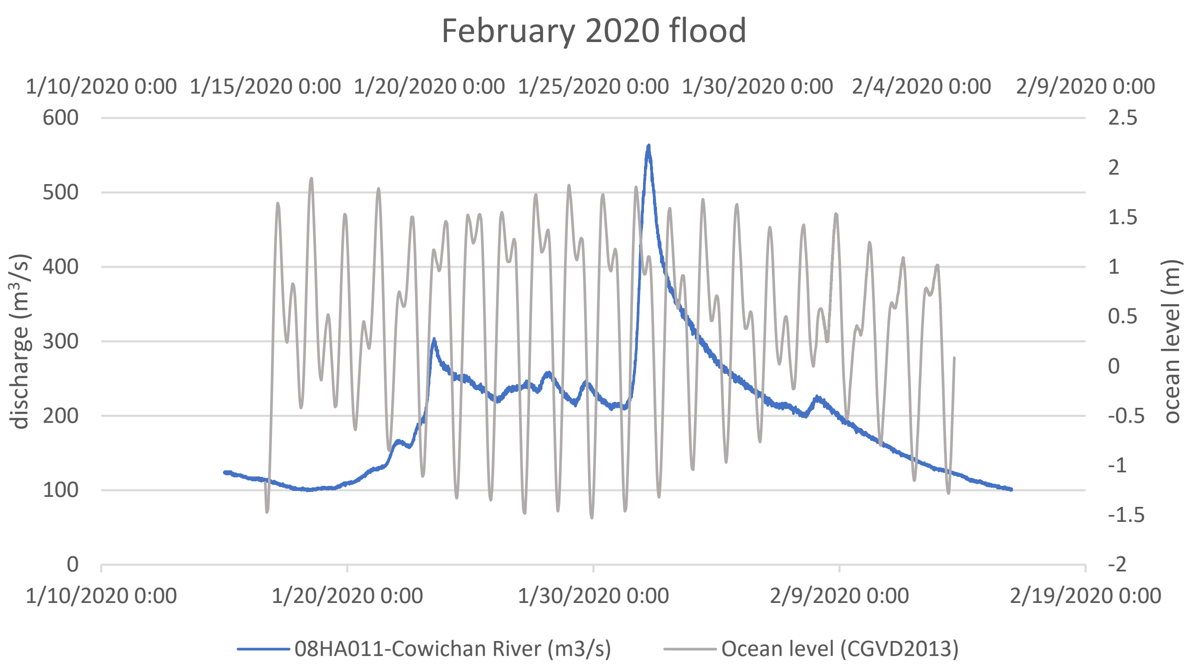


Figure 7-1: Observed discharge and ocean levels during the February 2020 flood event.

7.2 Joint Occurrence of River and Coastal Flooding

To determine the appropriate combination of ocean levels and river discharges for the designated flood scenarios NHC undertook a joint probability analysis adopting methods as outlined in (White, 2007). This involved a statistical analysis of daily maximum ocean levels and the corresponding daily discharges using coincident records between 1952 and 2018. Figure 7-2 is a scatter plot illustrating that there is only a weak dependence between high river flows and high ocean levels. The level of dependence was quantified in terms of defining the probability that if the river inflows exceeded a given threshold (say a 1% exceedance), the ocean level would also exceed a corresponding threshold. The detailed methodology and results of the joint probability assessment are presented in Appendix D. The results of this analysis confirmed that extreme river inflows and ocean levels have a low probability of occurring simultaneously. Based on the estimated level of dependence it was decided to represent the designated 200-year river inflow and ocean level scenarios as shown in Table 7-1. The first scenario represents an extreme river discharge (200 year event) combined with a moderately high ocean level (10 year event). The second scenario represents a moderately high river discharge (10 year flood) combined with an extreme ocean level (200 year event). The river inflow values in the table are from the previous results summarized in Table 6-2. The corresponding ocean levels in Table 7-1 are based on the analysis presented in Appendix C and summarized briefly later in Section 9. The hydraulic model results from each scenario were run and then the highest of the two values at each location on the floodplain were selected to represent the final adopted 200 year water level.

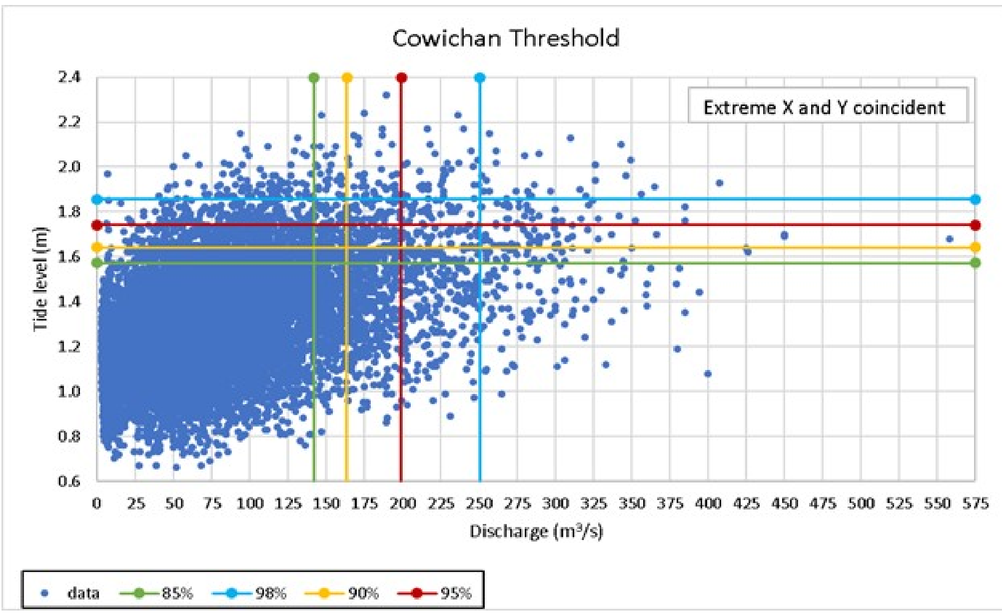


Figure 7-2: Joint occurrence of ocean levels and river discharges on Cowichan River

Table 7-1: Adopted flood scenarios for joint occurrence of river floods and ocean levels

Scenario	Return period (Years)	River Inflows (m^3/s) Cowichan R	River Inflows (m^3/s) Koksilah R	Ocean Levels Return Period (Years)	Ocean Levels Elevation (m)
Present day	200	747	501	10	2.23
	10	468	311	200	2.41
Year 2100	200	896	601	10	3.23
	10	562	373	200	3.41

8 RIVER MODELLING

8.1 Model Development

Model development involves the following steps (Figure 8-1):

1) defining inflow hydrology and ocean levels;
2) connecting the river channel bathymetry to LiDAR data to form a DEM;
3) defining a cell size for hydraulic modelling and building the model geometry; and,
4) undertaking calibration and validation.

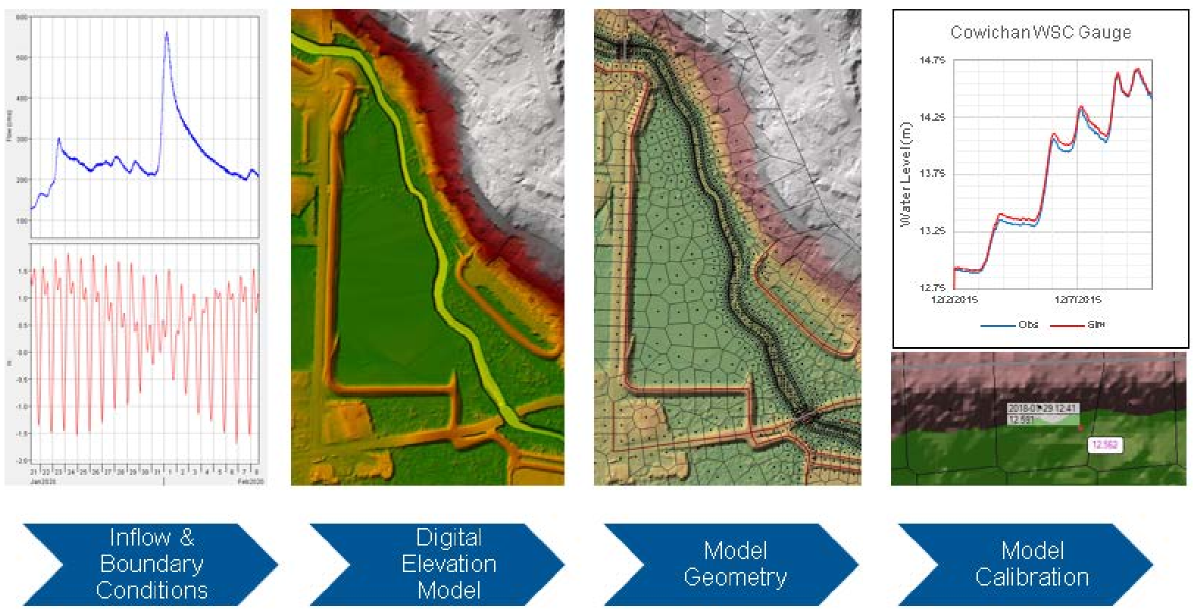


Figure 8-1: Overview of steps undertaken for development of the 2D HECRAS model used for this project.

The 2D model developed for this project covers the Cowichan and Koksilah River floodplains (Figure 8-2). Channel bathymetry was connected to 2019 GeoBC LiDAR in order to create a seamless representation of the terrain. The resulting DEM forms the main building block of the model. Model geometry was generated using various cell sizes to optimize model result accuracy and computation times. A nominal cell size of 10 m was used in the Cowichan and Koksilah River main channels and of up to 100 m in the floodplain. To ensure accurate representation of hydraulic control structures such as dikes, bridges and elevated roads, breaklines were digitized and enforced along these features. Roughness coefficients based on river characteristics, land use and ground cover, were assigned and then refined during the calibration process. Further technical information regarding set up of the hydraulic model can be found in Appendix E.

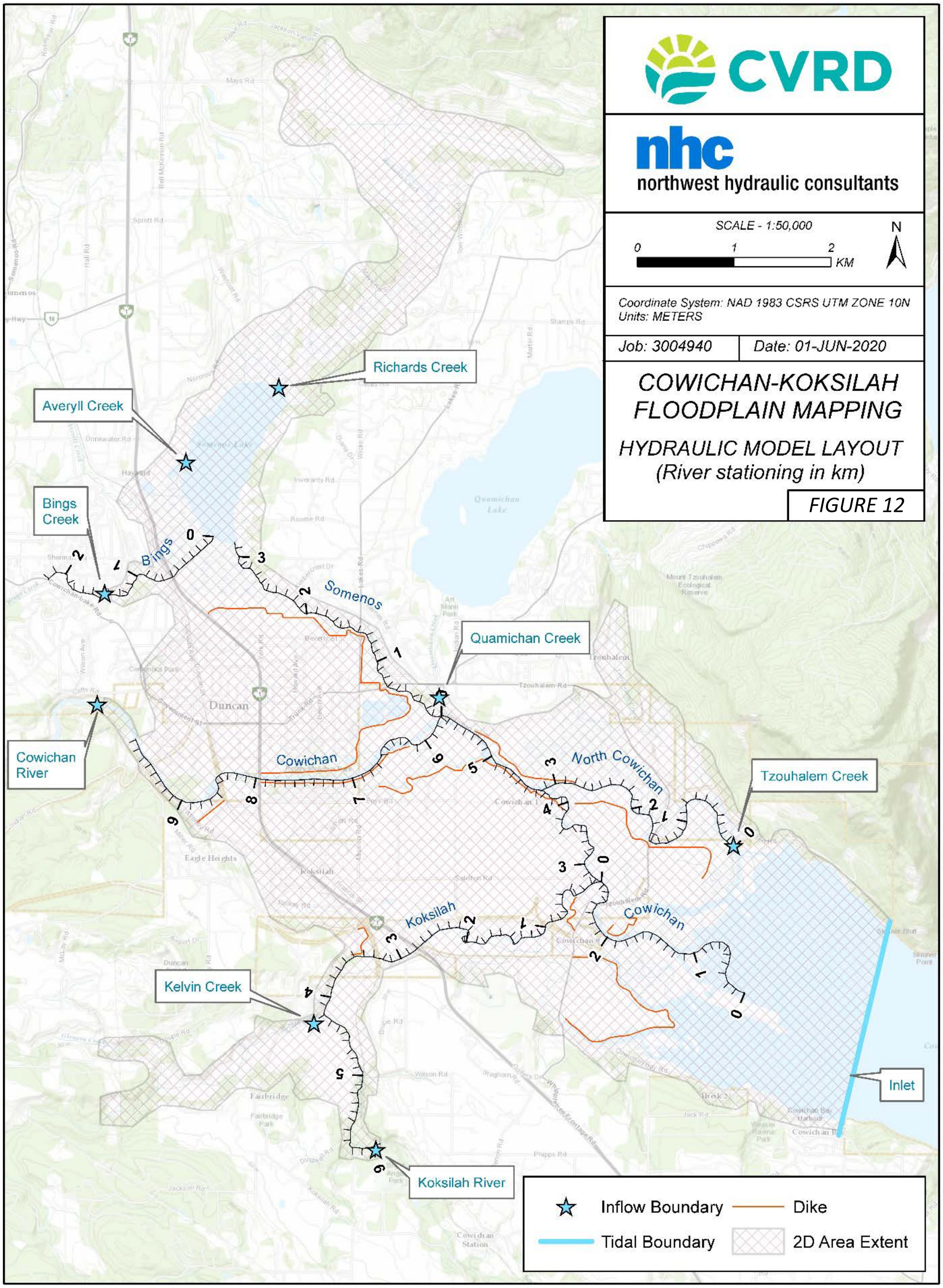


Figure 8-2: Overview of model domain.

