Floodplain Mapping Report

Village of New Denver

March 2025

Project No. 1479-111

TRUE

ENGINEERING ■ PLANNING ■ URBAN DESIGN ■ LAND SURVEYING

2089 Falcon Rd | Kamloops BC | V2C 4J2 | true.ca | tel 250.828.0881

Revision Log

Revision #	Revised by	Date	Issue / Revision Description
1	PP	Mar 28, 2025	Issued to client

Report Submission

Report Prepared By:

PROFESSIONAL PROVINCE OF P. PRODANOVIC # 52340 BRITISH COLUMBIA ENGINEER

Permit to Practice
No. 1000129
2025-04-02

Pat Prodanovic, Ph.D., P. Eng.
Sr. Water Resources Engineer

Report Reviewed By:

PROFESSIONAL PROVINCE OF J. P. WELKE # 35705 BRITISH COLUMBIA ENGINEER

2025-03-31

Jonathan Welke, P. Eng.
Sr. Water Resources Engineer

Report Reviewed By:

Permit to Practice #1000129

PROFESSIONAL PROVINCE OF D.S. WALLACE # 30341 BRITISH COLUMBIA ENGINEER

2025-04-01

Scott Wallace, P. Eng.
Project Manager

R:\Clients\1400-1499\1479\1479-11105 Reports\Floodplain Mapping Report\1479-111-Village of New Denver-Floodplain Mapping Report-2025-03-28.docx

Table of Contents

Executive Summary iv
1.0 Introduction 1
1.1 Project Background 1
1.2 Study Objectives and Scope of Work 2
1.3 Horizontal and Vertical Datum 3
2.0 Background Review and Data Collection 5
2.1 Previous Studies 5
2.1.1 Floodplain Mapping Study, Slocan River (NHC, 1989) 5
2.1.2 RDCK Floodplain and Steep Creek Study, Slocan River (BGC, 2020a) 6
2.1.3 RDCK Floodplain and Steep Creek Study, Kaslo River (BGC, 2020b) 6
2.1.4 Carpenter Creek Flood Mitigation (SNT, 2022) 7
2.2 Existing Municipal Infrastructure in the Floodplain 7
2.3 LiDAR Topography and Lake Bathymetry 12
2.3.1 LiDAR Topography 12
2.3.2 Slocan Lake Bathymetry 12
2.4 Site-specific Topographic Data 13
3.0 Digital Terrain Modeling 14
3.1 Above Water Digital Elevation Model 14
3.2 Below Water Digital Elevation Model 14
3.3 Merged Digital Elevation Model 15
4.0 Flows, Levels, Winds and Geomorphology 16
4.1 Carpenter Creek Flows 16
4.2 Slocan Lake Water Levels 17
4.3 Slocan Lake Wind Climate 20
4.4 Carpenter Creek Geomorphologic Assessment 21
5.0 Riverine Hydraulic Assessments 23
5.1 Model Description 23
5.2 Model Development 24
5.2.1 Digital Surface and Hydraulic Roughness Data 24

5.2.2 Model Mesh and Breaklines ... 24
5.2.3 Hydraulic Structures ... 25
5.2.4 Initial and Boundary Conditions ... 26
5.3 Calibration and Verification ... 27
5.4 Model Limitations ... 27
5.5 Model Results ... 27
6.0 Lakeshore Wave Analysis ... 29
6.1 Modeling of Wind Generated Waves ... 29
6.2 Assessment of Wave Runup ... 32
6.3 Model Results ... 34
7.0 Floodplain Mapping ... 37
7.1 Floodplain Mapping Standards ... 37
7.2 Flood Hazard Mapping ... 37
7.2.1 Riverine Hazard Mapping ... 37
7.2.2 Lakeshore Flood Hazard Mapping ... 38
References ... 41

List of Tables

Table 4-1: End of Century Design Flows for Carpenter Creek at New Denver ... 17
Table 5-1: Hydraulic Roughness Values ... 24
Table 5-2: Highway 6 Bridge Characteristics ... 26
Table 6-1: SWAN Model Results at Offshore Nodes of Study Area ... 31
Table 7-1: Lakeshore Flood Hazard Limit ... 39

List of Figures

Figure 1-1: Study Area ... 4
Figure 2-1: Existing dike construction post 1973 flood event ... 9
Figure 2-2: Existing Riprap Protection Upstream of Highway 6 ... 10
Figure 2-3: Existing Riprap Protection Downstream of Highway 6 ... 10
Figure 2-4: Relic Bank Protection Consisting of Rock Wrapped in Wire ... 11
Figure 2-5: Low lying Lakeshore Tableland Adjacent to the Health Centre ... 11
Figure 4-1: PCIC Simulations for Slocan River at Crescent Valley ... 19
Figure 4-2: CWEEDS Wind Rose at Castlegar (May-July, 1954-2005) ... 21
Figure 4-3: CWEEDS Wind Rose at Nelson (May-July, 1998-2017) ... 21
Figure 5-1: HEC-RAS 2D Model Grid at New Denver ... 25
Figure 5-2: Highway 6 Bridge at New Denver, Looking Downstream ... 26
Figure 5-3: Carpenter Creek 200-yr Flood Inundation ... 28
Figure 6-1: Slocan Lake Bathymetry ... 30
Figure 6-2: Slocan Lake Wave Model Output Nodes ... 30
Figure 6-3: Definition Sketch of the Nautical Direction Convention ... 32
Figure 6-4: Definition Sketch Related to Wave Model Output ... 32
Figure 6-5: Lakeshore Flood Hazard and Wave Runup on Steep Slopes ... 33
Figure 6-6: Lakeshore Flood Hazard and Wave Runup on Flat Slopes ... 33
Figure 6-7: Climate Adjusted 200-yr Flood (Blue) and Lakeshore Flood Hazard (Red) ... 35
Figure 6-8: Lakeshore Hazards at Community Health Centre ... 36
Figure 7-1: Creek Section and Flood Hazard Area Beyond Dike ... 38

List of Appendixes

Appendix A – Flood Frequency Analysis of Carpenter Creek

Appendix B – Lake Level and Wind Speed Frequency Analysis at Slocan Lake

Appendix C – Geomorphological Assessment of Carpenter Creek Fan Hazards

Appendix D – Flood Hazard Map

Executive Summary

This work documents a comprehensive assessment of flooding for the Village of New Denver. The final product is a map that is intended to support future development applications adjacent to the shoreline, provide better land use planning, and inform better disaster preparation, response and recovery management.

Flooding within the Village of New Denver is attributed to riverine (from Carpenter Creek) and lakeshore (from Slocan Lake) sources. Each are briefly described below.

Riverine floods on Carpenter Creek are generally caused by spring snowmelt (freshet), and are often exacerbated by short duration high intensity rainfall occurring on top of snowmelt. Rainfall occurring during snowmelt leads to sharp increases in discharge and produces fast moving waters. Such floods can involve considerable transport and deposition of sediment and wood debris, which bring the potential for riverbed and bank erosion. A geomorphological assessment of the Carpenter Creek watershed identified that lowermost reaches consist of gravel bed braided channels that are susceptible to lateral shifting and movement during high flow events. Carpenter Creek is subject to clearwater flooding (where water is the medium transported) and debris flooding (where heavy amount of sediment laden water from bed and bank erosion is the medium transported). Notable riverine floods occurred in 1973 (extreme snowmelt flood), followed by floods in 2012/2013, and 2020 (rainfall on top of snowmelt). The 1973 flood event led to dike construction downstream of the Highway 6 bridge in New Denver, while more recent flooding from 2020 damaged an existing embankment upstream of the bridge on the right bank.

Lakeshore flood hazards for inland lakes are caused by high lake levels (typical during the spring's freshet) that occur concurrently with winds blowing over the surface of the lake which generates waves. When waves propagate inland and interact with the shoreline, they cause water to run up the slope and cause hazards. Lakeshore flood hazards are particularly relevant for low lying shoreline where propagated waves tend to have the most influence (and damage). For New Denver, the shoreline of Slocan Lake south of the outlet of Carpenter Creek is generally low lying and most vulnerable to lakeshore wave hazards. The presence of a continuous concrete wall on the low-lying tableland around the perimeter of the Community Health Centre attests to past lakeshore wave hazards.

The comprehensive assessment of flooding included completion of the following technical studies:

a) Flood Frequency Analysis of Carpenter Creek (Appendix A),
b) Lake Level and Wind Frequency Analysis of Slocan Lake (Appendix B).
c) Geomorphological Assessment of Carpenter Creek Fan Hazards (Appendix C, SLR, 2025).

Items a), b) and c) are technical reports that were used to establish and quantify riverine flows, lake levels, and geomorphologic factors relevant for floodplain mapping, and are attached as appendices. The floodplain mapping has been completed on the basis of the above technical reports.

A detailed investigation of possible future effects of climate change was included in the above technical studies. Climate change assessments were completed for flows in Carpenter Creek, and for water levels of Slocan Lake. Each are briefly summarized below.

Carpenter Creek watershed routinely experiences rainfall during the freshet where the snowmelt flooding intensifies by the contribution of short duration high intensity rainfall. The rainfall occurring on top of already melting snowpack accelerates the melt process and contributes to more intense catchment response. Analysis of rainfall characteristics in the region surrounding the study area identified that a 45% increase in peak rainfall is possible by the end of this century (by year 2100). The magnitude of the increase in peak rainfall came from data supplied by Environment and Climate Change Canada. Hydrologic simulations were set up to quantify how an increase in rainfall would impacts peak flows. The analysis concluded that peak flows on Carpenter Creek could increase upwards by 70% compared to historical values resulting from climate change.

Further, geomorphologic assessment of the steep creek hazards for Carpenter Creek has identified that clearwater and debris floods are possible. For the purposes of flood inundation, hazard, and development of Flood Construction Levels a bulking factor of 10% was identified to apply. A bulking factor accounts for the increase in peak flow from sediment laden water during debris floods.

Riverine design flood standard uses the 200-yr flood, which includes factors for climate change (to the year 2100) and sediment bulking.

The Slocan Lake watershed, given its sheer size, behaves differently than a smaller catchment (like Carpenter Creek). For such a large watershed the melt of the snowpack was identified as the dominant mechanism that causes flooding, and will remain in the future. Hydrologic modelling simulations completed by Pacific Climate Impacts Consortium (PCIC) suggests that peak flows in the Slocan River are not anticipated to increase in response to climate change. Winter flows are shown to increase, but are expected to be lower than freshet flows. The snowpack will generally decline, and the freshet will experience much earlier peaks. But the magnitude of peak flows is anticipated to remain unchanged in the future because of climate change (up to year 2100). Given that flows in the Slocan River directly control water levels in Slocan Lake, an inference is made that lake levels are likewise not anticipated to change in the future.

Lakeshore design standard uses 200-yr lake level factored for climate change (to the year 2100), in combination with waves that occur during the freshet season.

Technical analyses have been carried out to map Carpenter Creek flood inundation, flood hazards, and develop Flood Construction Levels (FCLs). Riverine hydraulic assessment using 2D flow modelling was set up to establish water surface profiles and flood inundation limits for the

200-yr flood. The riverine Flood Construction Levels and their extents were developed using standard practice and methods in BC, and are shown in the floodplain map developed for the project.

Technical analyses were also carried out to map the Lakeshore Flood Hazards. Coastal analyses and modelling were conducted to estimate the wave magnitudes during the freshet season (dominant mode of flooding for Slocan Lake) for several location along the Village's shoreline. Wave effects were quantified via a term that is referred as wave runup. Wave runup is defined as the vertical height above design lake level that is expected to occur during storms and was estimated by analysis of incident waves and shoreline geometry (steeper slopes produce much higher wave runup compared to shallower slopes). For the Village of New Denver, shoreline north of the river's outlet has high bluffs and steep slopes, thus producing a high runup (which does not reach the crest of the tableland and does not generally lead to flood hazards). For the shoreline south of the river's outlet the tableland has a generally low crest relative to the 200-yr design water level. During storms the waves overtop the lake banks and propagate wave energy a distance inland. Given the gentle slope of the tableland in this area, the flood hazard zone can be considerable. Lakeshore Flood Hazard Limits were established, intended to identify areas that are subject to lake hazards.

Most importantly, the contour line establishing Lakeshore Flood Hazard Limit is not considered a Lakeshore FCL, and can not be used to define future development elevations. This is because wave runup heights vary with distance from the shoreline (closer the development to the shoreline, the higher the incident wave, and the higher the wave runup). Further, wave effects also depend on surface treatment on which waves interact with during times of flooding (grassed or riprap slopes, vertical wall, etc).

Development within Lakeshore Flood Hazard limits can still be allowed, provided that effects of lake levels and waves are taken into account in the design. A site-specific wave runup study will be required for an individual development within the Lakeshore Flood Hazard, in order to demonstrate how the wave hazards are addressed in the proposed design. Alternatively, the Village may consider carrying out a future flood mitigation plan that could investigate development potential within Lakeshore Flood Hazard limits where setbacks, and types of shoreline protection would be considered to ultimately develop Lakeshore FCL information for the community.

The Community Health Centre in New Denver is most vulnerable to lakeshore wave hazards, as it is exposed to direct wave attack from south winds that funnel along the lake's long axis. The open water fetch generates highest waves, which then impact the low-lying shoreline nearly head on and cause flood hazards. The Community Health Centre is entirely within the footprint of the wave induced hazard.

1.0 Introduction

The aim of this work is to summarize riverine and lakeshore coastal analyses undertaken as part of the flood mapping project undertaken for the Village of New Denver. Included in the mapping project are preparation of inundation and hazard mapping for the floodplain of Carpenter Creek and shoreline of Slocan Lake within the municipal boundary. The present mapping project has been funded with a grant from the Community Emergency Preparedness Fund (CEPF).

This report summarizes data, methodology, results, and main findings of the floodplain mapping project, which include mapping river and lakeshore flood hazards. The result of the study is mapping that quantifies inundation limits, wave hazards, and establishes flood construction levels for the floodplain and lake shoreline.