The model was calibrated and validated using the 2019 and 2020 winter flood events, as indicated in Table 8-1. These storm events were selected as they were large flow events that occurred close to when the channel bathymetry data was collected. Moreover, the 2020 freshet is the largest event in recent years with an approximate return period or 30 years on both Cowichan and Koksilah rivers. The model was calibrated using a series of water level gauges in the study area as outlined in Appendix A and E.

Table 8-1: Summary of floods used for model calibration.

Date	Cowichan River near Duncan (08HA011)		Koksilah River at Cowichan Station (08HA003)	
	Instantaneous Q (m^3/s)	Approximate Return Period	Instantaneous Q (m^3/s)	Approximate Return Period
Jan 4, 2019	427	7	296	8
Feb 2, 2020	564	27	382	30

The root mean square error for the 2019 and 2020 flood events was 0.19 m and 0.13 m, respectively. Differences between observed and predicted levels were usually within $\pm$0.15 m at most stations. However, some variability occurred between specific gauges that could not always be explained in terms of model calibration (Table 8-2).

The discrepancies between the observed and simulated water levels are likely the result of three factors:

1) Uncertainty associated with the WSC discharge data due to the limited measurements at high flows and the problems of using different rating curves for different flood years (described in Section 6.2).

2) Uncertainty associated with observed water levels at hydrometric gauges. As described in Appendix A, some FLNRO hydrometric stations were not accompanied by meta data and only minimal quality assurance review was able to be completed.

3) Localized, short-term effects from log jams and debris, sediment accumulation and gravel removal over the period between bathymetric surveys and the flood events.

4) Uncertainty due to channel instability (erosion and deposition) and the formation of channel-spanning log jams which create obstruction to the flow and can initiate bank erosion and channel avulsions (re-opening abandoned side channels or initiating new channels to form).

Achieving a good model calibration using data from one particular flood event does not mean that similar accuracies will be replicated in another comparable flood due to unpredictable changes in channel topography and resistance. Realistic expectations of the ultimate accuracy of the predictions and some understanding of the actual uncertainties associated with floodplain mapping are needed to make this a useful exercise.

Table 8-2: Simulated and observed water levels at study gauges for calibration events.

			January 2019			February 2020		
Watercourse	Gauge	Station (m)	Mod	Obs	Diff	Mod	Obs	Diff
Cowichan	Cowichan WSC	9540	15.28	15.14	0.14	15.84	15.71	0.13
	JUB	6400	8.33	8.26	0.07	8.57	8.49	0.07
	Clem Clem	2410	2.40	2.30	0.10	2.55	2.59	-0.04
	Northside of Causeway	1270	2.07	2.15	-0.08	-	-	-
Cowichan Estuary	Southside of Causeway	1150	2.07	2.08	-0.02	-	-	-
Somenos	Beverly Pump Sta	1460	7.60	7.64	-0.04	7.91	7.94	-0.03
	Lakes Rd Pump Sta	1060	7.54	7.39	0.15	7.84	7.97	-0.13
	Quamichan	160	7.46	7.62	-0.16	7.75	7.95	-0.20
Koksilah	Koksilah Highway 1	2810	5.80	6.14	-0.33			
				RMSE	0.19		**RMSE**	0.13

Note: The difference (diff) is calculated as modelled (mod) minus observed (obs).

The modelled inundation extent of the February 2020 flood event is shown in Figure 8-3. The February 2020 flood occurred during the model development phase of this project and NHC was able to obtain input from the stakeholder group on actual flood extents during this event. It was noted that the area from Clem Clem, west along Sahilton Road to Highway 1 was inundated and areas around Quamichan were also flooded. The modelled output agrees with these observations.

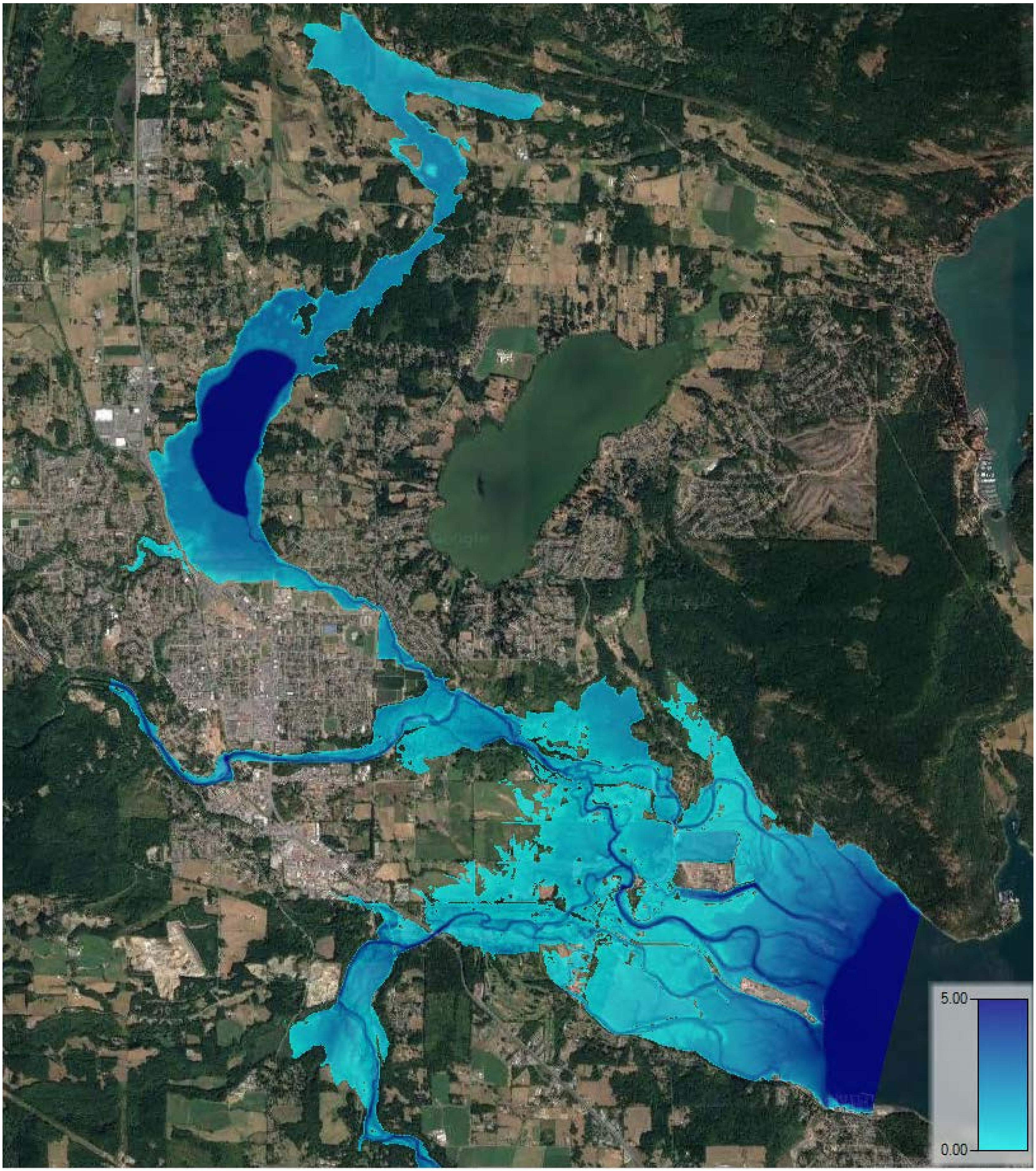


Figure 8-3: Simulated flood depth and inundation extent for the February 2020 flood.

8.2 Base Runs

After calibration was completed runs were made for a range of flow conditions for the existing channel and dike alignment. Base runs of the 200 year flood conditions were completed for the two scenarios in Table 7-1.

Figure 8-4 shows results of the present-day 200 year flood scenario. None of the primary dike structures on the Cowichan River and Somenos Creek were overtopped. Overtopping and flooding occured on the north bank of the North Branch of the Cowichan River downstream of Quamichan into Priests Marsh, between the North Branch and South Branch of the Cowichan River downstream of the junction, and across the low-lying land between the south branch of the Cowichan and north of the Koksilah River.

For the 'climate change 2100' base run, the left bank Cowichan River dike appeared to locally overtop at approximately 200 m upstream of Highway 1, at the Cowichan River Trestle Bridge and approximately 100 m upstream of the Allenby Road bridge. This may be due to the higher flows adopted for the 2100 year flood scenario in this study (895 m^3/s this study versus 770 m^3/s previously). The remaining primary flood control structures were not overtopped in this scenario.

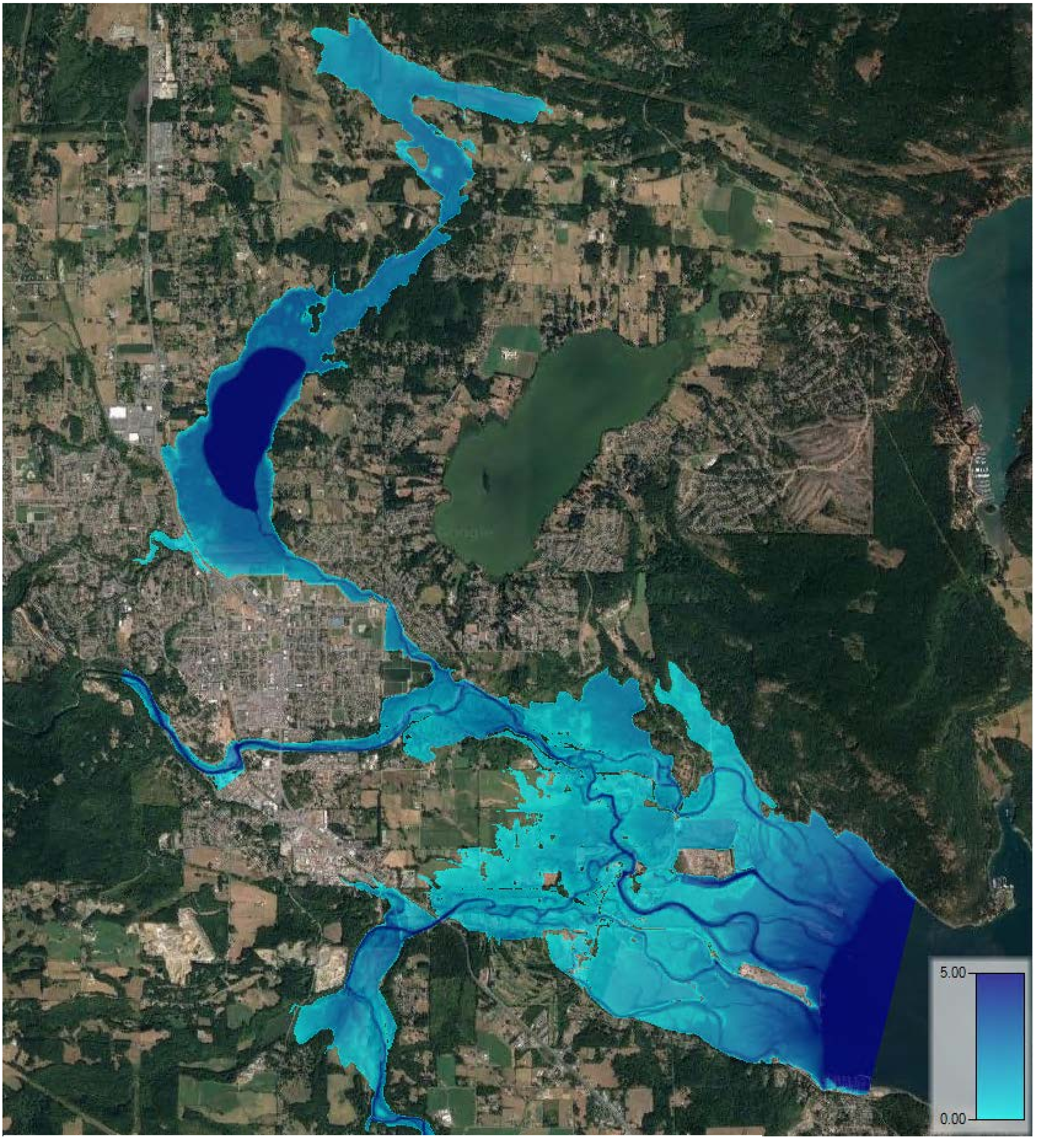


Figure 8-4: Flood depth and inundation extent for the present day 200-year flood base run (without climate change).

8.3 Dike Breach Modelling

In order to provide a conservative representation of flood extent and flood depth, floodplain maps assume that flood dikes will fail to function during design flood conditions. Two different methods have been used to represent dike failures. The first and simplest approach is to assume that the water level on the land-side of the dike will be equal to the water level on the river-side (Figure 8-5 top). The second approach, which was used in this study, is to assume that the dike will breach and to simulate the spill of water onto the floodplain (Figure 8-5 bottom). Secondary dikes were not simulated by breaching but were allowed to overtop and spill onto the surrounding floodplain.

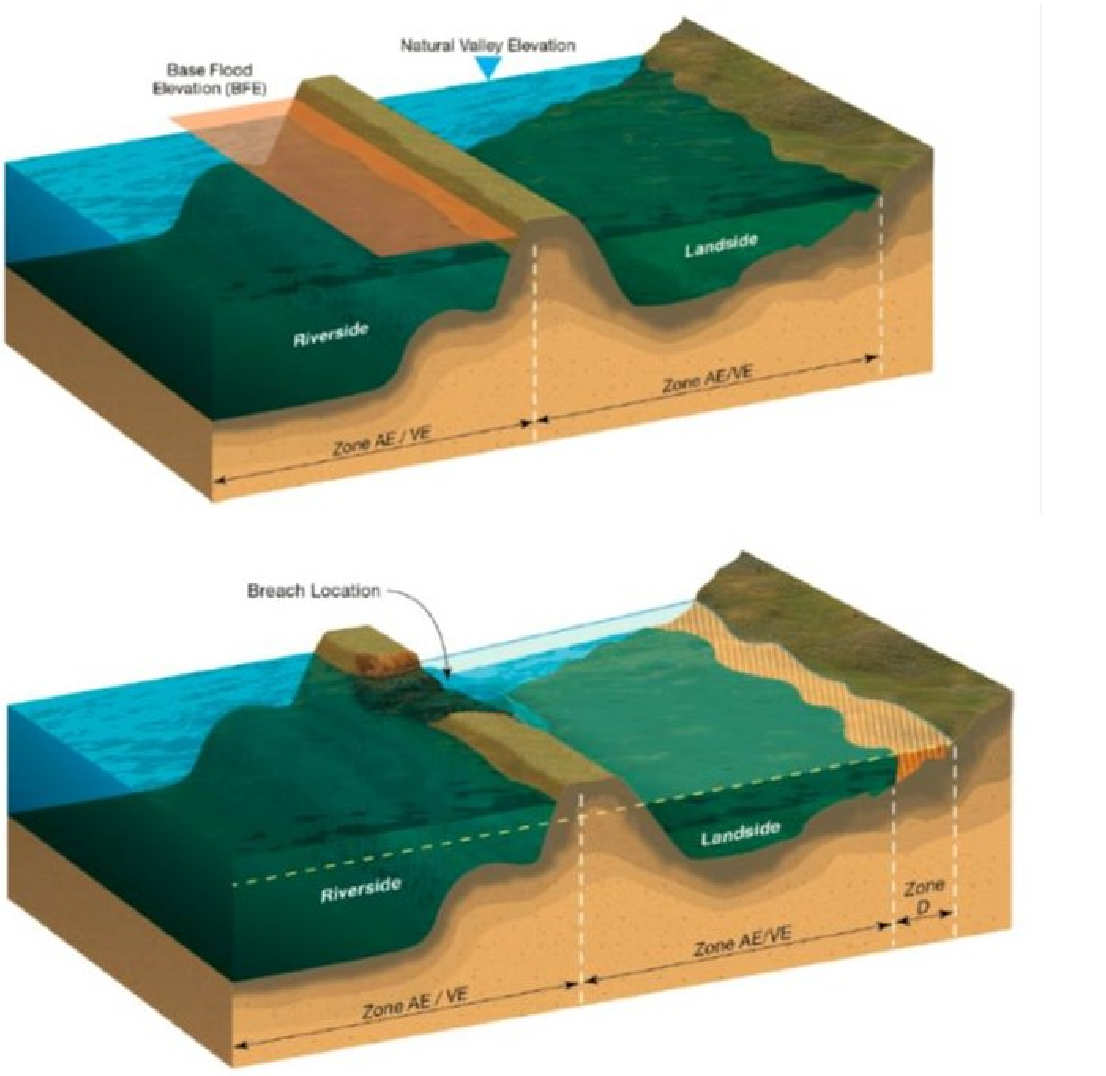


Figure 8-5: Two methods of representing dike failures. In case A (top), it is assumed that the water level on the landward side of the dike is the same as on the river side. In case B (bottom), a dike breach is represented, allowing water to spill onto the landside of the dike onto the floodplain (from FEMA, 2015)

Flooding behind the primary flood dikes was represented by simulating a series of local dike breaches and then overlaying the extent and depth from each individual breach. Dikes may breach as a result of scour, erosion and geotechnical failure. Conceivably, an almost infinite number of dike breach scenarios could be considered. Dike breach locations were selected based on review of structure vulnerability and breach locations that would lead to severe and wide-spread flooding. Structural vulnerability for example includes review of where dike crest elevations are low or where structural barriers need to be installed at existing dike openings. Breach locations were further refined based upon input from the stakeholder group. A total of 13 dike breach scenarios were simulate to represent potential failures along portions of the main primary dikes (Figure 8-6 and Table 8-3).

For all dike breach scenarios it was assumed that breach formation occurred at the peak of the flood hydrograph and breach width for all dikes was 150 metres. These runs were made for the 200 year climate change flood condition. Further technical information on dike breach modelling and model results for all dike breach runs are presented in Appendix E.

The results of select dike breach scenarios that were noted to cause the most inundation to key areas are presented in Figure 8-7 and outlined below:

<u>Breach 4</u>: Model results show that the breach on the left bank of the Cowichan River dike at approximately 400 m downstream of the Highway 1 causes significant inundation of businesses and residential neighbourhoods east of Highway 1.

<u>Breach 9</u>: Model results show that a breach of the flood wall on the right bank of the Cowichan River causes inundation throughout the Duncan industrial site and residential neighbourhoods west of Highway 1. Water flows from the Cowichan River, past the flood wall, continues south on the west of Highway 1 eventually entering the Koksilah River.

<u>Breach 10 & 11</u>: Model results show significant inundation in the vicinity of Boys and Sahilton Roads for both breach 10 and 11. A breach of the south side spur dike (breach 11) causes slightly greater inundation extent compared to breach 10.

The floodplain maps submitted with this draft final report are based on a composite of all of the flood breach runs (described further in Section 9).

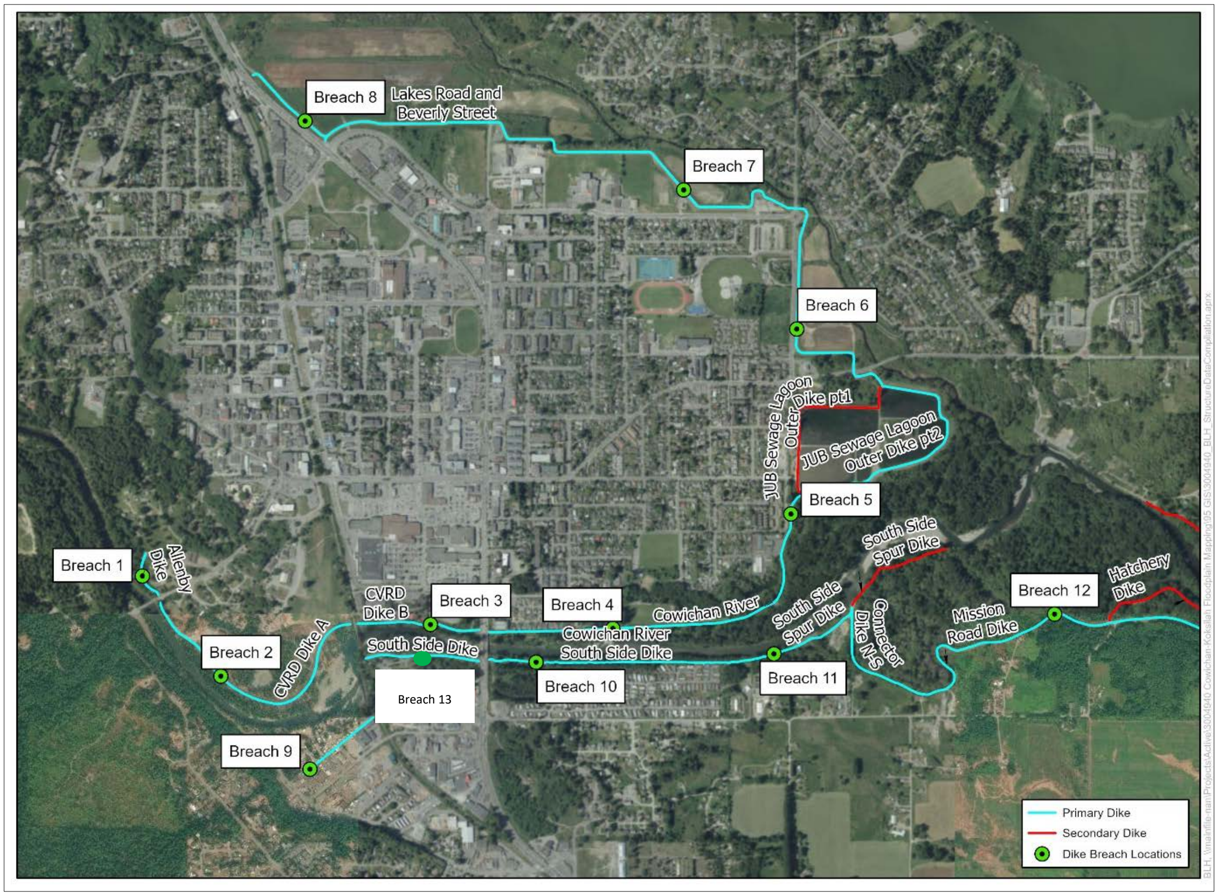


Figure 8-6: Overview of dike breach locations.

Table 8-3: Dike breach scenarios for primary flood control dikes.

ID	Dike	Watercourse	Bank	Breach Length (m)
1	Cowichan Phase 2-Allenby	Cowichan	Left	150
2	Cowichan Phase 2-Dike A	Cowichan	Left	150
3	Cowichan Phase 2-Dike B	Cowichan	Left	150
4	Cowichan (City of Duncan) Dike	Cowichan	Left	150
5	Cowichan (City of Duncan) Dike	Cowichan	Left	150
6	Lakes Road/Beverly St. Dike	Somenos	Right	150
7	Lakes Road/Beverly St. Dike	Somenos	Right	150
8	Canada Avenue	Bings	Right	150
9	Flood Wall /Cowichan Phase 2-Dike D	Cowichan	Right	150
10	Cowichan South Side Dike	Cowichan	Right	150
11	South Side Spur Dike	Cowichan	Right	150
12	Mission Road Dike	Cowichan	Right	150
13	Cowichan South Side Dike	Cowichan	Right	150