Given the region's mountainous terrain a geomorphological hazard assessment has also been completed as part of this assignment (SLR, 2025). The geomorphologic assessment documents hazards typical of steep creek watersheds and takes a deeper look into processes that can change alignment of mountainous streams and induce hazards beyond clearwater flooding.

Further, climate change is recognized as a significant factor influencing flood frequency and magnitude in BC, and needs consideration. As the planet warms the hydrologic cycle will intensify and lead to changes in temperature, rainfall, snowmelt and magnitude and frequency of floods. Future shifts in hydrologic effects could have a profound impact for flooding. This report assesses impacts of climate change on flood frequency using latest climate models, data and statistical techniques and establishes appropriate climate change factors, and ultimately develops design riverine flows and lake levels for use in floodplain mapping.

The floodplain mapping will provide support for the Village of New Denver in making informed decisions for future planning, policies and mitigation works related to projects along its floodplain and lake shoreline reaches.

1.1 Project Background

The intent of this project is to map riverine and lakeshore flood hazards within the municipal boundary of the Village of New Denver from Carpenter Creek and Slocan Lake. New Denver is a village of about 500 residents that was developed on lands of an existing alluvial fan. An alluvial fan is a landform feature found at the base of a mountain where riverine sediments have deposited and shaped the river's outlet over geologic timescale. New Denver was founded in 1892 (and incorporated in 1929) resulting from the mining boom in the late 1800's. The village is presently a small, vibrant community with a diverse population, and is surrounded by breathtaking views of

Slocan Lake with mountains on all sides. New Denver has a public school, a childcare centre, a regional health centre, an RCMP station, a post office, and various shops. It serves as a hub for the surrounding communities in the North Slocan region.

Floods within the Village of New Denver are caused by riverine (from Carpenter Creek) and lakeshore (from Slocan Lake) mechanisms. Each mechanism is briefly described below.

Riverine floods on Carpenter Creek are generally caused by spring snowmelt (freshet), and are often exacerbated by short duration high intensity rainfall occurring on top of snowmelt. Rainfall occurring during snowmelt leads to sharp increases in discharge, which implies fast moving waters given creek's steep gradients. Such floods involve considerable transport and deposition of sediment and wood debris, which bring the potential for river bed and bank erosion. Notable riverine floods occurred in 1973 (extreme snowmelt flood), followed by floods in 2012/2013, and 2020 (rainfall on top of snowmelt). The 1973 flood event lead to dike construction downstream of the Highway 6 bridge in New Denver, while more recent flooding from 2020 damaged an existing embankment upstream of the bridge on the right bank.

Lakeshore flood hazards for inland lakes are caused by high lake levels (typical during the spring's freshet) that occur concurrently with winds blowing over the surface of the lake (which generates waves). When waves propagate inland and interact with the shoreline, they cause water to run up the slope thus causing hazards. Waves can also cause erosion of lake banks by destabilizing the bank's toe of slope. When the toe of a lake bank erodes, it can destabilize the entire slope and ultimately cause erosion of the tableland. Lakeshore flood hazards are particularly relevant for low lying shoreline where propagated waves tend to have the most influence (and damage). For New Denver, the shoreline of Slocan Lake south of the outlet of Carpenter Creek is generally low lying and vulnerable to lakeshore wave hazards.

1.2 Study Objectives and Scope of Work

The scope of work includes completing a detailed floodplain mapping exercise within the municipal boundary of the Village of New Denver. The study includes approximately 1.3 km of river and floodplain along the Carpenter Creek and approximately 2.1 km of shoreline along Slocan Lake. Study requirements for floodplain mapping include:

- Background review and data collection (historic flooding, previous studies, large scale topographic data, aerial photography, etc.),
- Field investigations (completion of topographic and bathymetric surveys),
- Digital terrain modeling (merging large scale topographic data with in-river bathymetry),
- Hydrologic assessment (establishing design flows, including consideration of climate change),

- Hydraulic assessment (determining flooding inundation limits, flood hazards and flood construction levels using river hydraulic modeling),
- Lake levels and wind climate (establishing lake levels and winds for use in wave modeling),
- Wave uprush assessment (estimation of wave heights along Slocan Lake shoreline and identifying wave uprush heights),
- Floodplain mapping (developing relevant floodplain maps including inundation maps and flood construction levels), and
- Reporting (summarizing study recommendations and conclusions).

The study area for the present assignment is shown in Figure 1-1, and includes the floodplain of Carpenter Creek and shoreline of Slocan Lake, both within the municipal boundary of the Village of New Denver.

1.3 Horizontal and Vertical Datum

In this assignment, the horizontal reference plane used is NAD83(CSRS)/UTM Zone 11N. The vertical datum used is the Canadian Geodetic Vertical Datum 2013 (CGVD 2013). All topographic and bathymetric surveys, maps, inundation boundaries, flood elevations, and all other references are made to the above-noted standard. The project uses SI units, with dimensions reported in meters (m), and discharges reported in meters cubed per second (m^3/s).

New Denver

STUDY AREA

Flow Direction
River / Creek
Dike
Erosion Protection
Highway 6
Water Main
Municipal Boundary (Village of New Denver)

SCALE	1:15,000
DATE:	2/12/2025
PROJECT:	2813-031
Figure 1.1	TRUE

R:\Clients\1400-1499\1479\1479-111\03 Drawings\GIS\1479-111.aprx

2.0 Background Review and Data Collection

This section documents previous flood studies, historical flood events, and existing flood management infrastructure within the Village of New Denver. Data collection activities undertaken for the purposes of this assignment are also documented.

2.1 Previous Studies

Historical flooding documents and/or floodplain mapping relevant to the study area include the following.

2.1.1 Floodplain Mapping Study, Slocan River (NHC, 1989)

The NHC (1989) Floodplain mapping study included detailed hydraulic and hydrologic analysis of 58 km of Slocan River and 4 km of Little Slocan River. The main purpose of the study was to determine the position of the 200-yr floodplain and establish flood elevations (including freeboard).

All hydrologic analyses of water levels of Slocan Lake were carried out by staff of the BC Ministry of Environment (MoE), Water Management Branch and were used in the 1989 floodplain mapping. The data used for frequency analyses included the available historic water level data of the lake.

For establishing flood inundation limits, NHC (1989) used a calibrated HEC-2 hydraulic model (best available at the time) to estimate water surface profiles along the Slocan River from its outlet to its headwaters at the Village of Slocan. Computed 200-yr discharge for Slocan River was imposed in the HEC-2 model, which allowed estimation of a water surface profile along the study reach (which included the lower portion of Slocan Lake).

The NHC (1989) report also documents analyses of wind generated waves. Two different wind stations were used, including those at Castlegar Airport and at a BC Hydro dam near Castlegar. Estimates of wind magnitudes were provided in the report. Wave runup height were, however, not estimated in the NHC (1989) work. Instead of assessing a range of wave uprush heights during high water levels, a comparison was made between the Slocan Lake backwater level computed using the HEC-2 hydraulic model, and the sum of lake level plus wave heights. NHC (1989) found that the water level at Slocan Lake computed using the backwater calculation was higher compared to the sum of lake level and wave height, and for that reason used the computed backwater level for use in the lakeshore floodplain mapping.

2.1.2 RDCK Floodplain and Steep Creek Study, Slocan River (BGC, 2020a)

A floodplain mapping update study for Slocan River was completed by BGC (2020a) which provides an update to the previous mapping work from 1989. The BGC (2020a) study re-assessed hydrology of Slocan River and included a factor to account for future impact of climate change. Note that previous mapping work did not include a factor for climate change, as that was not typically included in studies from the 1980's.

BGC (2020a) used statistical and process-based methods to assess changes in peak streamflow characteristics resulting from climate change. The statistical modeling carried out showed a small decrease in the flood magnitude with climate change, while the process-based methods showed an increase. BGC (2020a) reported that trend analysis on streamflow data produced inconclusive results. For the floodplain mapping work, BGC (2020a) decided to increase flows in the Slocan River by 20% to account for uncertainty in climate change. A 20% increase in peak flows means that flows of 476 m^3/s (used in 1989) were increased to 575 m^3/s (used in 2020).

The above flows were used in hydraulic modeling of the Slocan River from its headwaters at Slocan Lake to its outlet at Kootenay River. The modeling was conducted using the HEC-RAS 2D hydraulic model (best available presently). Similar to the original mapping from 1989, Slocan Lake levels were estimated using backwater calculations using the hydraulic model. Since higher flows were used compared to the previous work, the backwater calculation yielded a correspondingly higher water level for Slocan Lake compared to 1989.

Coastal wave analysis was not carried for Slocan Lake in BGC (2020a) mapping update, and correspondingly shoreline flood hazards for Slocan Lake resulting from wave propagation and runup were not assessed.

2.1.3 RDCK Floodplain and Steep Creek Study, Kaslo River (BGC, 2020b)

BGC (2020b) completed a floodplain mapping and steep creek hazard study for the Kaslo River, a catchment directly adjacent to Carpenter Creek (just east of the mountain range). Steep creek hazards of Kaslo River were assessed by carrying out site investigations, topographic and bathymetric surveying, channel change and bank erosion and debris analysis.

Hydrologic analysis was carried out using classical flood frequency analysis using observed flow records. Climate change effects on flows were assessed using statistical and process based models. BGC (2020b) reported that their climate change analyses were inconsistent across Regional District of Central Kootenay, and as such it was difficult to select climate adjusted peak discharge on a site specific basis. Instead, peak discharges were increased by 20% to account for climate change (as above).

Estimation of flood inundation limits were completed using HEC-RAS 2D hydraulic modeling by using topographic and bathymetric surveying, along with latest latest large scale LiDAR terrain data. Flood depths, velocity and hazard intensity maps were prepared for 20, 50, 100, 200, and 500-yr events. Designated floodplain maps for the 200-yr flood event (including freeboard) were produced, thus mapping the Flood Construction Levels (FCLs).

Even though BGC (2020b) domain included shoreline of Kootenay Lake, coastal wave analysis was not carried out. As such, shoreline wave hazards (wave propagation and runup) were not calculated, and not included in the lakeshore mapping on Kootenay Lake with Kaslo.

2.1.4 Carpenter Creek Flood Mitigation (SNT, 2022)

After experiencing high freshet flows during the 2020 season, diking along Carpenter Creek in New Denver was damaged. The 2020 flood event resulted in the creation of new log jams and an enlargement of existing log jams and gravel bars, particularly upstream of Highway 6. An engineering consultant (SNT Geotechnical) was retained to determine the feasibility of removing the log jams and trees on the existing gravel bar, and to direct flows through the bridge opening by excavating a new channel through the gravel bar.

SNT (2022) report provides a detailed flood history within New Denver, which was supplemented via analysis of aerial photographs from 1939 to present. The event from 2020 included high stream velocities and floating debris which impinged directly onto the dike upstream of the Hwy 6 bridge, causing damage.

2.2 Existing Municipal Infrastructure in the Floodplain

There are several assets within the Village of New Denver which are either utilized for flood management or have the potential to be impacted by flooding due to their proximity to the creek and lake. These assets are summarized in this section.

Approximately 1000 m of riprap protection exists along the banks of Carpenter Creek in New Denver, constructed sometime following the 1973 extreme flood event. The riprap (shown in Figure 2-1) is located downstream of the Hwy 6 bridge, and extends along both banks of the river. This original riprap is still offering erosion protection to the banks of Carpenter Creek.

An additional riprap exists on the north (right) bank of Carpenter Creek, immediately upstream of the Hwy 6 bridge (Figure 2-2). This bank is protected with riprap stone, which has become damaged following the 2013 event (repaired in 2014) and following the 2020 event (repaired in 2023). According to the provincial registry, the bank protection on the north bank upstream of the bridge is registered as a dike. However, flood modeling carried out in this work suggests that this structure does not hold back water during the design flood event (design flood elevations are lower than the surrounding ground elevation). More recent riprap bank protection is visible downstream of the Highway 6 bridge (Figure 2-3).

Flood management infrastructure in the Village of New Denver consists of an existing bridge at Highway 6, which carries water distribution infrastructure on its lower chord. The bridge deck is raised well above the creek bed.

Relic bank protection (large rounded cobbles wrapped with steel wire) exists on the north approximately 250 m upstream of the Highway 6 bridge. The lower portions of the floodplain adjacent to the said bank protection are presently covered with mature trees, and do not experience erosion in its present configuration (Figure 2-4)

Low lying lakeshore shoreline adjacent to the Community Health Centre has a small concrete block wall installed on top of the lake bank to address wave related hazards from the lake. Figure 2-5 shows the photograph of the shoreline in this area.

A municipal marina is located south of the outlet of Carpenter Creek, on the shoreline of Slocan Lake. The marina includes an access channel to the Slocan Lake, floating docks, and a concrete boat launch ramp.

South of the marina is Centennial Park, which lies on lands inland of the lake’s shoreline. The park includes designated locations for camping, along with a BBQ cookhouse and shelter, along with washrooms. In addition to sports fields, swimming area, public boat launch, beach volleyball court and children’s playground, the park features a gazebo for community use.

FIGURE 2-1: EXISTING DIKE CONSTRUCTION POST 1973 FLOOD EVENT

FIGURE 2-2: EXISTING RIPRAP PROTECTION UPSTREAM OF HIGHWAY 6

FIGURE 2-3: EXISTING RIPRAP PROTECTION DOWNSTREAM OF HIGHWAY 6

FIGURE 2-4: RELIC BANK PROTECTION CONSISTING OF ROCK WRAPPED IN WIRE

FIGURE 2-5: LOW LYING LAKESHORE TABLELAND ADJACENT TO THE HEALTH CENTRE

2.3 LiDAR Topography and Lake Bathymetry

2.3.1 LiDAR Topography

In 2018 the BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development commissioned a campaign that collected LiDAR (Light Detection And Ranging) for several areas within the Kootenays (including the present study area at the Village of New Denver). LiDAR techniques use a laser beam to measure the duration of light reflecting from an object to its receiver. When mounted on an aircraft, a LiDAR instrument can collect high-resolution topographic (above water) data for large geographic areas.

The riverine and lakeshore floodplain area within the Village of New Denver were included in the LiDAR data collection campaign of 2018. As such, the 2018 LiDAR represents the best available large-scale topographic data within the study area. The 2018 LiDAR data (collected between July 6 and July 26, 2018) is used in this floodplain mapping project. The supplied data includes:

The supplied data includes:

- Classified LiDAR point cloud, and
- 1.0 m pixel size Digital Elevation Model (DEM)

Aerial imagery was also collected during the 2018 LiDAR data collection campaign, but was not released publicly.

2.3.2 Slocan Lake Bathymetry

To assess lakeshore flooding and its impacts, bathymetry is required to estimate generation and propagation of waves, and their wave effects (how high will the waves runup the slopes and/or on existing structures).

A search of publicly available records for bathymetry revealed that lake-wide bathymetric contours were produced in 1965 by the Fish and Game Branch, of the Department of Recreation and Conservation. The 1965 bathymetric data for Slocan Lake is believed to be the only publicly available data that includes depth contours of the entire lake. The depth contours generally included 100 ft contour interval, developed from a large number of individual soundings.

Water surface elevation at the time of the 1965 bathymetric survey was provided, which allowed referencing the data to the CGVD2013 vertical datum (used in this project). The 1965 bathymetric survey did not include horizontal control information, which made accurate geo-referencing challenging. For the purposes of this assignment the 1965 contours were digitally stretched to visually match the 1965 lake's perimeter to the present-day aerial imagery/LiDAR topography of the lake.

2.4 Site-specific Topographic Data

Site specific topographic survey data was collected as part of this assignment. The survey was carried out using a Real Time Kinematic Global Navigation Satellite System (RTK-GNSS) unit, having instrument accuracy of 10 mm in the horizontal and 20 mm in the vertical plane. The vertical datum used was CGVD2013 and is thus consistent with the LiDAR data.

All survey work was performed by TRUE staff during October 12, 2023. Due to low flows in the creek at the time of the survey, all field work could be safely completed using a field crew of two equipped with chest waders. The survey crew collected approximately 300 survey points within the study limit, many of which were in-water and/or along the shoreline.

A survey crew of two collected the following data at the Highway 6 bridge:

- Photograph of the opening,
- Crest elevation of the bridge deck or road crossing,
- Measurement from the bridge deck to the underside of the soffit,
- Dimensions of structure opening (invert elevations on upstream and downstream sides)
- Geometry of the creek's cross section, and
- Location and size of pier.

The survey crew collected a total of nine cross sections of river and floodplain, ranging from upstream of the Hwy 6 bridge to the outlet. The survey data collected was used to incorporate bathymetry into the LiDAR digital elevation model (documented in a subsequent section of this report).

Further, a site visit of the study area was also completed by TRUE's engineering staff during July 26, 2024. This site visit included a general inspection of the river and lake shoreline within the Village. Observations of infrastructure, including bridges and flood protection structures (i.e., dikes, riprap armouring), were noted.

3.0 Digital Terrain Modeling

LiDAR derived digital terrain models are used for riverine and coastal modeling as they efficiently capture geometry of the terrain for large areas adjacent to water bodies. However, typical LiDAR derived data does not include elevations for areas below the water line, thus resulting in reduced accuracy for terrain surfaces below water. The geometry of the terrain under the water's surface is thus not captured using typical LiDAR products but is nonetheless required for accurate assessments of flood levels and wave effects for floodplain mapping purposes.

This section outlines the methodology employed that combines the LiDAR derived Digital Elevation Model (DEM) with DEMs derived from bathymetric surveying. The combining of LiDAR with the survey derived DEMs are used to construct a merged DEM that is ready for numeric modeling of riverine and coastal wave propagation. The end product of the terrain modeling exercise includes a digital surface accurate for both above and below water portions of the study area, which is used in all subsequent work in this assignment.

3.1 Above Water Digital Elevation Model

The 2018 LiDAR data (section 2.3.1) available included a DEM having a horizontal resolution of 1.0 m, and a classified LiDAR point cloud. Given that existing channel widths of Carpenter Creek are small, the provided 1.0 m grid cell spacing provides limited number of grid cells across the channel. Since the LiDAR data was provided as a classified point cloud, staff from TRUE re-processed the LiDAR point cloud to create bare ground 0.5 m grid cell size DEM for use in the project. Smaller resolution grid size DEM was found to capture the channel geometry of Carpenter Creek much better than the original (1.0 m) DEM.

The LiDAR DEM provides consistent information for the above water portion of the terrain to sufficient resolution to be used in the present undertaking. The topographic surveys within the study area were used to compare elevations between data collected using survey grade instrumentation and the LiDAR DEM product. In areas where the two sources of data overlapped, comparisons showed that on the ground measurements of elevations were consistent with the LiDAR DEM product, thus providing confidence in use of the LiDAR DEM elevations.

3.2 Below Water Digital Elevation Model

For Carpenter Creek the surveyed channel geometries were used to create a Triangulated Irregular Network (TIN) model of the riverbed below the water surface. A customized procedure, similar to one provided by Merwade et. al. (2005), was used to transform the river alignment and the survey geometry from a Cartesian to a Curvilinear-Orthogonal system. The reason for the coordinate transformation is that construction of a TIN surface using cross section-based river geometry is much simpler in the Curvilinear Orthogonal system than in the Cartesian system. After construction of the TIN surface in the Curvilinear Orthogonal system was completed, the surface was converted back to the Cartesian system, and used to construct an in-stream only DEM.

The 1965 bathymetric data (section 2.3.2) was digitized and used to develop a DEM for the below water portion of the Slocan Lake. All noted data sources were used to create a Triangulated Irregular Network (TIN) model on the below water portion of the study area. The TIN model was converted to a 0.5 m bathymetry DEM for the underwater portion of the lake. The cell size of the bathymetry was set to simply match the cell size used for the above water portion of the DEM.

3.3 Merged Digital Elevation Model

The 0.5 m LiDAR DEM and the 0.5 m below water DEM were combined to produce a final merged DEM for use in this project. The merged digital surface (consisting of LiDAR topography and surveyed bathymetry) includes the best available geometric data for the study area which is used in the technical analyses in this work. Note that the merged DEM developed is only valid for use in this project (for calculations associated to flood and wave related effects) and may not be applicable for other purposes.

4.0 Flows, Levels, Winds and Geomorphology

This section summarizes design flow characteristics for Carpenter Creek (needed for river hydraulic modeling), and lake level and wind climate (needed for lakeshore wave modeling). Separate reports have been prepared for this project that provide technical details for riverine (Flood Frequency Analysis of Carpenter Creek, Appendix A), lakeshore forcings (Lake Level and Wind Speed Frequency Analysis at Slocan Lake, Appendix B), and geomorphology (Geomorphologic Assessment of Carptenter Creek Fan Hazards, Appendix C). Key points from each of appendix reports are summarized below.

4.1 Carpenter Creek Flows

Detailed flow frequency analyses (summarized in Appendix A) classifies Carpenter Creek as a freshet dominated stream, where the annual flooding typically results from the melting of snowpack during the spring. Observed streamflow records suggest that nearby watersheds often experience rainfall during the freshet season, which can accelerate the melt process and contribute to a shorter duration but more intense catchment response (high flood peaks). Present day flood magnitudes for return periods ranging from 2-yr to 500-yr have been determined using regional analyses, and have been found to generally agree with previous works in the Kootenays (see Appendix A).

Impacts of climate change on the hydrologic flow regime for Carpenter Creek has been assessed using results of Pacific Climate Impacts Consortium's (PCIC) hydrologic modeling, where simulations are showing significantly earlier occurrence of snowmelt, and significantly more rainfall during the winter. However, the PCIC's hydrologic modeling was not able resolve catchment behaviour from the potential changes in rainfall during the snowmelt. To assess how future changes in rainfall intensity and magnitude may impact flooding, a limited scope hydrologic modeling was set up in this work. This modeling assessed the catchment response from rainfall during snowmelt for the present and future periods. A comparison of answers from present and future periods identified a climate change factor of 1.7 to adjust current peak flows to end of century (year 2100) design peak flows. Further, the geomorphologic assessment of steep creek processes at Carpenter Creek at New Denver identified that a bulking factor of 1.1 be applied on top of peak flow from clearwater floods. For further details, see Appendix A for details on flow statistics and climate change factors, and Appendix C for details regarding flow bulking.

A summary of design flows is presented in Table 4-1.

TABLE 4-1: END OF CENTURY DESIGN FLOWS FOR CARPENTER CREEK AT NEW DENVER

COMPONENT	FLOW (m^3/s)
200-yr Peak Clearwater Flow	107.7
Climate Change Adjustment (70%)	75.4
Sediment Bulking Adjustment (10%)	10.8
200-yr Peak Design Flow	**193.9**

4.2 Slocan Lake Water Levels

Water level analyses of Slocan Lake are detailed in Appendix B. The observed data used in the analyses suggests that lake levels can vary as much as 1.5 m throughout the year. During the freshet season (when the snowmelt generates runoff) data shows lake levels increase, and then lowers to its normal range during the summer and fall.

Statistical analyses of the historic lake level records were carried out. The historic record of water levels was used to extract annual maximum levels from the historic record. Next, the annual maximum levels were used to fit the data to several statistical distributions commonly used in hydrology. Results from the Generalized Extreme Value (GEV) statistical distribution, with parameters computed using the Method of L-Moments. Daily lake levels were adjusted for instantaneous levels.

To estimate changes to water levels at Slocan Lake from climate change, this work analyzed outputs from long-term hydrologic modeling from PCIC. Water levels in Slocan Lake were not available directly from the PCIC's hydrologic modeling; instead, modeling output included streamflow at Slocan River at Crescent Valley (located downstream of Slocan Lake) and can be considered as a proxy indicator to Slocan Lake levels. If the flow in Slocan River changes because of climate change, so will Slocan Lake water levels.

The PCIC's hydrologic model output data was analyzed by extracting annual maximum peak flow for each year (for each climate period, scenario, and global climate model). The data suggests that peak freshet flows are not anticipated to increase because of climate change in the Slocan River. Further, the data also shows a trend that peak flows will generally occur earlier in the year (average day of year when peak flows occur will be almost a month earlier by the end of the century). The regularity (spread around the peak) is anticipated to stay the same. A graphic showing the PCIC projected flows for Slocan River at Crescent Valley is shown in Figure 4-1.

The analysis and visuals in Figure 4-1 demonstrate that peak freshet flows in the Slocan River (which also control levels in Slocan Lake) are not anticipated to increase in response to climate change. Visual inspection of the year-over-year hydrograph plots for different climate periods show that while winter flows will increase, they are not anticipated to have significant magnitudes compared to peak freshet flows. In other words, the freshet conditions are anticipated to stay dominant up to year 2100.

Although winter rainfall is anticipated to increase in the region, it is not a driving factor that is responsible for generating flows at Slocan River at Crescent Valley (which has a drainage area of 3300 km^2). For such large catchments, the melt of the snowpack is the dominant mechanism that causes flooding, and this will remain in the future.

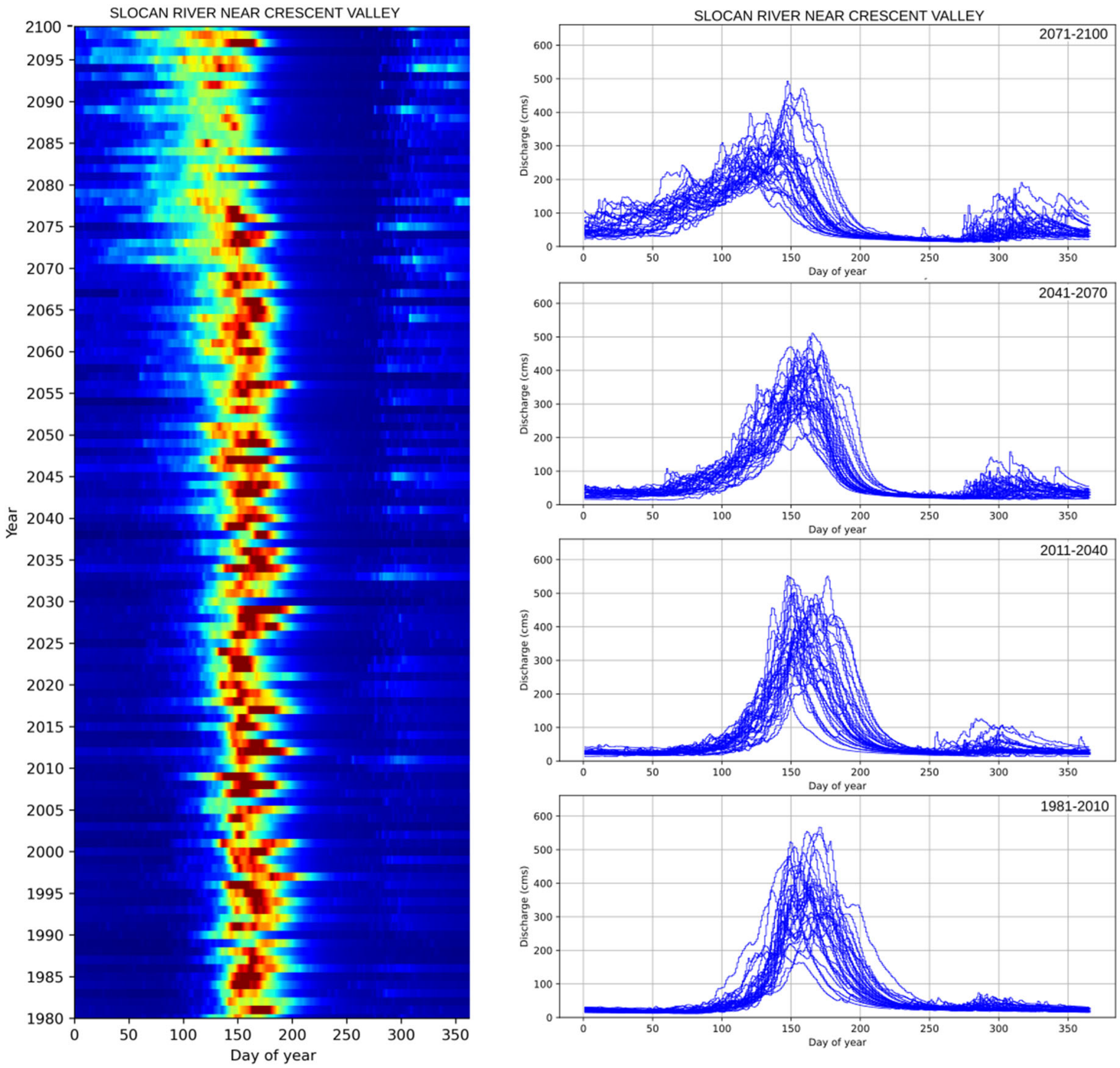


FIGURE 4-1: PCIC SIMULATIONS FOR SLOCAN RIVER AT CRESCENT VALLEY

No climate change adjustment factors are thus applied for water levels at Slocan Lake.