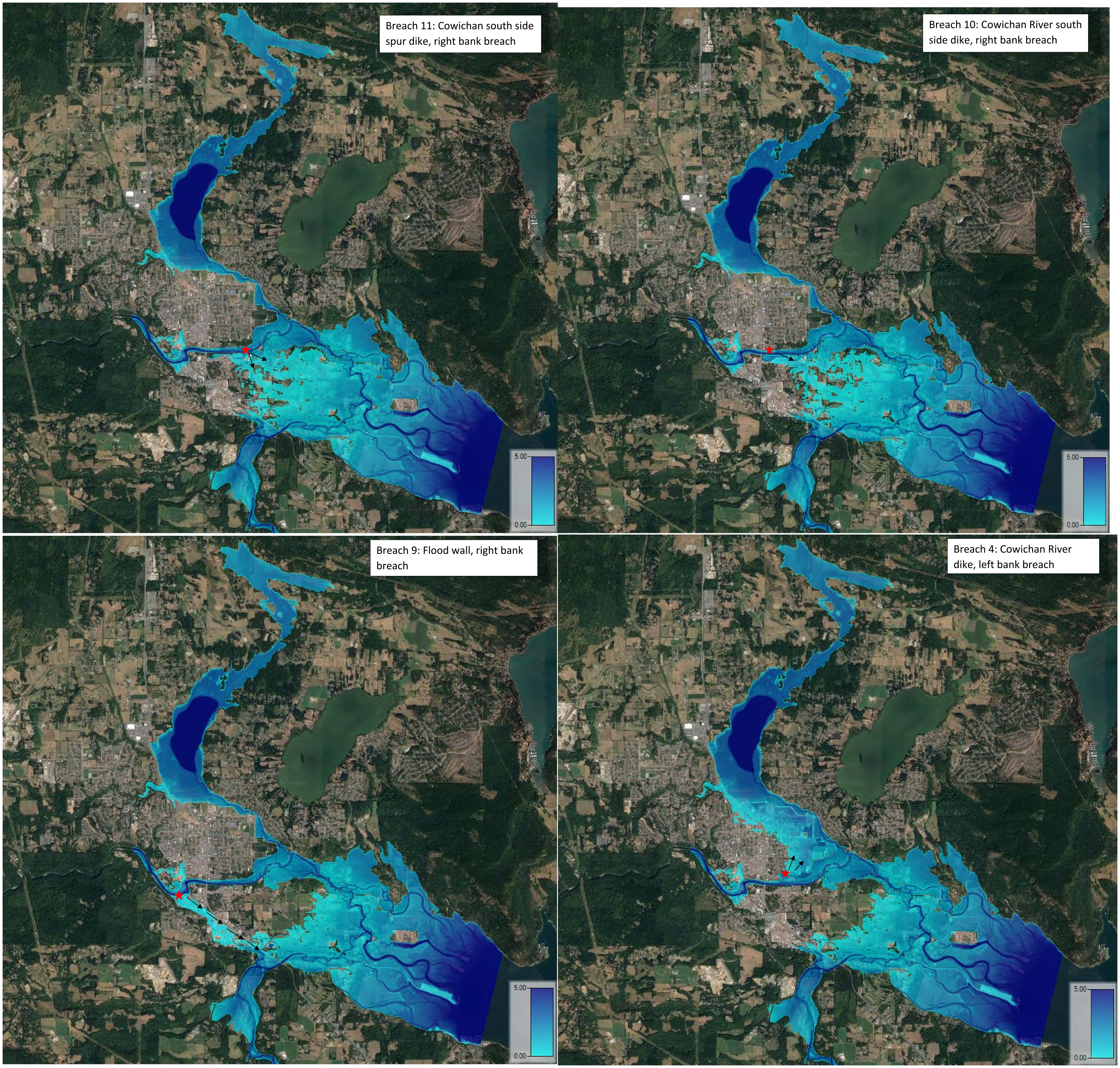


Figure 8-7: Model results for dike breach scenarios 4, 9, 10 and 11 for the climate change 2100 200-year flood. Breach location indicated by red star.

8.4 Modelling of Mitigation Concepts

Through consultation with the stakeholder group two mitigation concepts were assessed at this phase of the project (Table 8-4).

Table 8-4: Overview of modelled mitigation scenarios.

Scenario	Description	Notes
1	New South Cowichan-Koksilah Dike	Requires Highway 1 to be raised to meet the present day 200-year flood construction level
2	Sediment Management Scenarios	

8.4.1 New South Cowichan-Koksilah Ring Dike

Extensive flooding can occur in the eastern portion of the floodplain between the north side of the Koksilah River and south of the south Branch, downstream of the Hatchery Dike. The source of the water includes spills from the Koksilah River and backwater flooding from the south branch of the Cowichan River. The area was inundated in February 2020 and the magnitude and extent will increase substantially in the future in response to climate change and sea level rise.

A preliminary dike alignment was defined and is shown in Figure 8-8. The proposed alignment was inserted into the hydraulic model geometry. The dike was tied into the Hatchery Dike near the Cowichan River and into Highway 1 near the Koksilah River. The section of Highway 1 indicated in Figure 8-8 does not meet the 200-year flood level; therefore, this section of Highway 1 was also raised in the model geometry. Model simulations were completed for the present day scenario (Figure 8-9). Results indicate that the south Cowichan-Koksilah dike alignment provides protection for the low-lying floodplain area between the Cowichan and Koksilah River provided that a portion of Highway 1 is also raised.

8.4.2 Effect of Sediment Management on Flood Levels

The second mitigation concept was developed as a result of the sediment and debris management program that has been undertaken in the lower Cowichan watershed since 2012. The sediment and debris management program involves removing gravel and log jams from various locations on the Cowichan River on an annual basis. Log jams and sediment accumulation are serious concerns on the Cowichan and Koksilah Rivers. These processes can locally elevate river levels and can trigger channel shifting and erosion of dikes that are not adequately set-back from the river.

The effect of gravel removals on the Cowichan River flood levels was demonstrated by representing the approximate river bed topography after completion of channel excavations in 2019 and running the February 1, 2020 flood scenario. The approximate volume and location of gravel removals are described in Table 8-5 (locations are shown on Figure 4-3).

Table 8-5: **Gravel removal quantities from 2019**

Year	Location	Gravel Removal (m^3)
2019	CR1	20,400
2019	CR3	13,000
2019	CR5	4,200
2019	CR6	27,800

The predicted water levels with the excavation was compared to flood levels prior to excavation (Figure 8-10). The model indicated that the gravel removal lowered water levels at the junction of the North and South Branches by 0.2 m during the rise of the February 1 flood and by 0.15 m at the peak of the flood. Water levels were lowered by 0.2 to 0.3 m near the start of the flood and by less than 0.1 m at the peak. The model predicted water levels were slightly increased downstream of the excavations at the lower end of the North Branch at Pimbury Bridge. This increase downstream of the excavations was caused by the increase in conveyance in the North Branch, which resulted in an increase in the flow split and increased discharge in the lower section of the river.

Simulation of a single flood event and single gravel removal project does not adequately capture the value of the sediment management program. Annual gravel removal under this program is intended to maintain channel conveyance and promote a more stable channel; as such the cumulative effects of gravel and log jam removal since 2012 provide a better measure of the programs effectiveness. Table 8-6 compares observed peak flood levels at two critical locations near Duncan. In 2009 the channel was obstructed by log jams and sediment had accumulated near the JUB outfall and at the junction of Somenos Creek. In February 2020 the channel was in much better condition due to the channel maintenance work carried out by Cowichan Tribes in August-September 2019. Even though the flood in 2020 experienced a much higher discharge, the actual peak water levels were lower. If the flood in 2009 reached a discharge of 556 m^3/s, the resulting damage to the region would have been much higher than was experienced. These results provide a more realistic measure of the importance of the sediment management program in terms of maintaining flood dikes and other infrastructure.

Table 8-6: **Comparison of peak flood levels in 2009 and 2020 on Cowichan River near Somenos Creek**

Location	November 20, 2009	February 1, 2020
	Peak Discharge: 447 m^3/s	Peak discharge: 556 m^3/s
Lakes Road-Beverly Street	7.95	7.94
JUB lagoons	8.65	8.49

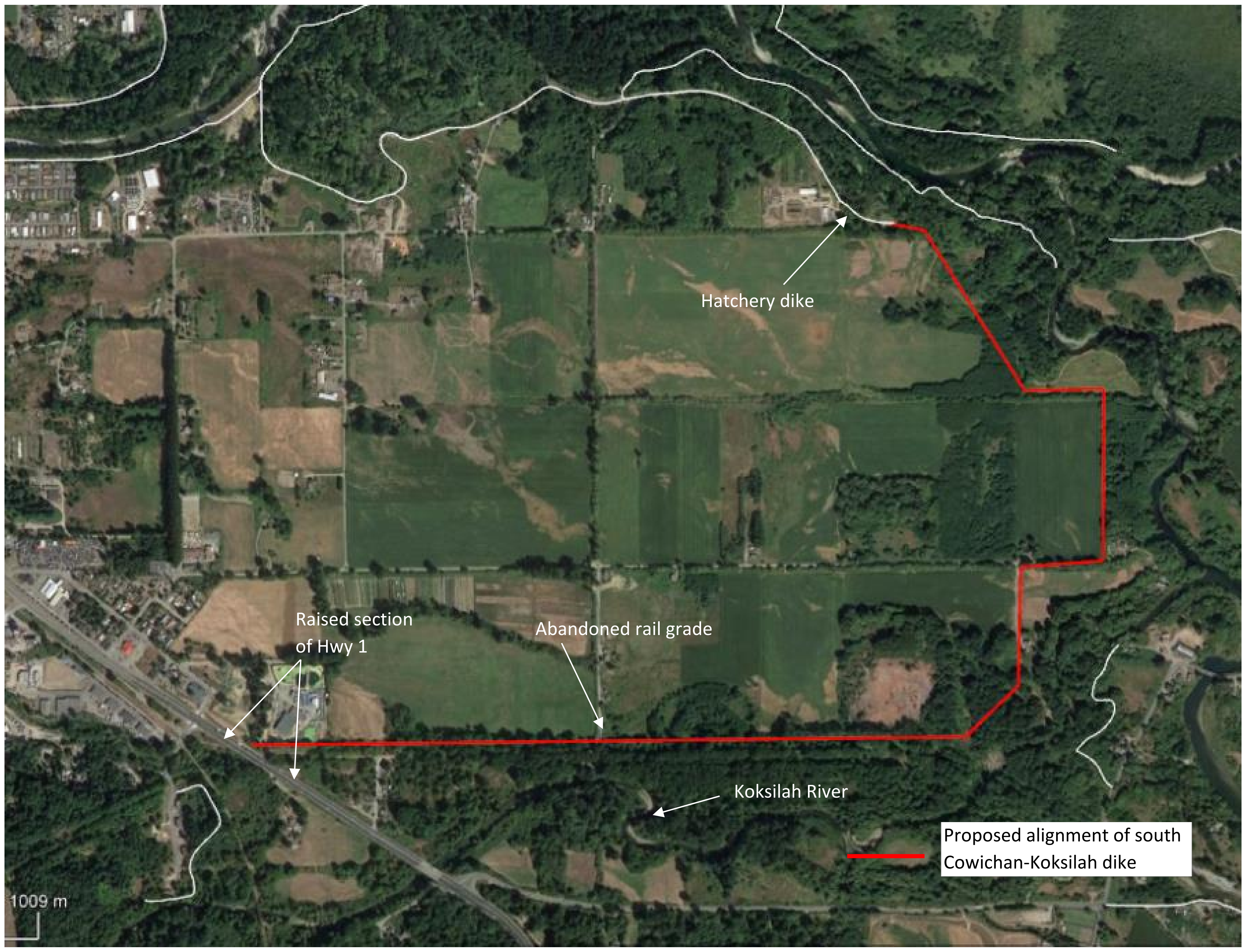


Figure 8-8: Proposed alignment of the south Cowichan-Koksilah dike.

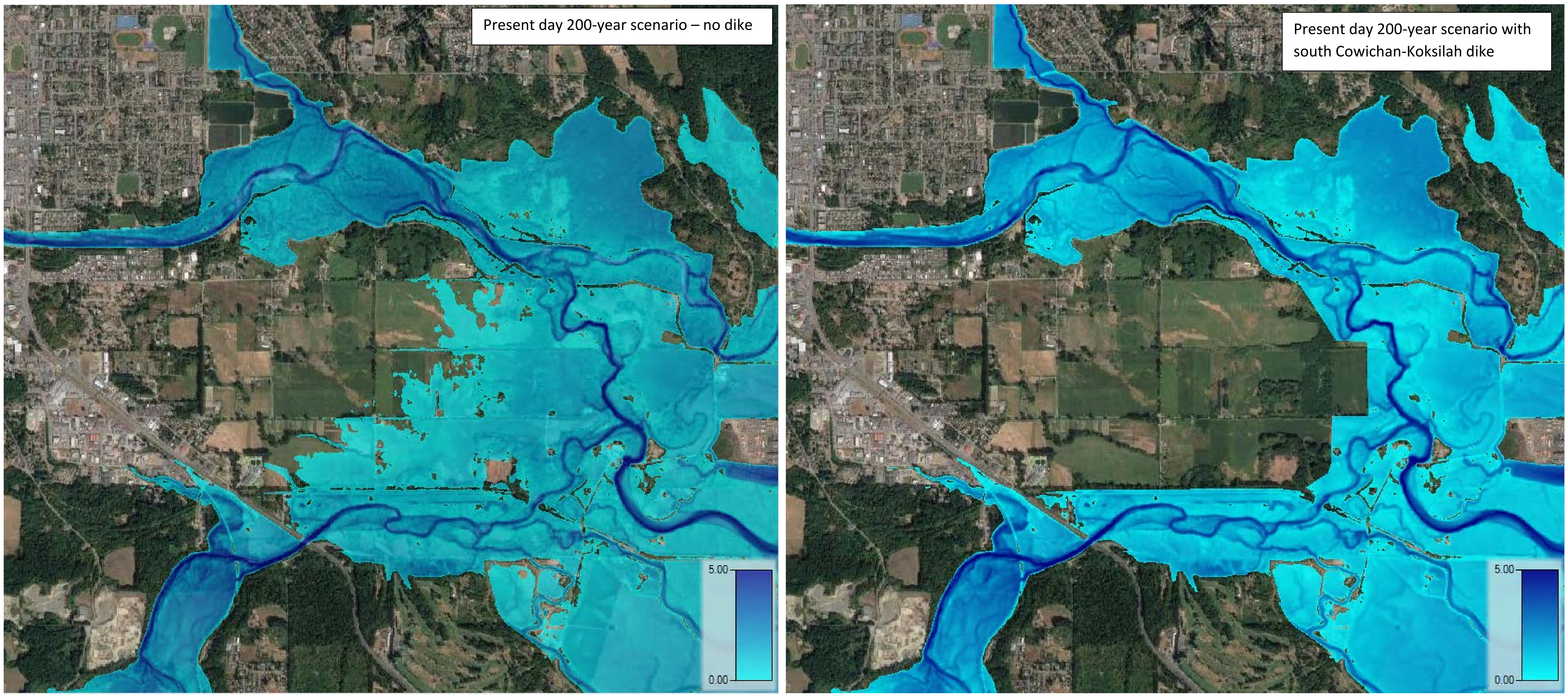


Figure 8-9: Flood depth and inundation extent for the present day 200-year flood scenario compared to the south Cowichan-Koksilah dike mitigation option under the present day boundary conditions.