For the purposes of lakeshore floodplain mapping at Slocan Lake, it is recommended that 200-yr peak water level of 538.8 m CGVD2013 be used (daily 200-yr level statistic adjusted to instantaneous level).

Note that previous flood modeling by BGC (2020) identified higher values for the 200-yr peak design water level, stemming from their application of a climate change factor of 20% for Slocan

River flows (which correspondingly increased Slocan Lake levels). This work does not apply a climate change factor for Slocan Lake levels, and thus uses a lower 200-yr peak design lake level.

4.3 Slocan Lake Wind Climate

Wind climate characteristics are necessary for the computation of waves on inland lakes. Local winds blowing over a fetch of open water of Slocan Lake will generate waves, which will propagate to the shoreline and induce wave effects (wave runup). The wave effects require quantification for the lakeshore floodplain mapping. Details on the wind climate analyses are presented in Appendix B.

A high-fidelity data source from the Canadian Weather Energy and Engineering datasets (CWEEDS) obtained from Environment Canada and Climate Change was used to assess wind climate for Slocan Lake. The CWEEDS database was used to extract hourly wind speed and direction data for several stations. The analyses that follow quantify wind characteristics that occur during the flood season only (using winds from the months of May, June, and July). This data filtering was necessary as the intention of the exercise was to estimate lake induced hazards during times when peak stillwater levels are highest (the freshet season). Using annual maximum winds is not appropriate for delineation of lakeshore flood hazards for systems where freshet flooding dominates, as over estimation of effects would result (and would be physically unrealistic).

Wind data is shown graphically with wind rose plots, which show the percentage of wind blowing from each of the 16 cardinal wind directions. Figures 4-2 and 4-3 show the wind rose plots for Castlegar and Nelson CWEEDS data, respectively (data filtered to include the freshet season only).

For the Castlegar and Nelson wind rose data it is readily apparent that dominant wind direction aligns with the open fetch of the Columbia River (north-south) and Kootenay River/Lake, respectively. Surrounding mountains funnel winds through the river valley, which is wind's path of lowest resistance. The mountains surrounding open water act to funnel the winds along the lake's long axis, thus generating maximum wave effects. Castlegar observations of wind speed and direction span a longer period than other stations considered and is relatively close to the project site. For this reason, the Castlegar station was used in this work.

Based on the wind rose plots and statistical analyses, it is recommended that a 200-yr wind speed of 16.0 m/s (taken as the 200-yr wind speed during the freshet) be applied during the 200-yr peak stillwater level at Slocan Lake. The design direction for the noted wind speed is taken as the long axis of Slocan Lake. The same speed is to be applied for winds blowing from the north, and south directions, adjusted for maximum exposure.

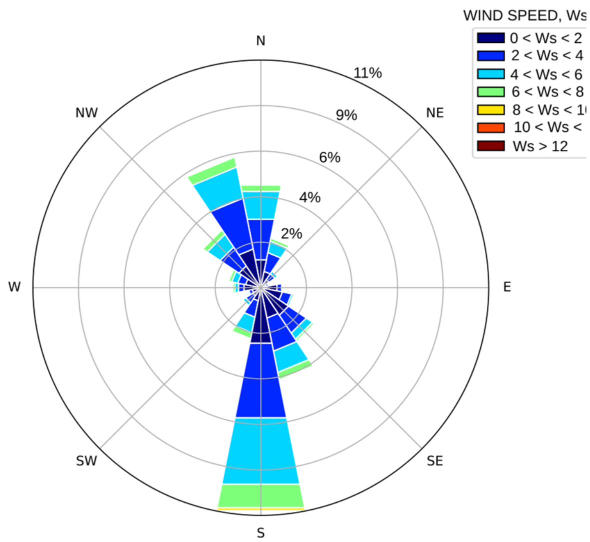


FIGURE 4-2: CWEEDS WIND ROSE AT CASTLEGAR (MAY-JULY, 1954-2005)

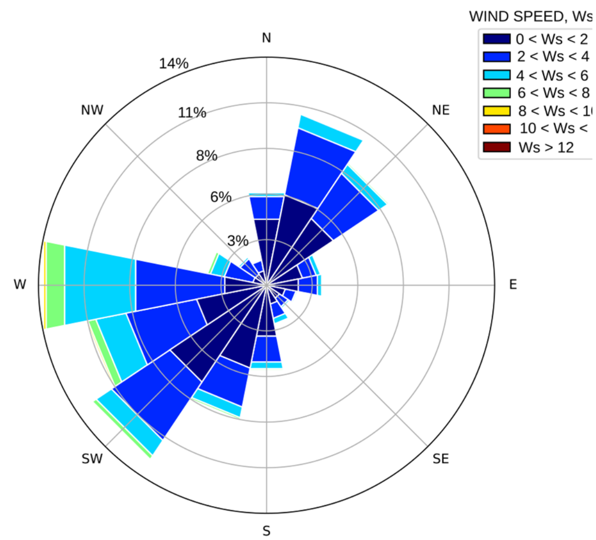


FIGURE 4-3: CWEEDS WIND ROSE AT NELSON (MAY-JULY, 1998-2017)

Environment and Climate Change Canada (ECCC) is currently researching the impact of climate change on wind magnitude and frequency using global and regional climate models. This ongoing research aims to understand how climate change may alter future wind patterns. Additionally, the Pacific Climate Impacts Consortium (PCIC) presently offers a publicly accessible Design Value Explorer tool providing 10-year and 50-year wind pressure variables for use in building design. However, wind pressures used in building design do not completely relate to winds blowing over open fetches of water, and may not apply.

To the best knowledge of the authors of this work, there is no precedent in BC that justifies increasing or decreasing design wind speeds to account for climate change in the context of lakeshore flood hazard mapping studies. This finding, however, may need to become updated in the future when results from ongoing research studies become available, and effects of climate change on wind speed and direction are better understood.

4.4 Carpenter Creek Geomorphologic Assessment

A geomorphologic assessment of the alluvial fan hazards at Carpenter Creek has been completed by SLR (2025) as part of this project, and is included as Appendix C. The geomorphologc report has identified that clearwater and debris floods are possible for Carpenter Creek. A clearwater flood occurs when rainfall and/or snowmelt occur, where the water is the only medium transported by the stream. Debris floods occur when gravel, cobbles, and boulders from the bed and banks lifts within the water column, and is transported downstream during flood conditions. In addition to bed material, debris floods can carry woody debris (log jams). Evidence of riverbed reshaping is present in the main channel along the lower reach of Carpenter Creek at New Denver.

For the purposes of flood inundation, hazard, and development of Flood Construction Levels, the geomorphologic assessment has recommended a 10% bulking factor should be added to the design flow to account for the increase in peak flow from sediment laden water during high flow events. Lands next to Carpenter Creek are at risk from erosion during high flow events, as evidenced by migration of the channel over time (visible in historic aerial imagery) along with efforts to repair the dike upstream of the bridge. Even though the geomorphology study authors deem it unlikely, they still note that a major flood event could lead to partial obstruction (with log jams) of the channel near the bridge. These types of channel restrictions could result in floodwater overspilling the banks and inundating adjacent land areas. SLR (2025) recommends that a sensitivity analysis should be completed in the future to assess avulsion potential and pathways, to support risk management and emergency preparedness.

5.0 Riverine Hydraulic Assessments

This section focuses on hydraulic modeling and provides details on data and analytical tools used in the assessment. Hydraulic models are analytical tools that evaluate characteristics of movement of water over time and space. They use existing geometry of river/floodplain with specified design flows to determine water surface elevation profiles and inundation depths/extents for a river reach in question.

Hydraulic modeling in this assignment is completed using 2D numerical modeling. The 2D analyses allow for accurate assessment of spatial and temporal characteristics of flooding processes, and its resulting overland flow inundation patterns in greater detail than older 1D analyses.

5.1 Model Description

The hydraulic analysis carried out in this assessment uses the Hydrologic Modeling Center's River Analysis Systems (HEC-RAS), developed and maintained by the US Army Corps of Engineers. The HEC-RAS model is currently the standard hydraulic model widely used in North America and beyond. HEC-RAS allows its users to carry out river hydraulic analyses, using steady or unsteady techniques. Version 6.5 of the HEC-RAS model is used in this work, as it was the latest at the time of this writing.

In this work a 2D variant of the HEC-RAS hydraulic model is used to quantify detailed behavior of the hydraulics within the study area. The ability of the model to capture river and floodplain hydrodynamics makes it ideal for the study where 2D effects dominate (such places where flow is suddenly released into relatively flat areas). HEC-RAS 2D model uses the theory of sub-grid finite volumes to solve the governing flow equations and capture governing flow phenomena.

The 2D model uses a large number (in the tens or hundreds of thousand) of discrete elements to represent the geometry (river and floodplain) of the study area. Using such a large number of elements allows for capturing geometry of the physical system with a high degree of accuracy. The advantage of 2D modeling is that a range of flood flows (from small to extreme) can be assessed, while making a minimum number of assumptions.

2D hydrodynamic models are depth averaged, implying that computations of flow velocity are averaged along the water column. For relatively shallow flows and wide flooded areas capturing vertical velocity is not necessary to represent the problem under consideration.

Required data for 2D modeling includes:

a) Terrain surface that captures key geometric features within the river and floodplain (i.e., hydraulic model ready DEM),
b) Model grid or mesh that discretizes the study area into a large number of computational elements,
c) Hydraulic structures (bridges, culverts, weirs, dikes, etc.),
d) Initial and boundary conditions (flows and levels), and
e) Manning's roughness coefficients for the main channel and the overbank areas.

5.2 Model Development

HEC-RAS 2D hydraulic modeling is used to develop simulation models for this work. One distinct modeling domain is developed for the Carpenter Creek within the municipal boundary of the Village of New Denver. The hydraulic modeling domain includes river and floodplain areas from 1.1 km upstream of Highway 6 bridge to the creek's outlet at Slocan Lake.

5.2.1 Digital Surface and Hydraulic Roughness Data

The hydraulic model ready DEM, documented above, is used as the basic terrain surface data for the 2D modeling work. The DEM used includes best available data for above and below water floodplain geometry of the study area.

Hydraulic roughness in terms of Manning's coefficient is derived using 2018 aerial photography within the study areas. Values used in the modeling were based on typical roughness values correlated with the surface treatment (existing ground surface materials). Table 5-1 shows the roughness values used and are consistent with standard practice for similar land use classes.

TABLE 5-1: HYDRAULIC ROUGHNESS VALUES

Land use type	Manning's n value
Channels	0.035
Grasses	0.030
Forest	0.100
Light Forest	0.050
Residential	0.060
Barren	0.025

5.2.2 Model Mesh and Breaklines

Model grid for the study area is constructed using unstructured elements of varying geometric proportions. To adequately represent river and floodplain geometry within study area the modeling domain is discretized using elements of various sizes. Fine resolution mesh is used in areas that were deemed to control flow characteristics, like main channels, bridges approaches, dikes, roadways, top and bottom of slopes, etc. Coarser resolution mesh is used elsewhere in the model domain in areas that are not anticipated to control flow propagation but could still be inundated. Care was taken to include appropriate grid resolution in the model to capture relevant features, and still keep computation times to a minimum.

A HEC-RAS 2D model schematic is presented in Figure 5-1, where the numerical model grid is shown, along with breaklines and hydraulic structures. Generally, areas within the 2D model domain that are anticipated to carry bulk of the flow are discretized with finer elements (such as main channels and hydraulic structures). Areas farther away were assigned larger grid cells, as these areas will likely not govern in controlling flow behavior (such as open fields for example). Model breaklines were placed at locations where geometry changes slope (like top of channel banks, tops, and bottoms of slopes, etc). When used properly, breaklines allow the model to limit the number of grid cells (and thus reduce computational time), while capturing relevant flow hydraulics.