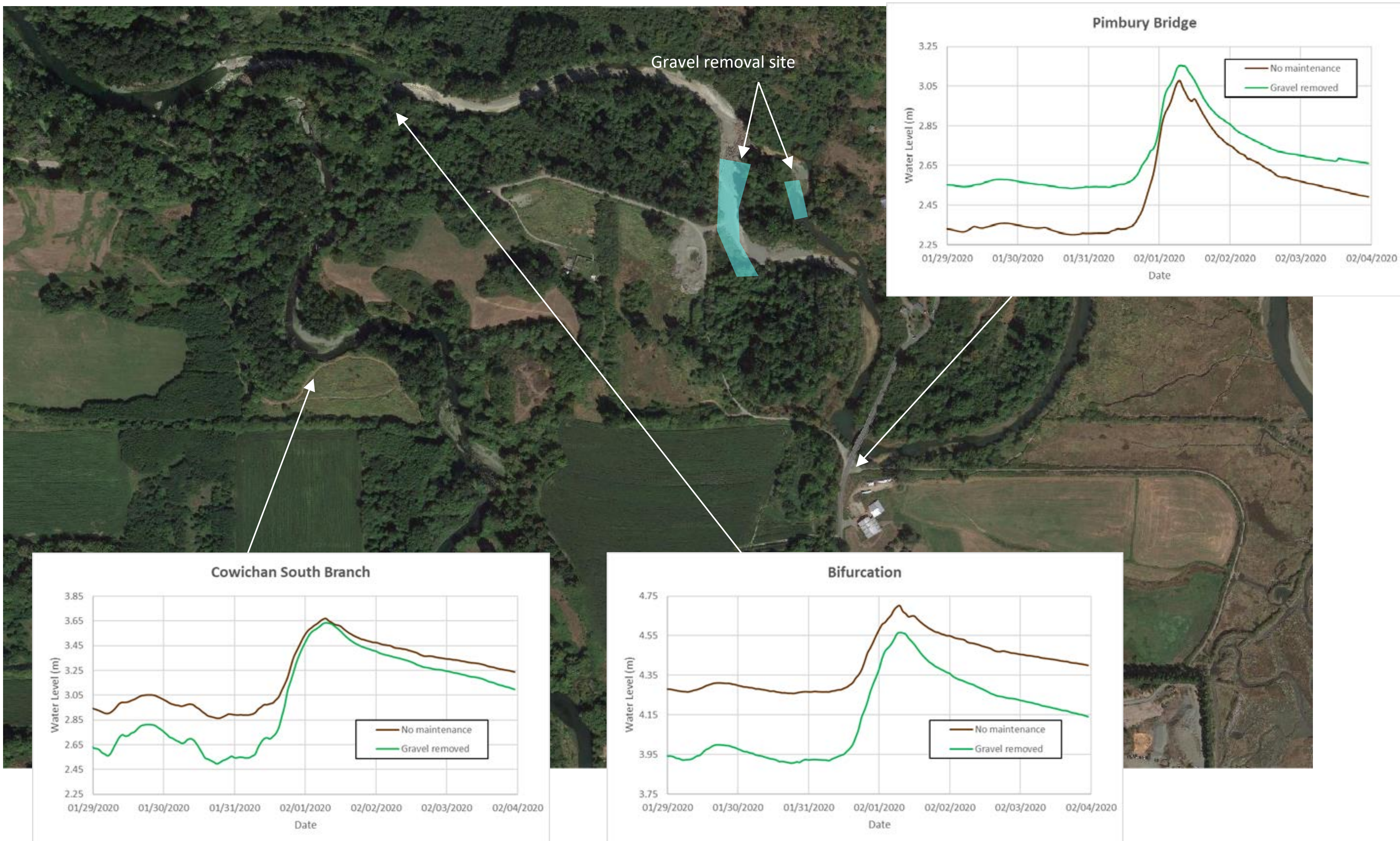


Figure 8-10: Model results for sediment removal mitigation option. Water levels represent 2020 flood levels before and after gravel.

9 COASTAL MODELLING

This chapter assesses the coastal Flood Construction Levels along the shoreline of Cowichan Bay for a designated 200 year flood in the year 2100. A sea level rise of 1 m was applied to the calculations. Further information on the adopted climate change scenario is described in Section 4.3.2.

9.1 Input Data

The coastal assessment portion of this study included review of the tide levels and wave modelling for Cowichan Bay. The 2D hydraulic model developed for this study requires tide data in order to simulate flood levels in the lower portion of the Cowichan watershed. A wave analysis is required to determine shoreline wave effects and complete flood mapping for Cowichan Bay. An overview of the coastal assessment is provided below. Further detailed technical information regarding the coastal analysis can be found in Appendix C.

9.1.1 Ocean Levels

An extreme event analysis was completed using water levels in Fulford Harbor and Patricia Bay to estimate designated still water ocean levels for various return periods. Results from the extreme value analysis indicated water levels recorded at Patricia Bay are higher than Fulford Harbor. Therefore, the Patricia Bay water level extreme value analysis results were used as the base input for water levels for the coastal wave model (Table 9-1).

According to the Canadian Hydrographic Survey, the difference in water levels datums from Patricia Bay to Cowichan Bay is +0.10 m. As such, 0.10 m was added to the Patricia Bay extreme event analysis results to obtain water levels in Cowichan bay. The resulting water level analysis includes the effects of tide and storm surge. The results from the water level analysis and sea level rise were incorporated into the downstream boundary conditions for the hydraulic modelling portion of this study.

Table 9-1: Water levels for various return periods for Cowichan Bay.

Return Period (year)	Water Level (m GD)
2	2.04
10	2.23
20	2.28
50	2.34
100	2.38
200	2.41
500	2.45

9.1.2 Wind Analysis

A wind and wave analysis was carried out to determine the wave climate in the project area. The local and regional wind climate were analyzed from eleven Environment Canada (EC) meteorological wind stations; 3 buoys and 8 land stations (**Table 9-2**).

Table 9-2: Environment Canada wind stations.

Station Name	Station No.	Latitude	Longitude
Halibut Bank	c46146	49.34	-123.73
Sentry Shoal	c46131	49.91	-124.99
Patricia Bay	c46134	48.65	-123.5
Ballenas Island	1020590	49.35	-124.16
Entrance Island	1022689	49.21	-123.81
Nanaimo Airport	1025370	49.05	-123.87
Sandheads CS	1107010	49.11	-123.30
Saturna Island CS	1017101	48.78	-123.04
Sisters Island	1027403	49.49	-124.43
Victoria Int'l A	1018620	48.65	-123.43
Kelp Reefs	1013998	48.55	-123.24

Observed wind speed magnitudes were transformed to the standard 10 m wind speed (U_{10}), based on the common exponential wind profile assumption. To deduce return periods for wind events, an extreme event analysis was conducted on the wind data from Halibut Bank (**Table 9-3**). As Cowichan Bay is susceptible to wave events originating from the South east, wind speed data from wind directions of 0° to 90° and 180° to 360° was omitted from the analysis.

Table 9-3: Wind events from 90° to 180° for various return periods for Halibut Bank.

Return Period (year)	Wind Speed (South East) (m/s)
2	19.0
10	20.7
20	21.4
50	22.3
100	23.0
200	23.7
500	24.6

By utilizing the results from the extreme event analysis of wind speeds at Halibut Bank, wind storm events from the past could be identified that are very similar in magnitude to the values shown above in **Table 9-3**. Two storms from the past were identified, a 1:10-year wind event and a 1:200-year wind event. As shown in **Table 9-4**. No wind events from the south east sector with wind speed magnitudes similar to the 1:10-year event exist in the time series, therefore a storm with similar wind speed magnitudes but directions outside the original analysis were used.

Table 9-4: Historical wind events observed at Halibut bank

Similar Return Period	Date	Wind Speed (m/s)	Wind Direction (degrees)	Correction Factor
1:10-year	15-Dec-2006	20.8	307	1.00
1:200-year	2-Apr-2010	22.1	118	1.07

The eleven Environment Canada meteorological wind stations (**Table 9-2**) were used to develop a spatially varying wind field to drive the wave model. The spatially varying wind field was created by using the peak wind data from the wind events and correction factors listed above, and conducting a linear interpolation on a 250 km by 250 km square grid **(**Figure 9-1).

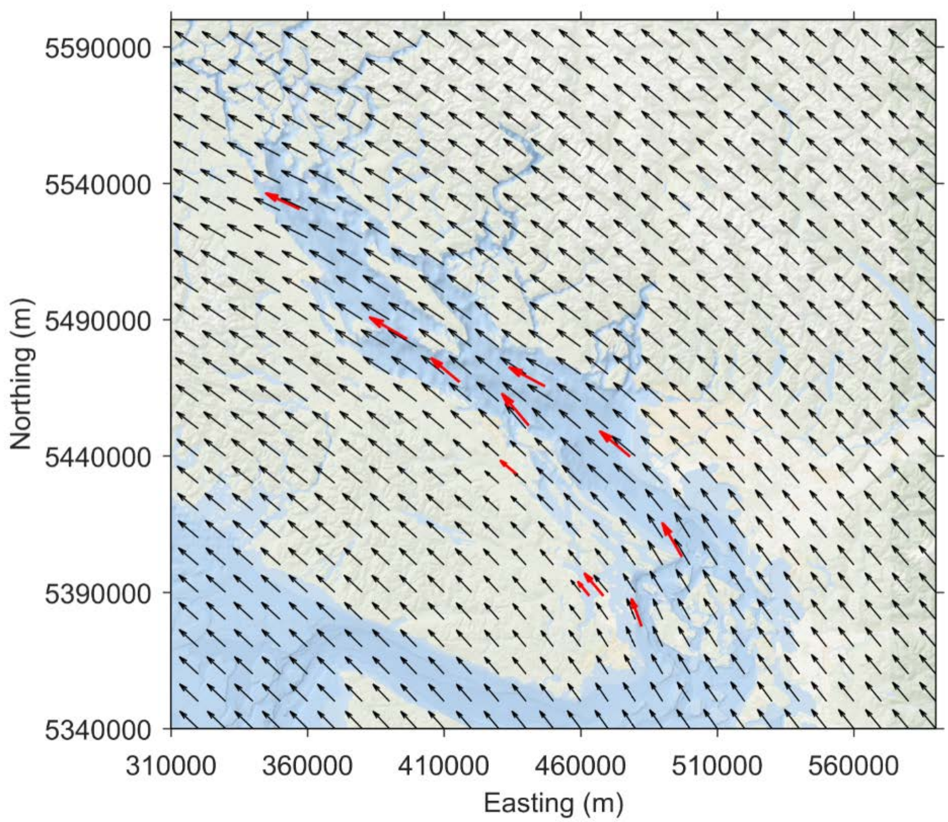


Figure 9-1: Synthesized wind field of the 1:200-year wind storm.

9.2 Wave Analysis

9.2.1 Wave Generation and Propagation

The wave model SWAN (Simulating Waves Nearshore or SWAN) of the Strait of Georgia, Saanich Inlet, and Cowichan Bay was developed to model wave generation and propagation from deep water into coastal areas and shorelines. SWAN is a third-generation wave model, developed at Delft University of Technology in the Netherlands, that computes random, short-crested wind-generated waves in coastal regions and inland waters. SWAN incorporates physical processes such as wave propagation, wave generation by wind, white-capping, shoaling, wave breaking, bottom friction, sub-sea obstacles, wave setup and wave-wave interactions in its computations. SWAN version 41.20 was used for this study.

The wave model consists of three grids 'within' or nested in each other, increasing with resolution and as the extents narrow in on the project site. The wave model grid parameters can be found in **Table 9-5** below.

Table 9-5: Wave model grid parameters.

Grid	Origin (UTM 10N – m)	Rotation (degrees-cw)	Grid Cells (#)	Grid Size (m)
Strait of Georgia	470000E, 5349000W	38	226x506	500m
Saanich Inlet	459000E, 5370000W	14	126x390	100m
Cowichan Bay	456000E, 5397500W	70	400x750	10m

Seafloor elevations or bathymetry for the wave model was collected for the Strait of Georgia, Saanich Inlet and Cowichan Bay from multiple sources. Topography of Cowichan Bay was received from GeoBC LiDAR and processed by NHC GIS analysts. Wave model bathymetry was compiled by grid cell averaging and triangular interpolation to achieve a smooth surface. **Table 9-6** provides a summary of elevation data used for the wave modelling.

Table 9-6: Wave model bathymetry.

Bathymetry Source	Product	Wave Model Area Uses
Canadian Hydrographic Service	Digitized Navigation Charts	Strait of Georgia Saanich Inlet Cowichan Bay
NHC Bathymetric Survey	Single Beam	Cowichan Bay
Canadian Digital Elevation Model	Digital Product	Cowichan Bay
GeoBC LiDAR	Airborne LiDAR	Cowichan Bay

The wave model grid Cowichan includes wave damping due to vegetation typical to brackish salt marsh in British Columbia. The extents of vegetation in the Cowichan Bay SWAN model are shown in **Figure 9-2**. Wave dampening due to vegetation was implemented for four areas in the Cowichan Bay grid: forests, agricultural plots, rural property and wetlands.

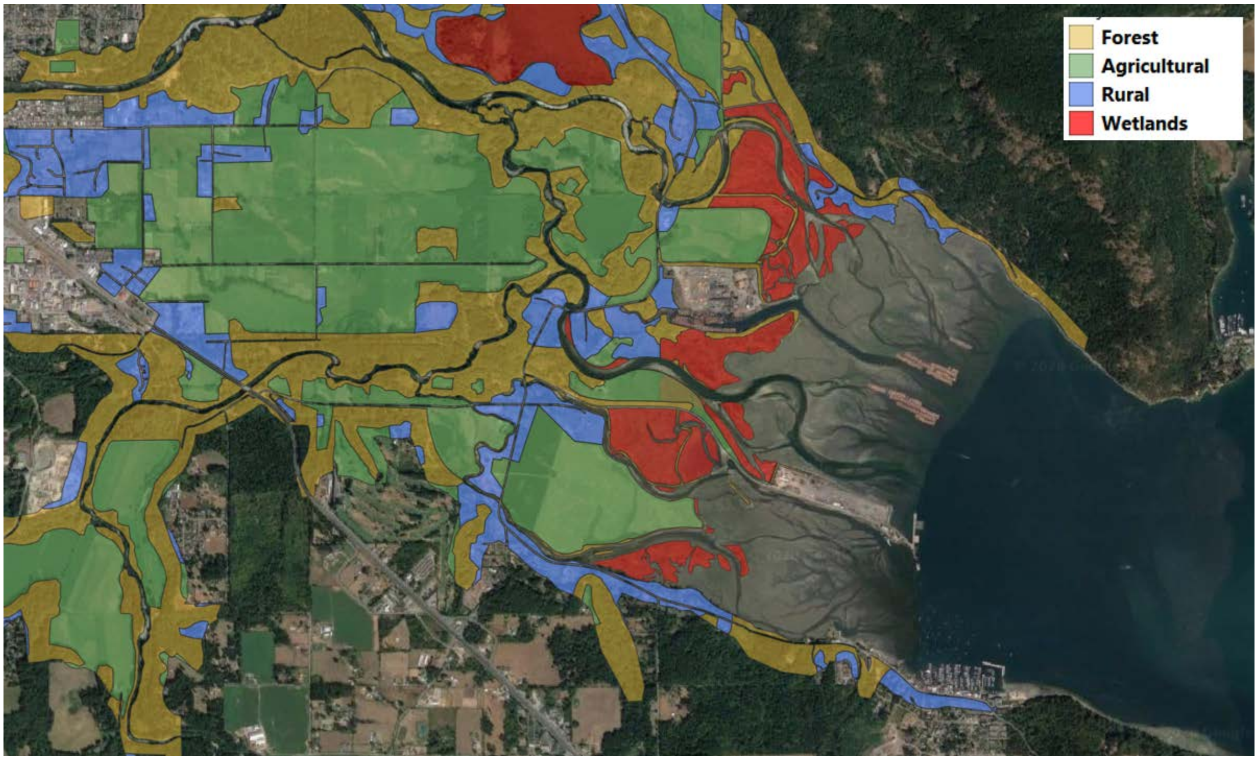


Figure 9-2: Vegetation extents in Cowichan Bay SWAN wave model.

The 10-year and 200-year AEP spatially varying wind field is applied over the model domain to simulate the wind-generated component of waves within the model. The winds are assumed to align with the Cowichan Bay geometry, and the wind direction follows the general alignment of the estuary. The model was run using the 10-year or the 200-year AEP total water level calculated in **Section 9.1** for present day and 2100 climate change scenario.

In addition to the standard EGBC guidelines for coastal flood construction level analysis, an additional three scenarios were modelled to investigate model sensitivity and determine the most conservative scenario. A summary of these conditions can be found in **Table 9-7**. The wave generation modelling scenario resulting in the highest waves for Cowichan Bay was Scenario B and was used for the analysis.

Table 9-7: Wave model base scenarios

Coastal Model Scenario	Wind Speed Event	Water Level Event	Sea Level Rise Event
Scenario A	10-yr	200-yr	+0.0m
Scenario B	10-yr	200-yr	+1.0m
Scenario C	200-yr	10-yr	+0.0m
Scenario D	200-yr	10-yr	+1.0m

The results of the 200-year wind-generated significant waves for the year 2100 climate change scenario are shown in Figure 9-3, Figure 9-4 and Figure 9-5. The corresponding significant wave heights along the shoreline of Cowichan Bay are provided for the "reaches" as shown in **Table 9-8**.

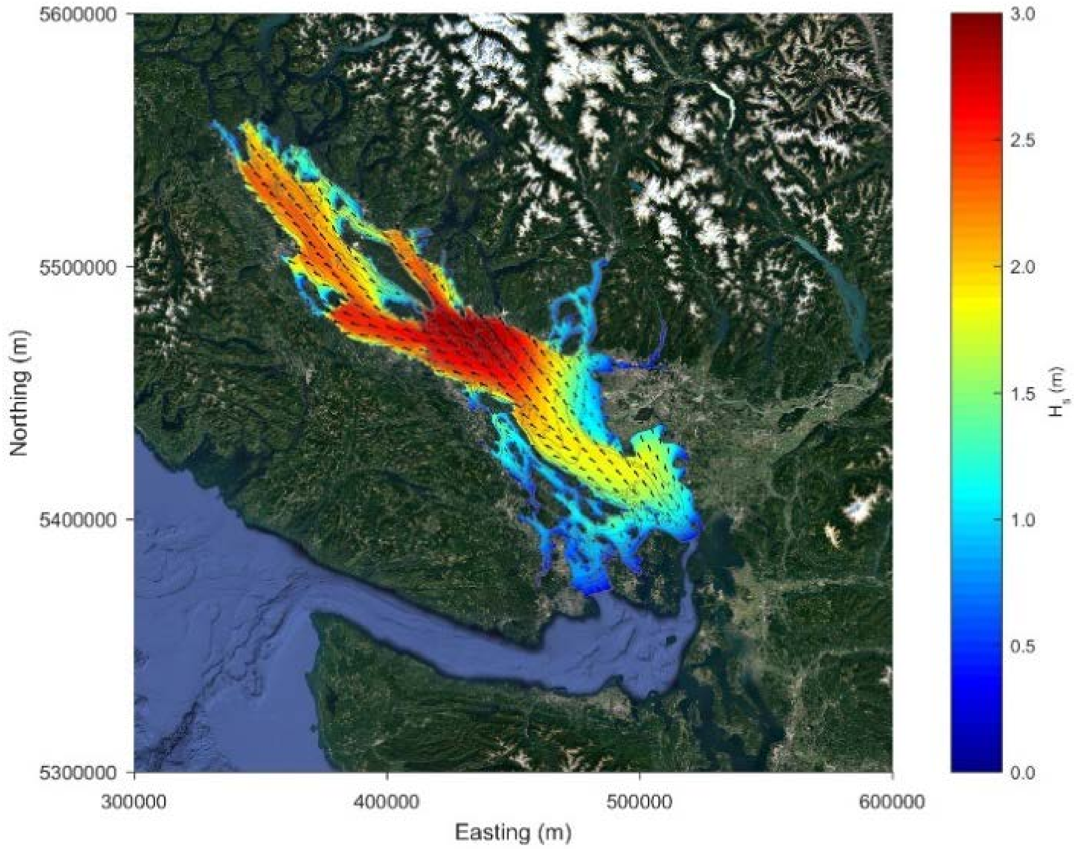


Figure 9-3: Strait of Georgia wave model results – Scenario B – 200-year southwesterly wave map for the year 2100.

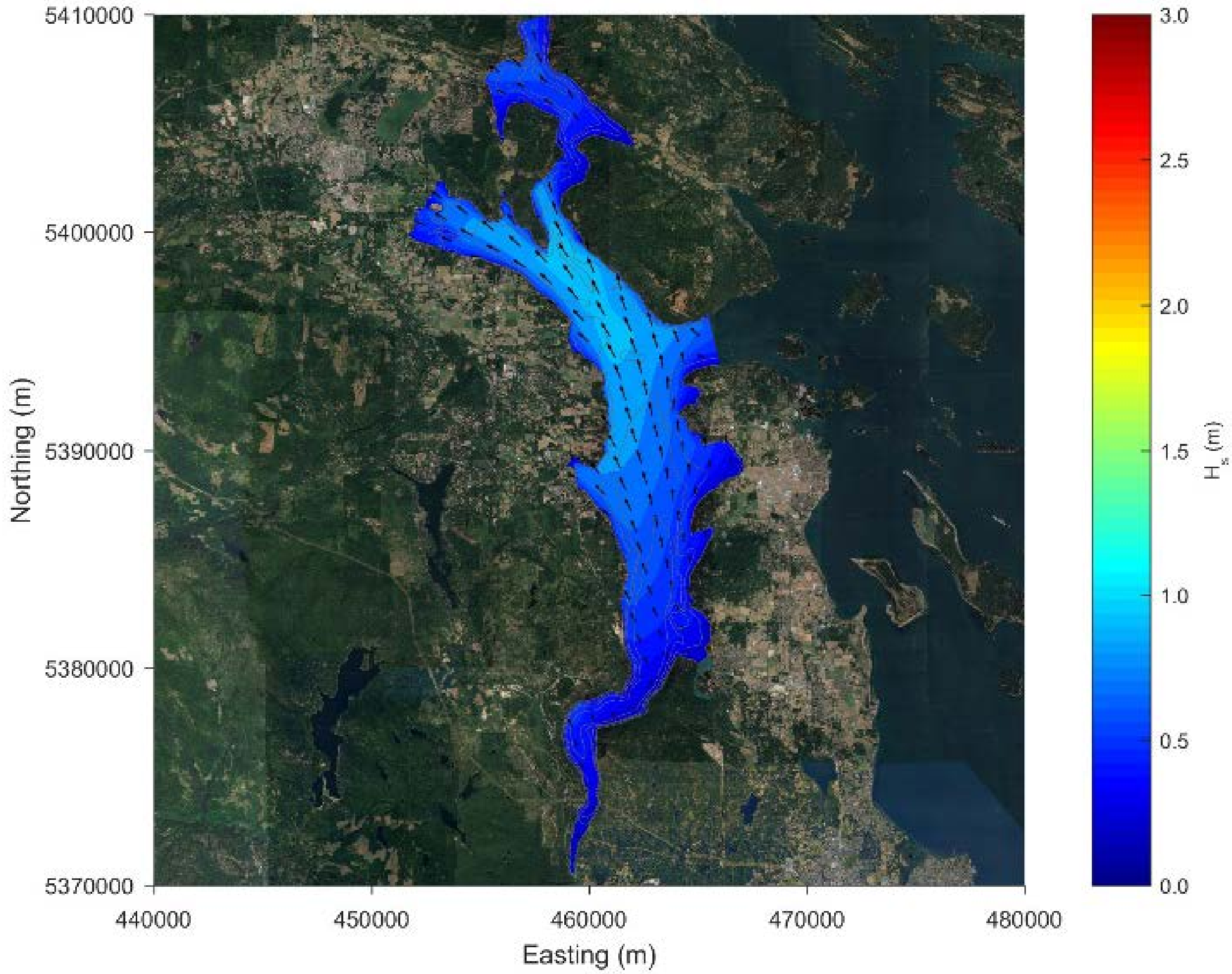


Figure 9-4: Saanich Inlet wave model results – Scenario B – 200-year southwesterly wave map for the year 2100.