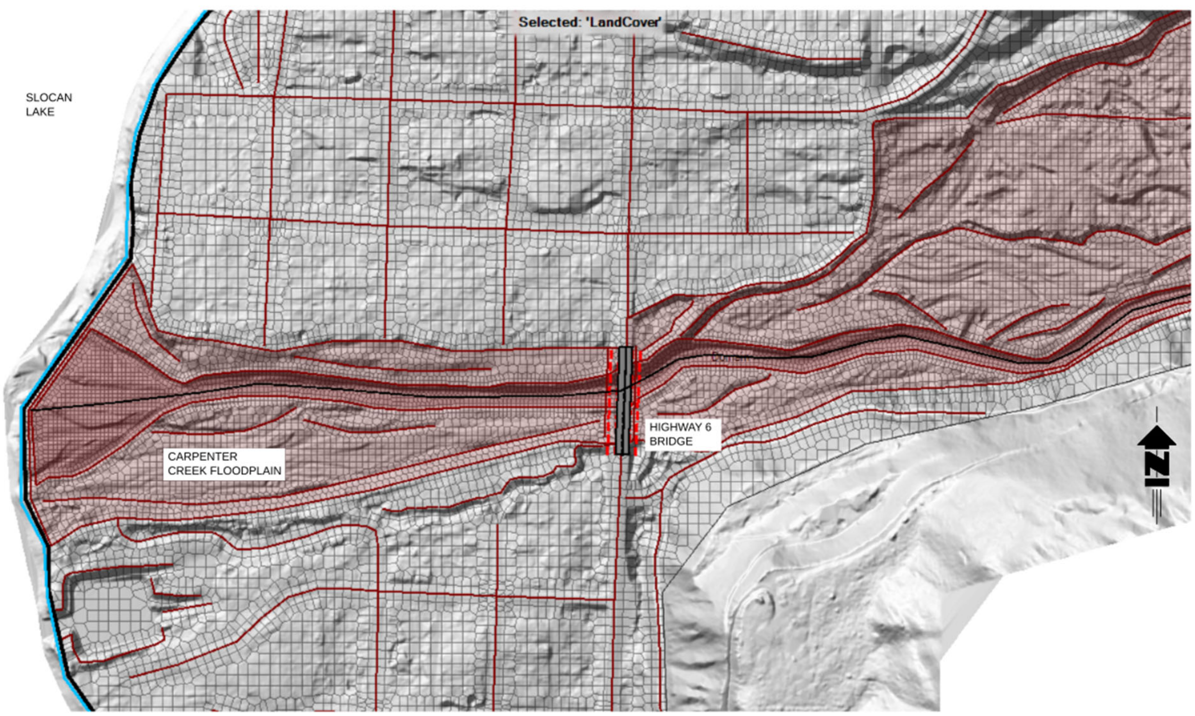


FIGURE 5-1: HEC-RAS 2D MODEL GRID AT NEW DENVER

5.2.3 Hydraulic Structures

The Highway 6 bridge is the only hydraulic structure within the modeling study area that was coded in the HEC-RAS model. Surveyed geometry of the structure (deck elevation, location and width of pier, channel cross section, etc.) was used to represent the Highway 6 bridge in the model.

A photograph of the Highway 6 bridge is shown in Figure 5-2, while key technical measurements are presented in Table 5-2.

FIGURE 5-2: HIGHWAY 6 BRIDGE AT NEW DENVER, LOOKING DOWNSTREAM

TABLE 5-2: HIGHWAY 6 BRIDGE CHARACTERISTICS

LOCATION (-)	STREAM (-)	TYPE (-)	DECK EL (M)	SOFFIT EL (M)	PIER WIDTH(M)
Highway 6 at New Denver	Carpenter Creek	Steel Beam	554.9	553.2	0.7

5.2.4 Initial and Boundary Conditions

Initial conditions in the HEC-RAS 2D model domain were set to dry bed conditions (i.e., no water in the river). The finite volume flow solvers are flexible enough to allow such starting conditions. Flow was gradually ramped up to establish base flow conditions (taken as 10% of the design flows).

Design flows were gradually added at the upstream model boundary to simulate peak flow conditions. As the present analyses involves floodplain mapping only, a constant steady design flow is used. The design flow is applied sufficiently long to achieve steady state conditions in the system and thus obtain maximum water surface profiles.

An inflow boundary condition was set for Carpenter Creek as per Table 4-1. Flows factored for climate change and sediment bulking were used in the floodplain mapping for the 200-yr condition. The downstream boundary condition was set as the 200-yr water level at Slocan Lake, as it was conservatively assumed that peak flood conditions of the Carpenter Creek and Slocan Lake systems occur concurrently. Since the gradient of Carpenter Creek is high (2.5%), its floodplain is not sensitive to lake levels (the 200-yr level only marginally extends upstream).

5.3 Calibration and Verification

Measured water surface profiles during high flow events on Carpenter Creek within the Village of New Denver were not available. It is for this reason that calibration and verification exercises could not be carried out. Should this data become available in the future during high magnitude flood events, calibration and verification tasks could be carried out to ground truth the hydraulic model simulations. For the present assignment, and until calibration and verification data become available, surface roughness values within the model are set to reasonable values and used in the simulations. The model output was inspected for consistency, ensuring results obtained are reasonable and representative for the study area.

5.4 Model Limitations

The modeling effort used in the development of the HEC-RAS 2D hydraulic modeling represents accepted engineering practice. However, all models and methodologies have inherent limitations that should clearly be acknowledged and understood. Some of the noted limitations include the following:

- The modeling assumes rigid bed conditions and neglects possible effects of channel migration and riverbed scouring during extreme events,
- Channel and floodplain are assumed to flow under clear water conditions, with potential influence of debris neglected from the simulations,
- Calibration data for the study area was not available, and therefore could not be carried out, and
- Further refinement to the modeling may be required for localized and/or site-specific hydraulic assessments and design work. Consultation with a Qualified Professional is required for such cases.

5.5 Model Results

Based on the hydraulic modeling of Carpenter Creek and its floodplain, climate adjusted 200-yr flood generally stays within the limit of the floodplain. A schematic showing inundation area is shown in Figure 5-2.

The relic floodplain is seen in the LiDAR terrain data upstream of the Highway 6 bridge is bounded by the high terrain to the north. Further upstream the floodplain spans between the valley slopes. Present hydraulic modeling shows that climate adjusted 200-yr flood inundates only areas immediately adjacent to the main channel in areas upstream of the bridge. However, as this region is a zone of strong geomorphic activity (ample sediment supply that can reshape both the channel and the floodplain), the floodplain extents may change in decades to come as river channel adjusts. At that point, a floodplain mapping update will be warranted.

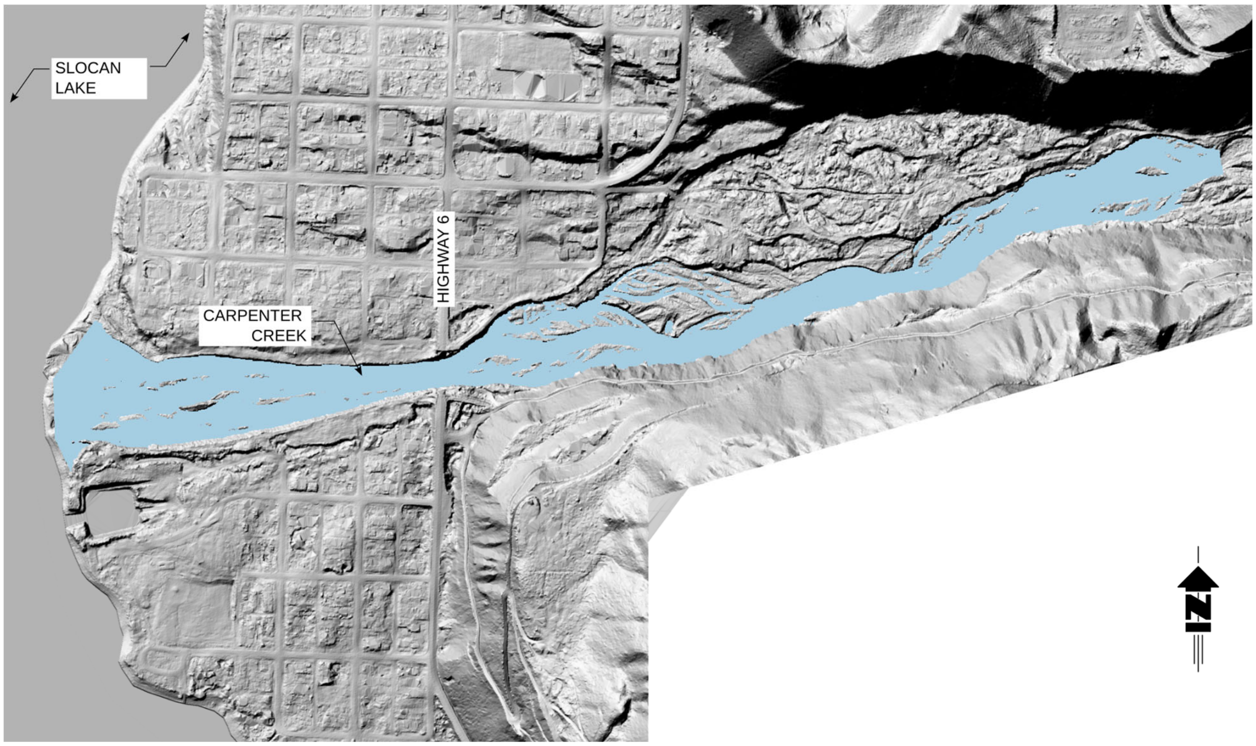


FIGURE 5-3: CARPENTER CREEK 200-YR FLOOD INUNDATION

The floodplain downstream to the creek's outlet at Slocan Lake are generally bound by the diking system on both sides of the river that were originally installed following the 1973 flood. No overland spills have been identified in this zone, as the crests of dikes and/or tableland sit above the climate adjusted 200-yr flood level.

6.0 Lakeshore Wave Analysis

Wind blowing over open fetches of water produces waves, which propagate landward and interact with the shoreline. Wave effects at the shoreline typically include wave runup (local rise in water level when waves impact the shoreline) and wave overtopping (the volume of water that comes over the crest of the bank from wave action). As this section of the report focuses on lakeshore floodplain mapping, runup is the wave induced quantity of interest. In the text that follows a description of the methodology used to quantify wave runup for the shoreline of Slocan Lake is presented, along with assumptions and results of the analyses.

6.1 Modeling of Wind Generated Waves

The first step in the assessment of wave effects is the quantification of wind generated waves. The Simulating WAves Nearshore (SWAN) numerical model is used in this work.

The SWAN model solves the spectral action balance equations and captures the effects of spatial wave propagation, refraction, shoaling, generation, dissipation and nonlinear wave-wave interactions. Processes of wave breaking, bottom friction and (simplified) diffraction effects are included as well. The most important feature of SWAN relating to the current project is its ability to estimate the growth and propagation of wind generated waves.

To establish the coastal climate at the study area, a lake wide 2D SWAN model was developed for the Slocan Lake using a 50 m model grid size. Given the size of the lake (40 km long, 2.8 km wide), and that study requirements are to obtain wind generated waves at the shoreline, the above noted grid resolution is deemed appropriate. The bathymetry from the merged Digital Elevation Model was used to assign elevations to each cell of the lakebed in the SWAN model domain. A default parameter set was used in the model which included parameterization of wind drag applied onto the water surface. The SWAN model domain for Slocan Lake, along with colour coded bathymetry, is presented in Figure 6-1.

Design water level in Slocan Lake was set as the 200-yr flood elevation of 538.8 m CGVD2013. Design wind of 16.0 m/s, with a direction of 336 deg Azimuth (NNW) and 202.5 deg Azimuth (SSW), both which aligns along the long axis of the lake) were specified as the main forcing input to the SWAN model. The wave direction was selected so that maximum fetch for the study area was used for shoreline that is exposed to the north and south fetches of open water.

SWAN model was simulated in a stationary mode, implying that imposed wind field were assumed to last infinitely long. Such an assumption is reasonable for domains such as inland lakes where wave growth is fetch-limited. For interest, non-stationary simulations would be required when modeling large coastal areas (in the order of 100's of km long), where waves at the project site are propagated from far away.