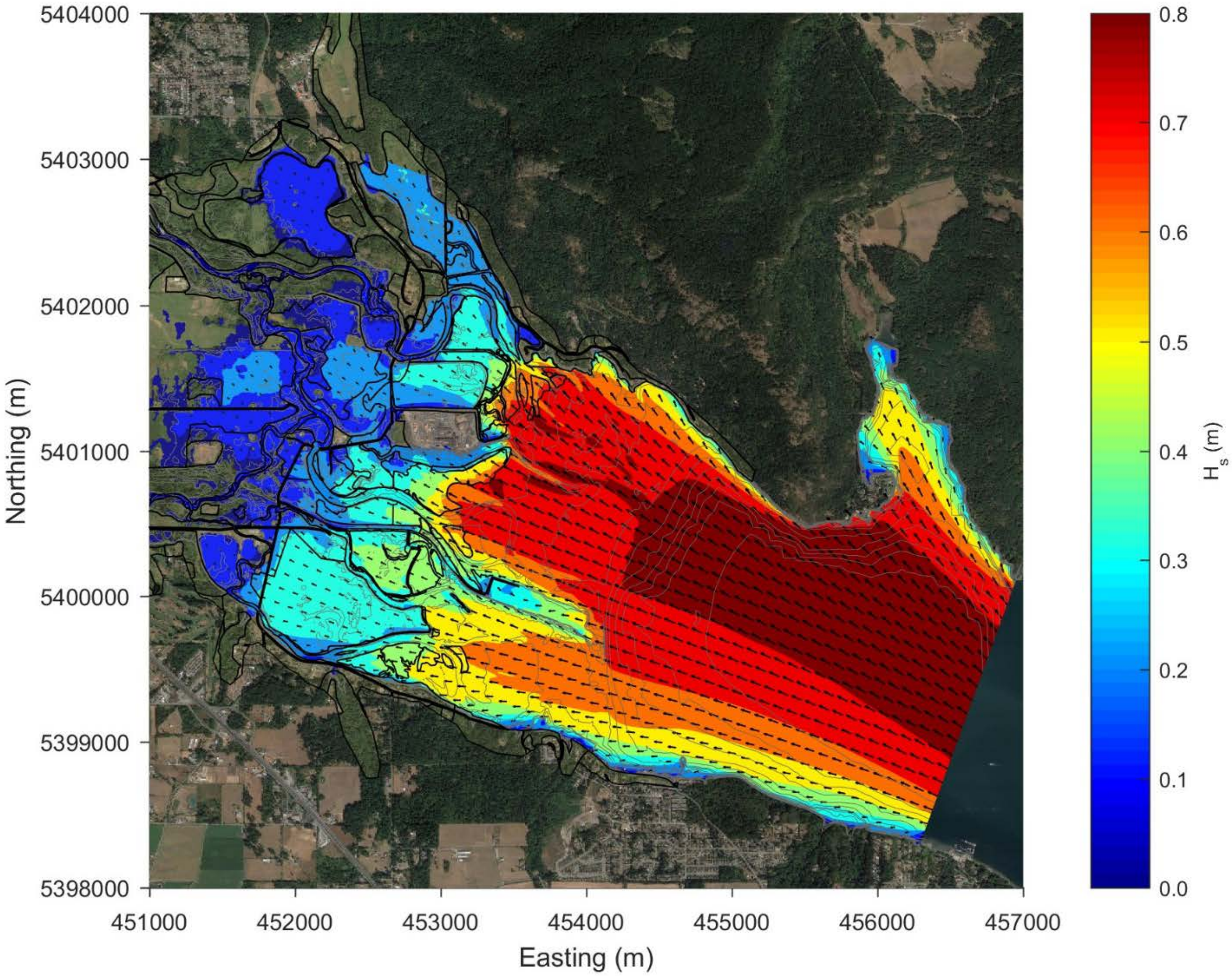


Figure 9-5: Cowichan Bay model results – Scenario B – 200-year southwesterly wave map for the year 2100. Vegetation polygons outlined in black.

Table 9-8: Significant Wave Height and Peak Period along Cowichan shoreline for scenario B (Year 2100)

Shoreline Reach	Significant Wave Height (m)	Peak Period (s)
CB-1	0.8	3.0
CB-2	0.7	2.7
CB-3	0.6	2.4
CB-4	0.5	2.1
CB-5	0.4	1.8
CB-6	0.3	1.5

9.2.2 Wave Effects Analysis

The results of the wave analysis are used to estimate the local wave runup along the shoreline for Cowichan Bay. Wave run-up represents the height that the waves will reach above the still water level after breaking. Wave run-up depends on the incident wave height at the point of breaking offshore of the shoreline, as well as the local shoreline topography (slope) and roughness. Wave run-up is calculated using the EurOtop (EurOtop, 2016) methodology, but differs depending on the shoreline characteristics. For anthropogenic shoreline types such as rip-rap, a reduction factor is used to account for rubble mound structures; for vegetated areas, such as wetlands or forested areas, a reduction factor is to account for vegetation, for oblique shorelines, a reduction factor is used to account for wave obliqueness.

The wave effects for Cowichan Bay were calculated by shoreline reach and shoreline type as shown in **Table 9-9** and **Figure 9-6**. The shoreline characteristics for Cowichan Bay vary significantly from property to property. Calculating the wave effects on this scale would be outside the scope of this study. Therefore, the results are presented depending on the characteristics of the shoreline.

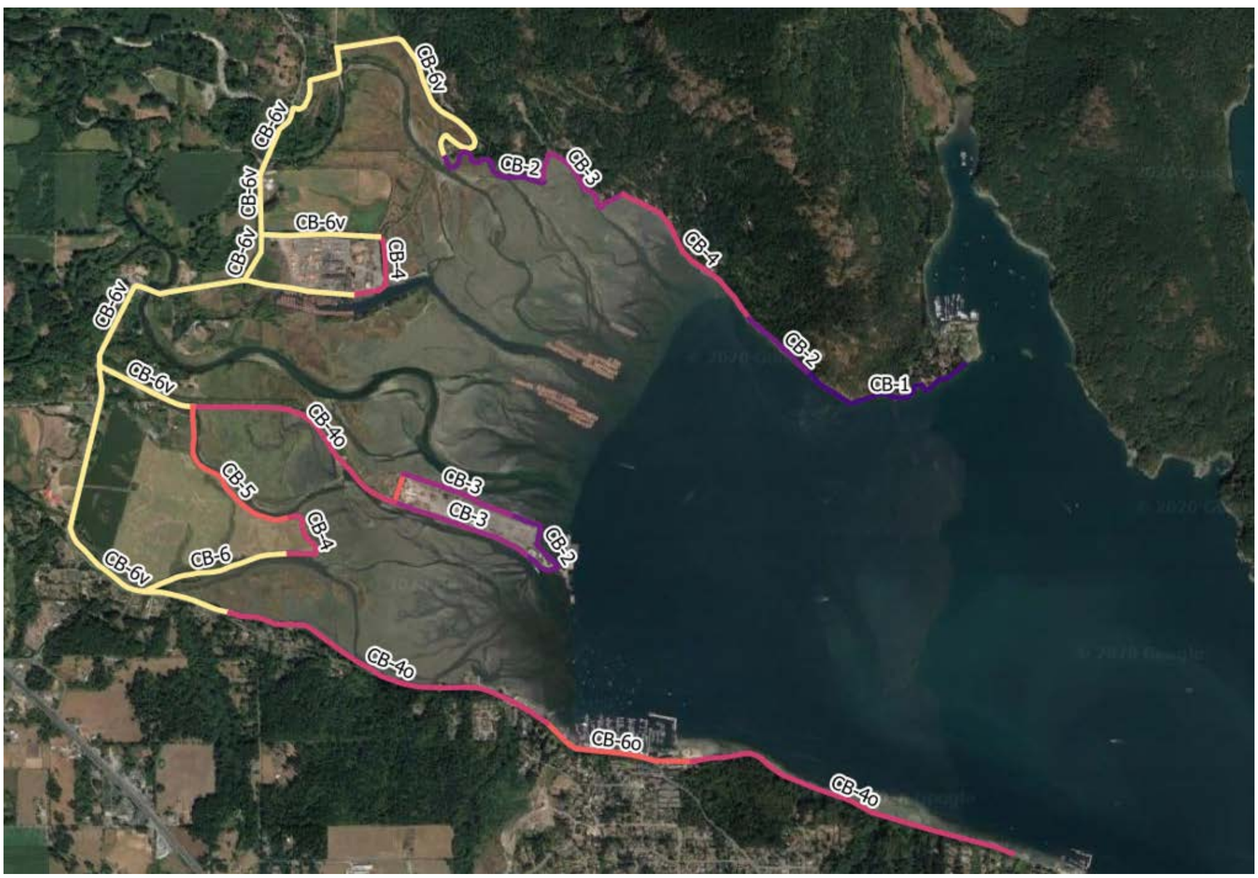


Figure 9-6: Shoreline reaches and wave effects for Cowichan Bay. Shoreline reach labels are differentiated by their wave run-up specific shoreline characteristics – no abbreviation for rip rap, 'v' for vegetation and 'o' for oblique

The delineation of shoreline reaches was made to be conservative (i.e. the highest wave runup was selected for a given reach) regarding wave exposure and wave runup due to the regional scale of this study. It is acknowledged that this approach could result in some properties having conservatively estimated FCL values and that a detailed study of an individual property might yield a lower FCL. However, such site specific analysis was not possible within the scope and scale of this project.

The largest wave effects are for a rip rap structure on the shoreline normal to the oncoming wave direction. The wave effects provided in **Table 9-9** are applicable for all SLR scenarios.

Table 9-9 Wave effects for Cowichan Bay shoreline by shoreline reach and type

Shoreline Reach	Wave Run-up (m) Rip Rap ( )	 Oblique Shoreline (-o)	 Vegetated (-v)
CB-1	1.5	1.2	1.0
CB-2	1.4	1.1	1.0
CB-3	1.2	1.0	1.0
CB-4	1.0	0.8	0.9
CB-5	0.8	0.7	0.8
CB-6	0.6	0.5	0.6

9.3 Freeboard

The freeboard is applied to account for temporal and spatial variances in wave climate and surge, as well as precision of the data and assessment. Freeboard for infrastructure according to the amendment to the Flood Hazard Area Land Use Management Guidelines (BCMFLNRD, 2018) is 0.6 m when using the probabilistic method. This value is appropriate for this study for coastal shorelines due to the nature of the assessment.

9.4 Coastal Flood Construction Level

Coastal FCLs apply to Cowichan Bay shorelines within the study limits that are exposed to coastal processes including: storm surge, wave effects, wind setup and/or wave setup. Coastal FCLs are provided in the following sections.

The FCL is the sum of design water level, future SLR allowance, subsidence/uplift, wave effect and freeboard. The FCL for the year 2100 Cowichan Bay shoreline reaches are summarized in Table 9-10.

Table 9-10: Cowichan Bay flood construction levels for year 2100

Component	Shoreline Reach							
	CB-1	CB-2	CB-3	CB-4	CB-5	CB-4o	CB-6o	CB-6v
1-in-200 AEP Total Water Level (m CGVD2013)	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41
Sea Level Rise (m)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subsidence/Uplift (m)	0	0	0	0	0	0	0	0
Wave Effects (R2% Run-up) (m)	1.5	1.4	1.2	1.0	0.8	0.8	0.5	0.6
Freeboard (m)	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
2100 Flood Construction Reference Plane (m CGVD2013)	**5.52**	**5.38**	**5.22**	**5.01**	**4.84**	**4.83**	**4.53**	**4.59**

10 FLOOD MAPPING

10.1 Mapping Products and Limitations

Based on the coastal and riverine model outputs, a variety of maps were produced to illustrate the results. The main focus was to produce digital mapping. The maps are submitted separately from this report as a set of drawings. Mapping products include:

- Designated floodplain map sheets and an associated index map at a 1:5,000 scale for the climate change (Year 2100) 200-year flood scenario. Flood Construction Levels (FCLs) and flood extents include a 0.6 m freeboard allowance. A total of 7 map sheets cover the study area.
- A flood depth map of the entire study area for the climate change (Year 2100) 200-year flood scenario. The extent and depth of flooding does not include freeboard. This map provides supplementary information to the floodplain maps, by classifying the computed water depths on the floodplain according to a hazard classification system. The map does not include FCL values and is not intended to be used without the designated floodplain map sheets.