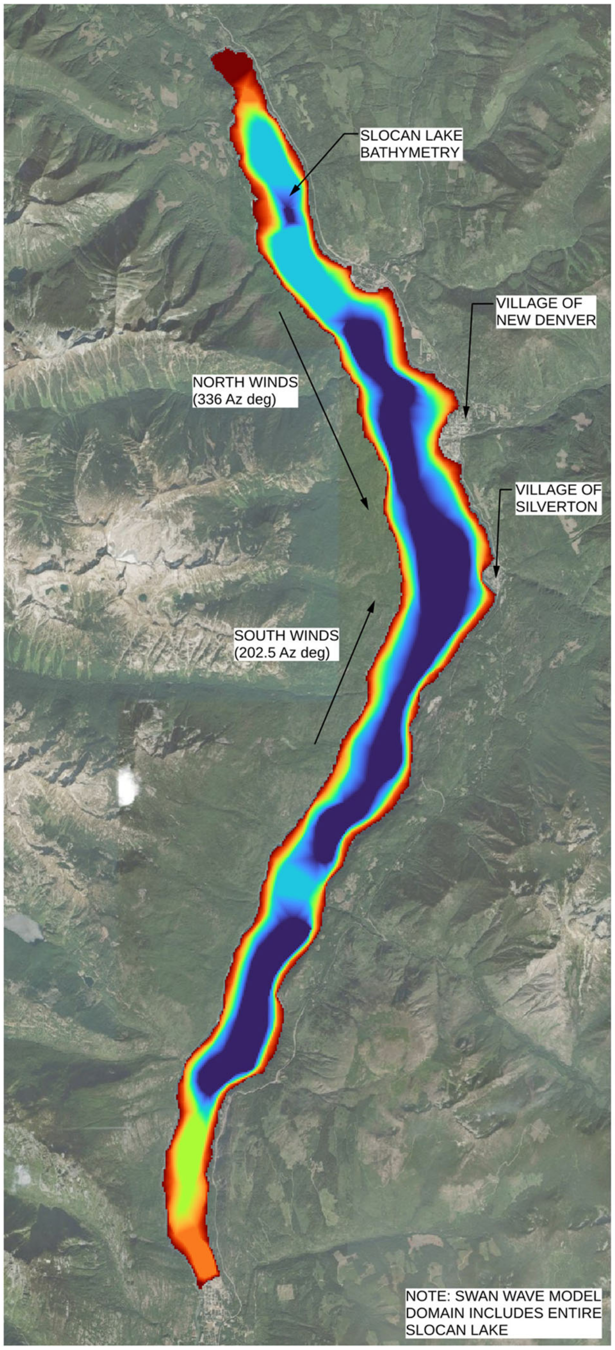


FIGURE 6-1: SLOCAN LAKE BATHYMETRY

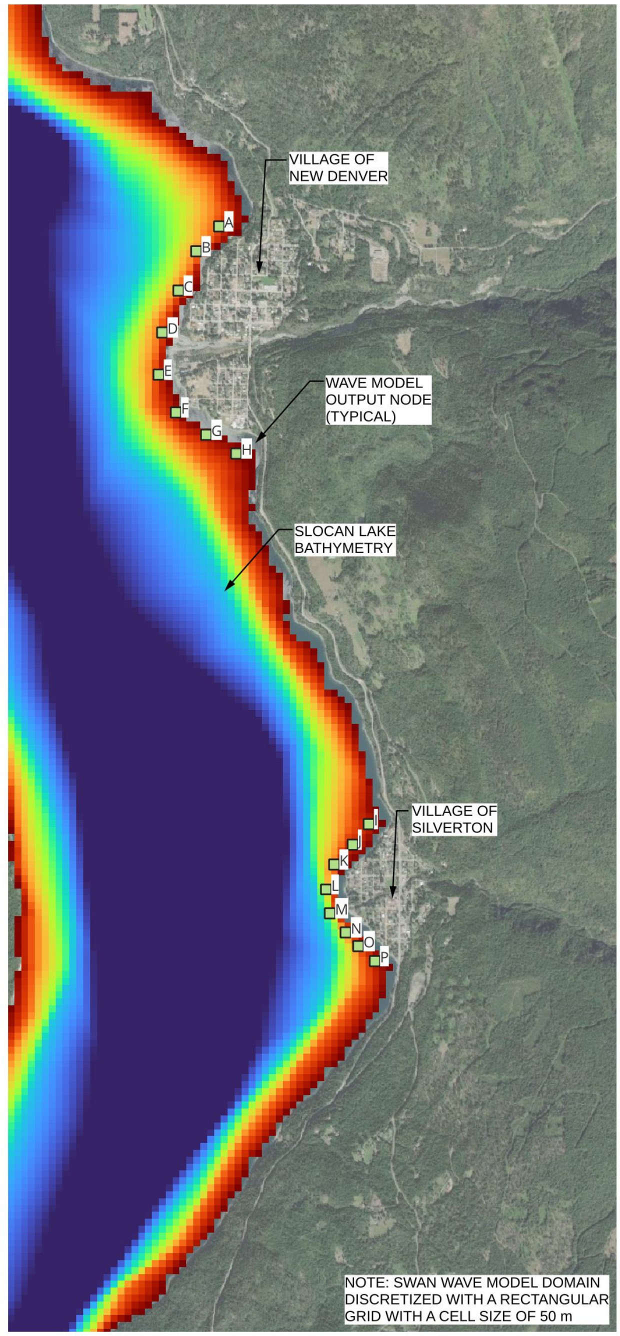


FIGURE 6-2: SLOCAN LAKE WAVE MODEL OUTPUT NODES

Wave characteristics at eight different locations along the Slocan Lake shoreline in the Village of New Denver were obtained from the SWAN model (see locations in Figure 6-2) and are summarized in Table 6-1 below. The model was simulated using north winds (for shoreline exposed to northern fetches) and south winds (for shoreline exposed to southern fetches). Same wind magnitude of 16 m/s was used for north and south wind simulations.

The SWAN model output from Table 6-1 suggests that design wind climate during the period of freshet is generally higher typical vessel generated waves. Even though the same design wind speed was used for north and south storms, the southern portion of the Village is shown to experience higher wave conditions because it is exposed to a longer open fetch. For the purposes of the lakeshore floodplain mapping, wave effects estimated from Table 6-1 are used. Definition sketches showing graphically the meaning of Az angles and obliqueness angles are shown in Figure 6-3 and Figure 6-4, respectively. As shown in Table 6-1, node locations A and H have lowest obliqueness angles (Beta), and experience most direct impact from wave action.

TABLE 6-1: SWAN MODEL RESULTS AT OFFSHORE NODES OF STUDY AREA

LOCATION (-)	HM0 (-)	TP (SEC)	DIR (AZ DEG)	BETA (DEG)
A	1.03	3.8	332.4	8.4
B	1.05	3.8	333.1	31.6
C	1.07	3.8	333.6	30.6
D	1.08	3.8	334.5	50.4
E	1.30	4.6	197.4	59.9
F	1.28	4.6	198.8	38.1
G	1.27	4.6	198.3	13.3
H	1.26	4.6	201.8	5.9

Notes: Hm0 Significant Wave Height
Tp Peak Wave Period
Dir Mean Wave Direction
Beta Angle Between Shore-normal and Incident Wave (obliqueness)

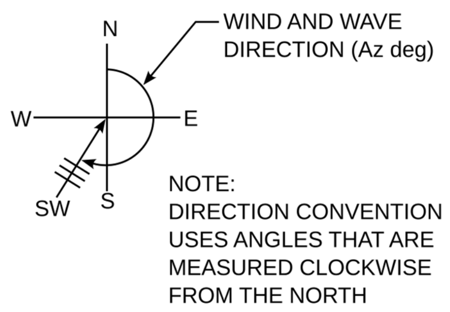


FIGURE 6-3: DEFINITION SKETCH OF THE NAUTICAL DIRECTION CONVENTION

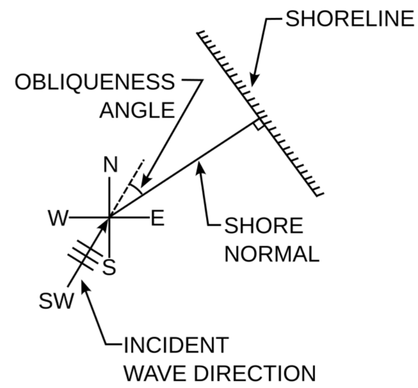


FIGURE 6-4: DEFINITION SKETCH RELATED TO WAVE MODEL OUTPUT

6.2 Assessment of Wave Runup

Wave effects in lakeshore floodplain mapping are quantified via a term that is referred to as wave runup. Wave runup is defined as the vertical height above design water level that is expected to occur during storm events, and thus cause flooding and/or other damage. As waves are cyclical and random in nature, not all waves in a storm will have the same characteristics. Current engineering practice has adopted a definition of wave runup that uses an average runup from the highest 2% of waves during design conditions (referred to as R2%). This study adopts R2% for quantification of wave effects, as it is standard industry practice.

Wave runup is influenced by several factors, including shoreline type (gentle beach vs. sloping rock revetment vs. vertical wall), shoreline surface treatment (sand beach, rock or grass slope, concrete wall etc.) and overland distance (for example, is the runup calculated close to shore where the waves are highest, or a distance inland where waves will dissipate before interacting with the shoreline). Each factor plays a role in how high (or low) the wave runup is.

For this assignment the wave runup is estimated using the existing shoreline configuration. The topographic data suggests the project site is situated within areas having different slopes above the 200-yr climate adjusted water level of Slocan Lake.

North of the outlet of Carpenter Creek the shoreline has a lake bank that is high and relatively steep, with an average slope inclination of 1.5H:1V. South of the outlet of Carpenter Creek, the tableland is relatively low relatively to the design water level (meaning waves run up onto gentle sloping inland areas). As a result of the different geometry, the wave uprush calculations have been divided into two zones:

1) North of the outlet (high bluffs with slopes having 1.5H:1V inclination, see Figure 6-5), and
2) South of the outlet (low lying tableland, which gradually slopes inland with slopes ranging from 20H:1V to 50H:1V, see Figure 6-6).

Wave runup for the two lakeshore zones are calculated separately, based on the shoreline geometry. For the zone north of the outlet, the slope is assumed to be lined with rock protection (natural or artificially placed). Waves conditions in Table 6-1 are applied along with noted slope geometry and surface treatment to estimate wave runup. Similarly, for the zone south of the outlet, the tableland is conservatively assumed to have an average landward slope of 20H:1V and generally lined with grass.

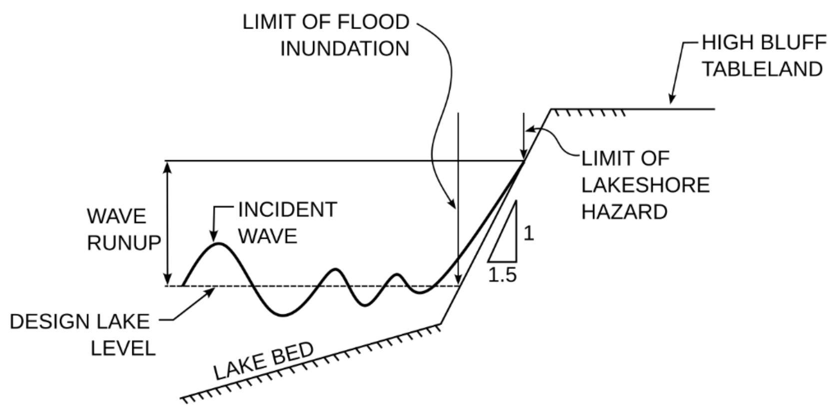


FIGURE 6-5: LAKESHORE FLOOD HAZARD AND WAVE RUNUP ON STEEP SLOPES

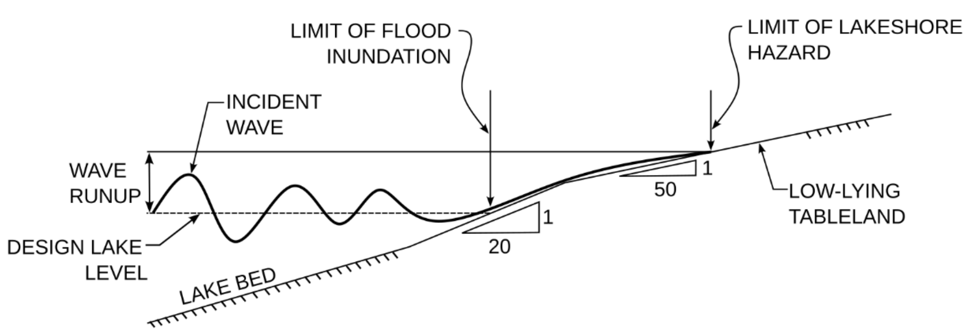


FIGURE 6-6: LAKESHORE FLOOD HAZARD AND WAVE RUNUP ON FLAT SLOPES

For the computations of wave runup the methodology presented in EuroTop (2018) has been applied for the steeper slopes (northern portion), and empirical formulation of Stockdon et al. (2006) for the low-lying tableland (southern portion).

The results of the wave runup calculations for the northern portion of the Village of New Denver amount to an average R2% of 2.5 m above the 200-yr climate adjusted water level. Similarly, the average R2% of 0.3 m is estimated for the southern portion of the Village, as waves interacting with gentle sloping tableland tend to produce much smaller runup heights.

6.3 Model Results

Climate adjusted 200-yr flood inundation extents along the Slocan Lake shoreline within New Denver are shown in Figure 6-7 (blue) along with the wave hazard line (red). The linework includes 0.6 m freeboard. The hazard linework is shown on the background of the LiDAR Digital Elevation Model.

The northern shoreline of the lake has high bluff, with the crest of the tableland being well above the 200-yr flood level. The northern shoreline is also fairly steep, meaning that wave runup generally impacts the face of high bluff. At only one location along the northern shoreline there is a section where there is section of the shoreline where the crest of the bluff is lower, which support two existing residences. These two residences are located within the lakeshore flood hazard.

The southern shoreline within the Village of New Denver has a generally lower crest elevation in relation to the climate adjusted 200-yr water level (shown in blue in Figure 6-7), which causes the water level to overtop the crest of the tableland in this area. Experiencing higher wave heights (due to longer open water fetches for the southerly exposure) means that waves will propagate inland and ultimately break against the gently sloping tableland. Given the gentle landward slope of the tableland, the wave runup heights are expected to be rather limited. But, due to the gentle slope, the wave induced hazard will extend a noticeable distance inland (shown in red in Figure 6-7).