The maps (designated floodplain maps and flood depth map) represent an overlay of model results for all 13 dike breach scenarios plus the base case flood scenarios. The maps assume that the existing dikes will fail during the designated flood event, allowing the river to spill across the floodplain. This approach is consistent with present floodplain mapping guidelines (APEGBC, 2017). The approach is conservative and is intended to ensure that any new sub-divisions and developments are constructed in a manner that minimizes damage from potential future flooding. Maintenance and upgrading of the dikes is still a critical component of the flood management strategy, since the dikes will still be needed to protect previously constructed developments on the floodplain.

Each mapping product includes a set of map notes and limitations. Mapping notes provide information on mapping symbology and boundary conditions. Mapping limitations include information on appropriate map use along with hydraulic and accuracy uncertainties. The main limitations are as follows:

- The maps depict the flooding conditions at the time of surveys. Future changes to the river channels, floodplain, and future climate change/sea level rise will render the maps obsolete. The information on the maps should be reviewed after 5 to 10 years have elapsed since publication or after any extreme flood occurrence.
- The floodplain limits have not been established on the ground by legal survey. The accuracy of the flood boundaries is limited by the Lidar base mapping and orthophotography.
- The flood maps do not represent flooding from local stormwater runoff, ponding from rainwater on the floodplain, groundwater seepage, or local drainage courses. Consequently, additional flooding may occur outside of the designated boundaries.
- Roads, railways, bridges, new dikes and future developments on the floodplain can restrict water flow and increase local water levels. Obstructions such as debris jams, channel sedimentation can also increase flood levels above the levels shown on the maps.
- The flood maps do not represent hazards due to erosion, avulsion, channel migration or tsunami.
- The flood maps are an administrative tool that depict the potential flood extent and minimum recommended Flood Construction Level for the designated flood. A Qualified Professional must be consulted for site-specific engineering analysis.

Further information on hydraulic modelling limitations can be found in Appendix E.

10.2 Differences With Previous Mapping

Floodplain mapping was completed previously in 1997 (BC MOE) and 2009 (NHC 2009). There has been a number of significant changes in flood mapping standards, design flood parameters, channel conditions and mapping techniques since the previous maps were produced. The main differences are listed below.

- The updated flood maps represent projected climate change and sea level rise scenarios in Year 2100, whereas previous maps represented historic flood conditions. The 200-year flood discharges in the Year 2100 on the Cowichan and Koksilah River (896 m^3/s and 601 m^3/s) have a return period of approximately 1,000 years under present conditions. The adopted discharges used for the mapping are 30% higher than the values that were used in previous flood maps issued in 1997 and 2009.

- New dikes since 2010 modify flow paths on Cowichan floodplain. Some dike breach scenarios create higher local flood levels due to ponding behind other adjacent dikes.
- The previous study assumed two secondary dikes (Quamichan Dike and Old Hatchery Dike) were raised, resulting in higher flood flows on the north branch of the Cowichan River and Somenos Creek. The present study represented these dikes using the 2019 LiDAR topography (without any raising).
- Sediment/debris management has occurred annually on the Cowichan River, and intermittently on the Koksilah River since the time of the 2008-2009 flood mapping work. The channel in 2008 -2009 was much more obstructed by log jams and sedimentation than in 2016-2019.
- The present study computed wave effects using a 2D SWAN wave model and estimated wave runup effects on the shoreline to estimate flood construction levels, whereas previous studies estimated only the still water level. Furthermore, the present coastal levels include a 1 m sea level rise to represent conditions in the year 2100. Previous mapping represented only historic sea level conditions.

11 PROJECT SUMMARY AND NEXT STEPS

11.1 Conclusions

Updated flood maps have been prepared for the Cowichan and Koksilah River floodplains using the available federal and provincial mapping guidelines . The maps represent a designated 200-year flood adjusted for a climate change and sea level rise scenario in the year 2100. The flooding extent and flood depths shown on the maps assumes all existing dikes and flood walls are non-functioning in order to provide a conservative representation of potential flood conditions.

The climate change scenario represented in this study is more severe than in previous investigations, with the designated river discharges being up to 30% higher than in previous flood mapping studies. As a result, Flood Construction Levels in some areas have increased, particularly adjacent to narrow, channelized sections of the Cowichan River.

The extent of flooding with the existing dikes in-place and functioning was also assessed for present conditions and the future climate change scenario. In these simulations, the area experiencing flooding was mainly limited to the floodplain of the Koksilah River and south branch of the lower Cowichan River.

The difference between the flooding extent with the dikes non-functioning and with the dikes functioning represents the benefits of maintaining the dikes in good operating order. Ongoing monitoring, sediment and log jam management and maintenance/upgrading of the existing dikes is the best approach to ensuring the dikes will continue to function in the future. These river management activities are even more vital under a changing climate than in the past.

A concept for mitigating flooding on the low-lying land between the south branch of the Cowichan River and north side of the Koksilah River was developed. This will require constructing a perimeter dike starting on the north side of the Koksilah River at Highway 1, extending downstream along the north side of the Koksilah River eventually turning northwards along the south side of the Cowichan River and then tying in to the end of the new Hatchery Dike. Model results indicated that, in order for a south Cowichan-Koksilah dike to be fully effective a section of Highway 1 will need to be raised (or blocked by a temporary flood barrier).

11.2 Recommendations

The new designated floodplain maps should be adopted for flood planning purposes, including establishing flood construction levels. The new designated floodplain maps should replace the previous published maps which did not represent future (Year 2100) sea level rise or climate change.

Floodplain maps need to be updated periodically to account for topographic changes, new developments which affect hydraulic conditions, and new information related to future climate change. The maps should be reviewed after a period of 10 years or after the occurrence of any large flood event (return period greater than 30 years).

11.3 Next Steps

The updated hydraulic models are powerful tools for assessing flood damages and flood risks and for developing long-term flood mitigation strategies under future climate change. Some applications of the model are listed below:

- Planning for future upgrades to roads and bridges. Virtually all bridges on the Cowichan River, Somenos Creek and Holmes Creek have inadequate clearance under present 200 year flood conditions, let alone under future climate change.
- Planning for emergency response and maintenance of the existing dikes. Dike breach simulations provide valuable information on the timing, inundation extent and depth of flooding related to a hypothetical dike failure. Failures at some locations result in only localized inundation and will have only limited impact. Failures at some other locations may result in much more extensive flooding and deep ponding of water on the floodplain. It is useful to know in advance where the most critical sections of the dikes are located in terms of potential consequences.
- Planning future upgrades to dikes in response to climate change. It is expected that the peak discharges will continue to increase over the century. However, the rate of increase is presently only poorly understood and the assumed climate change scenario adopted in this study will need to be continuously reviewed and revised in light of new information. Dike raising will be required in sections of the Cowichan River upstream of the JUB in order to maintain adequate freeboard.
- Planning future flood protection on presently unprotected areas of the floodplain, including the south branch of the Cowichan and Koksilah River. The dike concept presented in this

report is one example of a structural flood protection concept. However, additional modelling is required to assess its impacts to flooding upstream of Highway 1.

- Assessing and designing channel maintenance measures such as sediment removals and log jam removals to ensure the stability of the rivers can be maintained. The model can be used to assess the economic benefits of channel maintenance by comparing the potential flood damages with and without maintenance.
- The February 1, 2020 flood was a 30 year event and caused significant erosion and sedimentation along the north and south branch of the Cowichan River. It would be useful to re-survey the river and re-run the model to assess the risk of future channel instability and avulsions in response to these developments. Measures for restoring the channel could also be designed using the results from the model.

There are other flood-related issues that should be assessed in the region that require other types of investigations and analysis. For example, local drainage and flooding on some portions of the floodplain appears to be caused by ponding of rainfall, stormwater runoff and groundwater due to a high water table from groundwater inflows. These types of issues are likely to be important on the low lying floodplain adjacent to Boys Road and the land lying north of the Koksilah River. These problems need to be addressed using other methods, including water level and rainfall monitoring and stormwater modelling.

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Report Photos

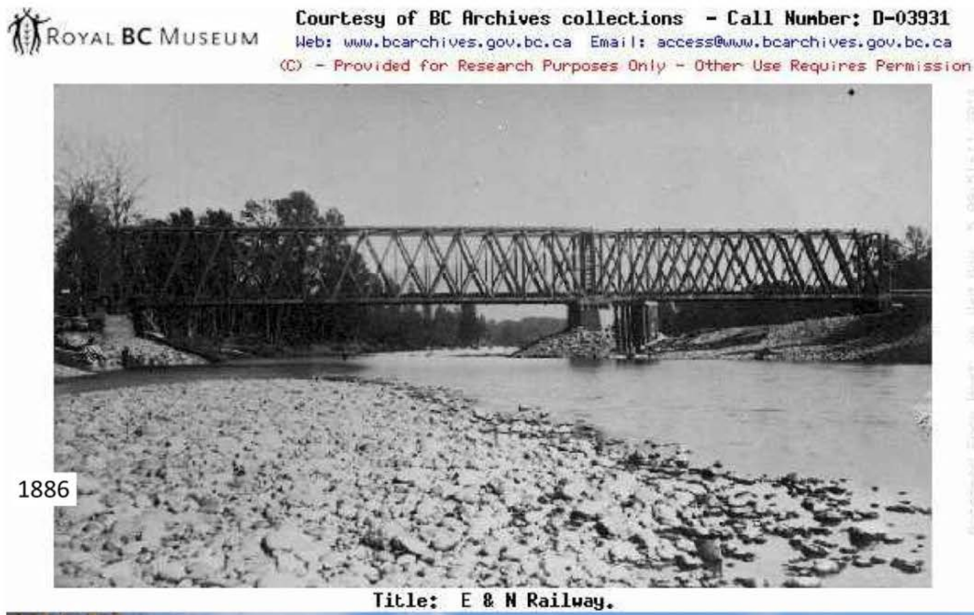
Photo 1: Construction of temporary no-post barrier on Lakes Road, Nov 20, 2009.

Photo 2: Highwater mark on outlet of Beverly Street pump station, Nov 20, 2009.

Photo 3: Log jam on Koksilah River downstream of Highway 1, June 2018.

Photo 4: Log jam spanning Cowichan River near Tooshley Island in March 2012.

Photo 5: Large log jam near JUB sewer lagoons, June 2010.



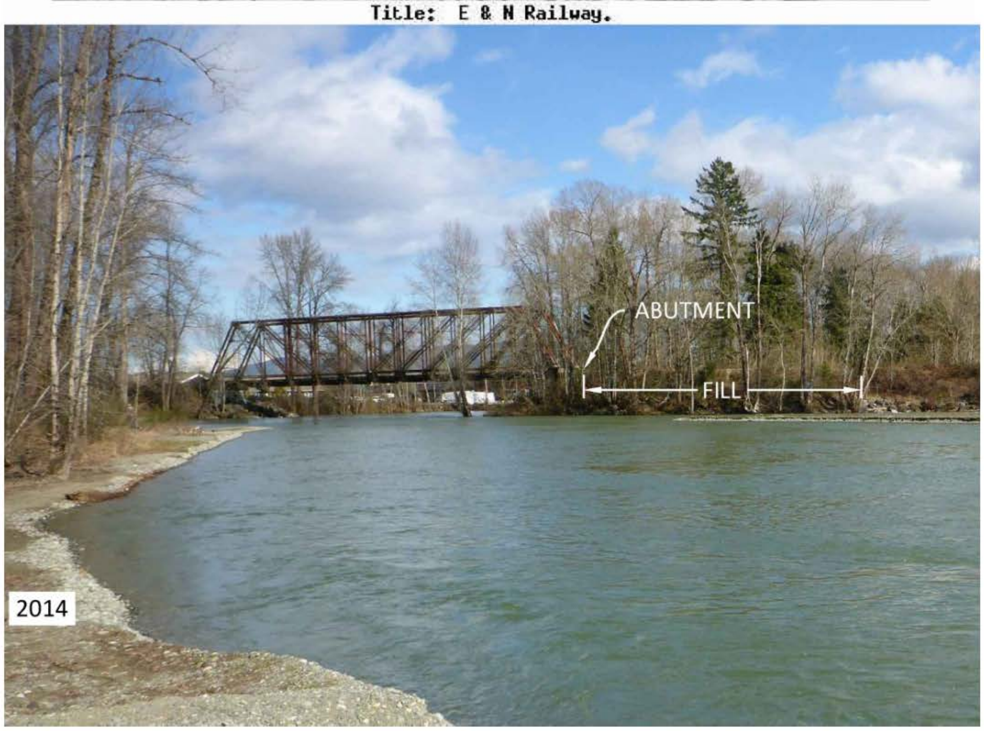


Photo 6: **Cowichan River upstream of Rail Bridge in 1886 and 2014, showing reduction in cross section.**