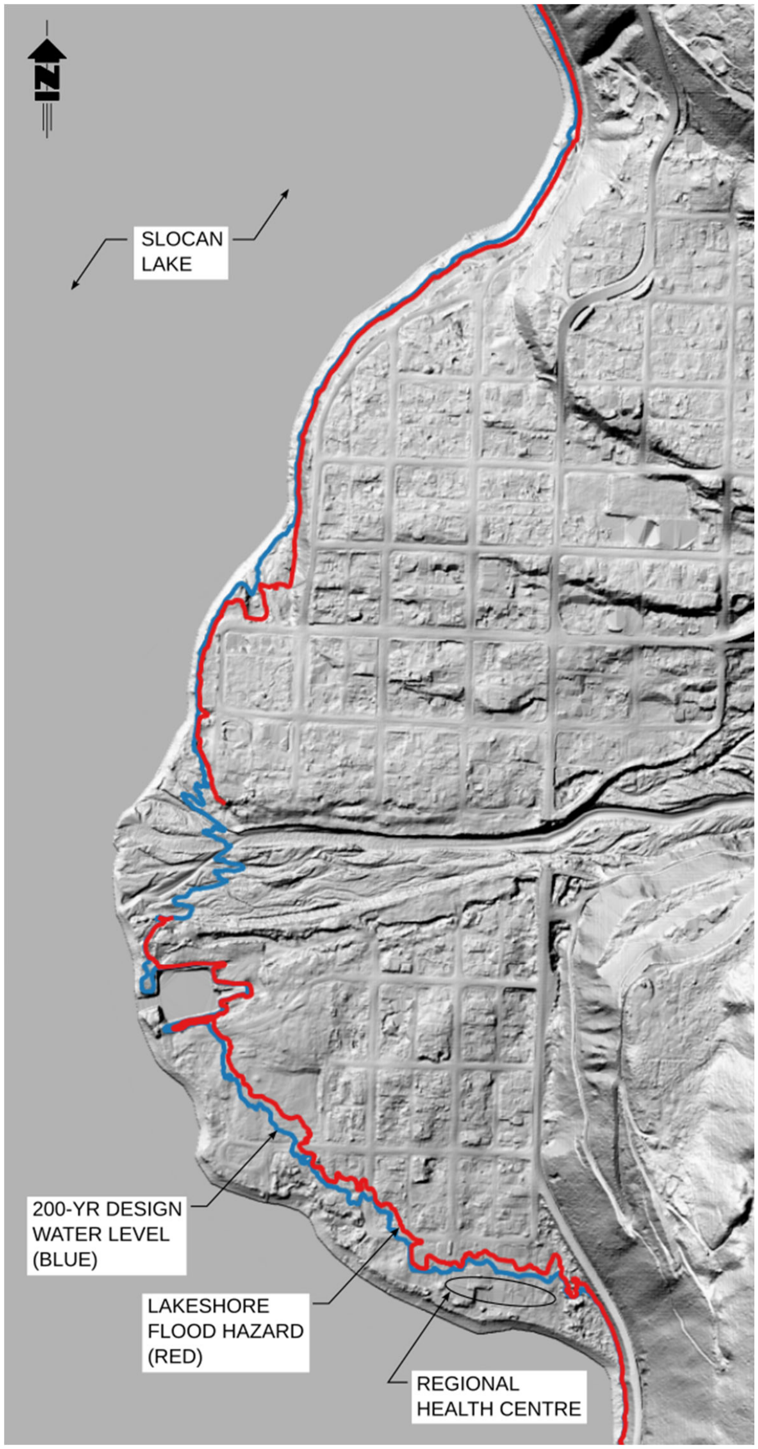


FIGURE 6-7: CLIMATE ADJUSTED 200-YR FLOOD (BLUE) AND LAKESHORE FLOOD HAZARD (RED)

Most notably, Figure 6-8 shows that most of the Community Health Centre property is within the footprint of the 200-yr design water level (200-yr water level plus 0.6m freeboard). The actual floor elevations of the Community Health Centre have not been confirmed. Given the gentle slope of the land, the lakeshore wave induced hazard marginally extends inland at this location, to account for the wave runup process (waves running up the shoreline during peak times of flooding.

FIGURE 6-8: LAKESHORE HAZARDS AT COMMUNITY HEALTH CENTRE

7.0 Floodplain Mapping

Results from the hydraulic modeling carried out in this work are presented, as are procedures used to develop flood hazards, and flood construction levels.

7.1 Floodplain Mapping Standards

The applicable standard followed in this work is the EGBC (2018) publication, titled 'Professional Practice Guidelines for Legislated Flood Assessments in a Changing Climate in British Columbia'. Maps developed follow standards defined in APEGBC (2017), as well as the recently produced Flood Mapping Standards (NHC, 2020).

7.2 Flood Hazard Mapping

Floodplain maps are used by local governments for regulatory purposes, such as developing floodplain bylaws. The most common regulatory application is where inundation mapping is incremented by a freeboard allowance to establish a Flood Construction Level (FCL). The concept of FCL has a long history of use in BC and is used to establish the elevation of the underside of a wooden floor system or top of a concrete slab for habitable structures.

FCLs only take effect if a local government adopts a floodplain by-law, or uses another tool (e.g., development permit areas) to restrict development. Production of the flood hazard maps is only an interim step in the process. The Village must adopt specific land use regulations for regulatory mapping to take effect.

A flood hazard map has been developed for potential adoption into a regulatory framework. Riverine and Lakeshore flood hazard areas, including the effects of climate change, have been developed in this work.

The flood hazard map is included in Appendix D, and is summarized in the following sections.

7.2.1 Riverine Hazard Mapping

Riverine FCLs within the Village limits were developed by adding 0.6 m of freeboard to the 200-yr climate adjusted flood profile produced via hydraulic modeling. Including freeboard on a flood map not only increases the flood depth, but also increase the potential inundated area. Including freeboard is common practice and accounts for inherent uncertainties in base data and analysis.

Aerial extents of flooding with added freeboard was generated via post-processing that included extending FCL inundation limits to places of higher ground. The generated flood extents were validated and manually adjusted to account for disconnected flooded ponding and high ground areas. To estimate the FCL inundation limits developed water surface elevation raster (produced via hydraulic modeling) were raised by 0.6 m to account for the freeboard criteria. The raised water's surface was converted to contours, with each contour assigned a respective elevation (i.e., the FCL). These contours are also referred to as FCL isolines. The raised contours were used to develop a Triangular Irregular Network (TIN) model representing an entire FCL surface. Intersecting the FCL surface with the hydraulic model ready DEM produced the spatial extent of the FCL, which is shown in the provided mapping.

For areas where dikes were located adjacent to the main channel, FCL isolines were extended through dikes (where applicable) as depicted on Figure 7-1. By doing so allows low lying areas protected by dikes to be included within FCL boundaries, and thus shown as flood hazard zones on floodplain mapping.

Note that any changes and/or development in the main channel and floodplain can alter the flood levels and extent of flooding (especially if road crests are altered, or if significant amount of development activity takes place in the floodplain). Should future development encroach into the floodplain, hydraulic models and mapping will required updates, and the flood hazard map accordingly revised.

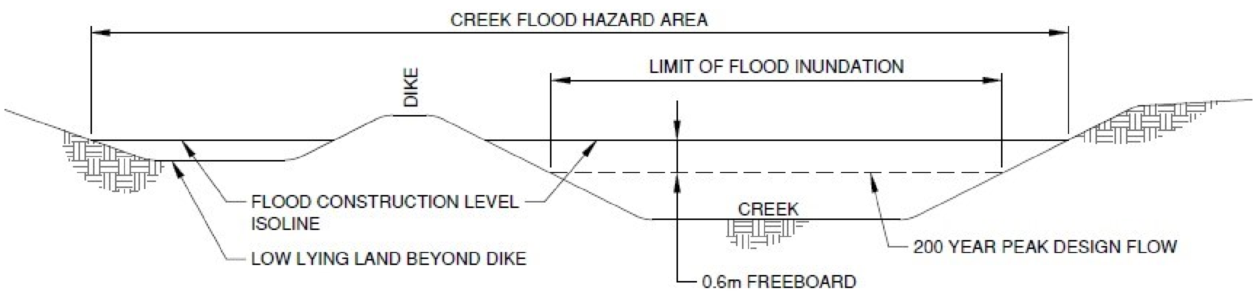


FIGURE 7-1: CREEK SECTION AND FLOOD HAZARD AREA BEYOND DIKE

7.2.2 Lakeshore Flood Hazard Mapping

A Lakeshore Flood Hazard Zone is defined for properties that are directly exposed to the lake, where wave effects are anticipated to be highest. For these areas the Lakeshore Flood Hazard limit is calculated as the sum of:

a) 200-yr water level,
b) freeboard, and
c) wave runup height

The 200-yr climate adjusted lake level (538.8 m CGVD2013), freeboard (0.6 m) and wave runup heights (2.5 m for areas north of the river's outlet, and 0.3 m for areas south of the river's outlet), are added and used to establish a contour line on a map associated with the limit of the Lakeshore Flood Hazard at the Slocan Lake shoreline in New Denver (see Table 7-1). Note that the Lakeshore Flood Hazard Limit is used identify areas that are subject to lake hazards under existing shoreline geometry.

TABLE 7-1: LAKESHORE FLOOD HAZARD LIMIT

PARAMETER	ZONE NORTH OF CARPENTER CREEK OUTLET	ZONE SOUTH OF CARPENTER CREEK OUTLET
200-yr water level (m, CGVD2013)	538.8	538.8
Freeboard (m)	0.6	0.6
200-yr Design Water Level (m, CGVD2013)	539.4	539.4
Wave Runup Height (m)	2.5	0.3
Lakeshore Flood Hazard Limit Contour (m, CGVD2013)	541.9	539.7

Most importantly, the contour line establishing Lakeshore Flood Hazard Limit is not considered a Lakeshore FCL. In other words, it can not be used to define minimum building elevations for future development.

Instead, Lakeshore Flood Hazard Limit simply delineates lakeward limit where, under existing shoreline geometry, lakeshore hazards are anticipated to occur. Development occurring outside of the Lakeshore Flood Hazard Limit is not subjected to lake flooding and wave effects.

FCLs within Lakeshore Flood Hazard limits, on the other hand, are required if development activities are proposed within identified Lakeshore Flood Hazard limits. Lakeshore FCLs can not be specified in the same manner as riverine FCLs can. This is because wave runup heights vary with distance from the shoreline (closer the development to the shoreline, the higher the incident wave, and the higher the wave runup). Further, wave effects also depend on surface treatment on which waves interact with during times of flooding (grassed or riprap slopes, vertical wall, etc).

Lakeshore FCLs will be some amount higher than the 200-yr design water level with freeboard (539.4 m CGVD2013), depending on wave effects (location of the proposed development and surface treatment of the proposed shoreline protection).

Development within Lakeshore Flood Hazard limits can still be allowed, provided that effects of lake levels and waves are taken into account in the design. A site-specific wave runup study will be required for an individual development within the Lakeshore Flood Hazard, in order to demonstrate how the wave hazards are addressed in the proposed design. Alternatively, the Village may consider carrying out a future flood mitigation plan that could investigate development potential within Lakeshore Flood Hazard limits where setbacks, and types of shoreline protection would be considered to ultimately develop Lakeshore flood construction guidelines for the community.

References

APEGBC (2017). Flood Mapping in BC – Professional Practice Guidelines, The Association of Professional Engineers and Geoscientists of British Columbia, Burnaby, 2017.

BC MoE (2011a). Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use - Draft Policy Discussion Paper (Project No. 143111 Rev. 0). Report prepared by Ausenco-Sandwell for BC Ministry of Environment (BC MoE). 45 pp.

BGC (2020a). RDCK Floodplain and Steep Creek Study, Slocan River. Report prepared by BGC Engineering Inc. on behalf of the Regional District of Central Kootenay, Vancouver, BC, March 2020.

BGC (2020b). RDCK Floodplain and Steep Creek Study, Kaslo River. Report prepared by BGC Engineering Inc. on behalf of the Regional District of Central Kootenay, Vancouver, BC, March 2020.

EGBC (2018) Legislated Flood Assessments in a Changing Climate in BC, Engineers & Geoscientists British Columbia (EGBC) – Professional Practice Guidelines, Version 2.1, August 2018.

EuroTop (2018). Manual on Wave Overtopping of Sea Defences and Related Structures, Second Edition, 2018.

Merwade, AH, Maidment, DR and Hodges, BR. (2005) "Geospatial Representation of River Channels", ASCE Journal of Hydrologic Engineering, Vol 10, p. 243-251.

NHC (1989). Floodplain Mapping Study, Slocan River. Report prepared by Northwest Hydraulic Consultants Ltd. on behalf of the Ministry of Environment, Province of British Columbia, BC, February 1989.

NHC (2020) Okanagan Floodplain Mapping Standards, Technical Report No. 3004430 prepared by Northwest Hydraulics Consultants, March, 2020.

PCIC (2025). Pacific Climate Impacts Consortium, Design Value Explorer, URL https://services.pacificclimate.org/design-value-explorer/, Last accessed March 7, 2025.

SLR (2025). Geomorphological Assessment of Carpenter Creek Fan Hazards, Village of New Denver, British Columbia. Report prepared by SLR Consulting (Canada) Ltd., on behalf of the Village of New Denver, February, 2025.

SNT (2022). Carpenter Creek Flood Mitigation, New Denver, BC. Report prepared by SNT Geotechnical Ltd. on behalf of the Village of New Denver, January, 2022.

Stockdon, H.F., Holman, R.A., Howd, P.A., and Sallenger, A.H. (2006). Empirical parameterization of setup, swash, and runup, Coastal Engineering Vol 53, pp. 573-588.

APPENDIX A

Flood Frequency Analysis of Carpenter Creek

Flood Frequency Analysis of Carpenter Creek

Village of New Denver

February 2025

Project No. 1479-111

ENGINEERING ■ PLANNING ■ URBAN DESIGN ■ LAND SURVEYING

2089 Falcon Rd | Kamloops BC | V2C 4J2 | true.ca | tel 250.828.0881

Revision Log

Revision #	Revised by	Date	Issue / Revision Description
1	PP	Feb 12, 2025	Issued to Client

Report Submission

Report Prepared By:

PROFESSIONAL
PROVINCE OF
P. PRODANOVIC
52340
BRITISH COLUMBIA
ENGINEER

Permit to Practice
No. 1000129
2025-02-13

Pat Prodanovic, Ph.D., P. Eng.
Sr. Water Resources Engineer

Report Reviewed By:

Permit to Practice No. 1000129

PROFESSIONAL
PROVINCE OF
J. P. WELKE
35705
BRITISH COLUMBIA
ENGINEER

2025-02-13

Jonathan Welke, P. Eng.
Sr. Water Resources Engineer

R:\Clients\1400-1499\1479\1479-111\05 Reports\Flood Frequency Analysis Report\1479-111-Village of New Denver-Flood Frequency Analysis-February 2025.docx

Table of Contents

1.0 Introduction 1

1.1 Description of Study Area 1

1.2 Study Objectives and Scope of Work 2

1.2.1 Professional Practice Guidelines 3

2.0 Streamflow Data 4

2.1 Historic Streamflow Data 5

2.2 Relationship Between Daily and Instantaneous Data 5

3.0 Methodology 9

3.1 Timing and Regularity of Freshet 9

3.2 Single Station Frequency Analysis 9

3.3 Regional Flow Analysis 10

3.4 Geomorphic Assessment of Fan Hazards 11

3.5 Climate Change Assessment 11

3.5.1 PCIC Climate Change Simulations 11

3.5.2 Rain-on-Snow Hydrologic Modeling 13

4.0 Results 16

4.1 Observed Data Analyses 16

4.1.1 Timing and Regularity 16

4.1.2 Frequency Magnitude Relationships 21

4.1.3 Regional Analyses 25

4.2 Climate Change Data Analyses 30

4.2.1 PCIC Climate Change Analyses – Magnitude, Timing and Regularity 30

4.2.2 Short-Duration High-Intensity Rainfall 34

4.2.3 Rain-on-Snow Climate Change Factor Estimate 35

4.2.4 Climate Change Uncertainty 35

4.3 Steep Creek Hazards 36

4.4 Design Flows 37

5.0 Summary of Findings 38

References 40

List of Tables

Table 2-1: Representative Streamflow Gauges 4
Table 4-1: Historical FFA Summary for Kaslo River (08NH005) 16
Table 4-2: Single Stations Frequency Analysis within Study Area 22
Table 4-3: Peak Flow Characteristics for Carpenter Creek at New Denver 25
Table 4-4: PCIC Climate Change Summary for the Study Area 30
Table 4-5: Rainfall Characteristics under Climate Change for Study Area 35
Table 4-6: End of Century Design Flows for Carpenter Creek at New Denver. 37

List of Figures

Figure 1-1: Carpenter Creek Catchment Location 2
Figure 2-1: Locations of Streamflow Gauges 4
Figure 2-2: Freshet Daily to Instantaneous Relation for Kaslo River (08NH005) 7
Figure 2-3: Freshet Daily to Instantaneous Relation for Keen Creek (08NH132) 7
Figure 2-4: Freshet Daily to Instantaneous Relation for Duhamel Creek (08NJ026) 8
Figure 2-5: Freshet Daily to Instantaneous Relation for Lemon Creek (08NJ160) 8
Figure 3-2: PCIC VIC Hydrologic Model Output Node Locations 12
Figure 3-3: Hydrograph Plot at Outlet of Kaslo River (08NH005) for 2020 and 2021 13
Figure 3-4: HEC-HMS Hydrologic Model for Lemon Creek. 15
Figure 4-1: Kaslo River below Kemp Creek (1965-1995) 17
Figure 4-2: Kaslo River below Kemp Creek (1996-2022) 17
Figure 4-3: Keen Creek below Kyawats Creek (1973-1995) 18
Figure 4-4: Figure 4-4: Keen Creek below Kyawats Creek (1996-2022) 18
Figure 4-5: Lemon Creek above South Lemon Creek (1973-1995) 19
Figure 4-6: Lemon Creek above South Lemon Creek (1996-2022) 19
Figure 4-7: Kaslo River Raster Hydrograph Plot (flows in m^3/s) 20
Figure 4-8: Keen Creek Raster Hydrograph Plot (flows in m^3/s) 20
Figure 4-9: Lemon Creek Raster Hydrograph Plot (flows in m^3/s) 21
Figure 4-10: Frequency Curve for Kaslo River (08NH005) 23
Figure 4-11: Frequency Curve for Keen Creek (08NH132) 23
Figure 4-12: Frequency Curve for Duhamel Creek (08NJ026) 24
Figure 4-13: Frequency Curve for Lemon Creek (08NJ160) 24
Figure 4-14: Regional Curve for 2-yr Peak Flow 26
Figure 4-15: Regional Curve for 5-yr Peak Flow 26
Figure 4-16: Regional Curve for 10-yr Peak Flow 27
Figure 4-17: Regional Curve for 20-yr Peak Flow 27
Figure 4-18: Regional Curve for 50-yr Peak Flow 28

Figure 4-19: Regional Curve for 100-yr Peak Flow.....28
Figure 4-20: Regional Curve for 200-Yr Peak Flow.....29
Figure 4-21: Regional Curve for 500-yr Peak Flow.....29
Figure 4-22: Proxy Flow Hydrograph for 1981-2010, CanESM2 Model.....31
Figure 4-23: Proxy Flow Hydrograph for 2011-2040, CanESM2 Model.....31
Figure 4-24: Proxy Flow Hydrograph for 2041-2070, CanESM2 Model.....32
Figure 4-25: Proxy Flow Hydrograph for 2071-2100, CanESM2 Model.....32
Figure 4-26: Proxy Flow Raster Hydrograph for 1945-2100 (flows in m^3/s).....33

1.0 Introduction

This report provides a summary of technical analyses undertaken to characterize streamflow via flood frequency analysis for the purpose of floodplain mapping within the municipal boundary of the Village of New Denver (New Denver), British Columbia (BC). Flood frequency analysis is a technique used by hydrologists and water resources engineers to establish flood frequency-magnitude characteristics for a particular stream (single station frequency analysis) or within a region of interest (regional analysis). By analyzing historical streamflow records flood characteristics are quantified and used in floodplain mapping projects. Up to date floodplain maps are required to support future land use planning, assist with emergency response efforts, and ultimately inform design of municipal infrastructure for decades into the future.

Characterization of flows is a first step in the development of floodplain maps. After design flows are quantified, the next step in the floodplain mapping process estimates water surface profiles in the floodplain, which are then mapped. Hydraulic modeling is used to establish water surface profile by using floodplain topography and geometry of major infrastructure (bridges, dikes, dams, weirs, etc.). In BC, Flood Construction Levels are also established as a byproduct of floodplain mapping and are defined as the minimum elevation at which livable floor space must be constructed to avoid damage from floods.

Climate change is recognized as a significant factor influencing flood frequency and magnitude in BC, and needs to be taken into account. As the planet warms the hydrologic cycle will intensity and lead to changes in temperature, rainfall, snowmelt and magnitude and frequency of floods. The shifts in hydrologic effects could have a profound impact for flooding. This report assesses impacts of climate change on flood frequency using latest climate models, data and statistical techniques to establishes appropriate climate change factors, and ultimately develop design flows for use in floodplain mapping.

1.1 Description of Study Area

The focus of this report is the catchment of Carpenter Creek, a mountainous stream in the Slocan Valley of the West Kootenays region of BC. The Carpenter Creek catchment is located between New Denver and Kaslo (see Figure 1-1) and consists of densely forested land between mountain ranges. The outlet of Carpenter Creek is at New Denver, a village of about 500 residents that was developed on lands of an existing alluvial fan. An alluvial fan is a landform feature found at the base of a mountain where riverine sediments have deposited and shaped the river's outlet over geologic timescale.

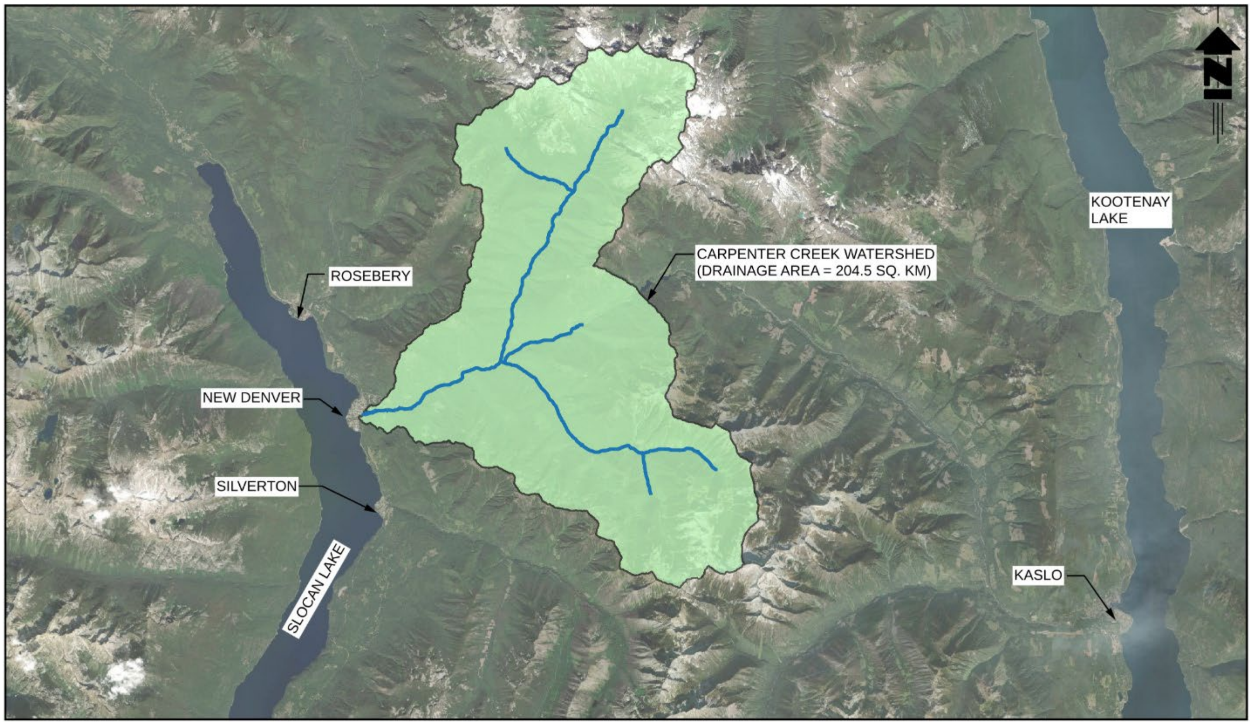


FIGURE 1-1: CARPENTER CREEK CATCHMENT LOCATION

The climate in the West Kootenays is characterized by significant variability due to the region's complex mountainous topography. The region experiences short and dry summers, while winters tend to be cold and generally snowy. Precipitation varies heavily across the region; it is generally highest in fall and winter, and lowest in spring and summer. Previous studies (CCAP, 2024) have commented that anticipated effects of climate change will include warmer and drier summer conditions (with an increasing wildfire risk), but with an increasing risk of spring flooding. The dominant mode of flooding presently is the spring snowmelt, where floods are caused by rapidly melting snowpack. Sometimes, snowmelt occurs in combination with heavy rainfall, which further exacerbates flooding. The most recent flooding from June 2020 was a result of snowmelt from the upper catchments occurring over several days where temperatures spiked to 25 degrees Celsius (thus causing rapid melt), in combination with a rainfall event that saw 35 mm of rainfall over a period of two days. Given future projections of climate change, such floods are anticipated to occur with higher frequency.

1.2 Study Objectives and Scope of Work

The intent of this report is to summarize hydrologic analyses and establish flow characteristics (including climate change) for Carpenter Creek at New Denver. Flow characteristics are established by analyzing historic records of streamflow and estimating frequency-magnitude relationships (i.e., flood flows ranging from 2-yr to 500-yr return period).

Climate change effects are included by factoring flow characteristics from existing conditions, with scaling factors estimated using several approaches. Including the effects of climate change is necessary to establish best estimates of flow in the future (to be used for long-term planning and design).

1.2.1 Professional Practice Guidelines

Engineers and Geoscientists British Columbia (EGBC) guidelines emphasize the integration of evolving climate science into flood risk assessments. The guidelines highlight that professionals acquire and maintain knowledge of the main drivers of climate change, and understand how these drivers ultimately translate to changes to streamflow characteristics in the future. Further, the guidelines aim to promote close collaboration between climate scientists, flood risk practitioners, and regulatory bodies to ensure that methodologies remain current and effective in addressing the complexities of climate change.

In BC, two main guidelines govern floodplain mapping and flood assessments: the *Professional Practice Guidelines – Flood Mapping in BC* and the *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC.* These guidelines emphasize the use of the 200-yr peak flow adjusted for climate change.

To consider potential effects of climate change when estimating peak flows, the guidelines suggest that best available data be analyzed statistically. If historic (or future) changes are anticipated, the guidelines recommend three procedures: i) regionally downscaled projections of precipitation and snowpack, ii) adjustment of Intensity-Duration-Frequency curves for expected future precipitation, and iii) adjustment of the expected flood magnitude and frequency to the projected change in runoff during the life of the project, or by 20% in small basins where information on future change is inadequate to provide reliable guidance.

In this work, regionally downscaled projections of precipitation and snowpack were analyzed via outputs from hydrologic modeling provided by the Pacific Climate Impacts Consortium (PCIC). It was identified that PCIC modeling could capture future changes in timing and magnitude of snowmelt but could not represent short-duration rainfall effects. The technical analyses carried out recognized that the governing flood-generating mechanism in the study area was short-duration high-intensity rainfall occurring during times of freshet (rain on snow events). An assessment was carried out to evaluate the impacts of the future changes in rainfall (which occurs during the freshet) on peak flood magnitudes. A climate change factor was identified that was appropriate, given the dominant flood mechanism at play in the study area.

The climate change assessment completed is consistent with the requirements provided in both the Professional Practice Guidelines – Flood Mapping in BC and the Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC.

2.0 Streamflow Data

The basic data used for flood frequency analyses are records of stream discharge versus time. In Canada, stream discharges are collected, processed, stored, and distributed by the Water Survey of Canada (WSC). There are no long-term WSC streamflow gauges within the Carpenter Creek watershed. Instead, streamflow data from four representative gauges were collected from nearby catchments that have similar size and are in the same hydrologic zone. The four streamflow gauges analyzed are listed in Table 2-1 and are shown graphically in Figure 2-1.

TABLE 2-1: REPRESENTATIVE STREAMFLOW GAUGES

WSC/USGS GAUGE ID	DRAINAGE AREA (KM^2)	DAILY DATA RANGE	HOURLY DATA RANGE	DESCRIPTION
08NH005	442	1965-2022	1996-2024	Kalso River below Kemp Creek
08NH132	92.3	1973-2022	1997-2024	Keen Creek below Kyawats Creek
08NJ026	52.9	1995-2022	1996-2024	Duhamel Creek above Diversions
08NJ160	181	1973-2021	1996-2024	Lemon Creek above South Lemon Creek

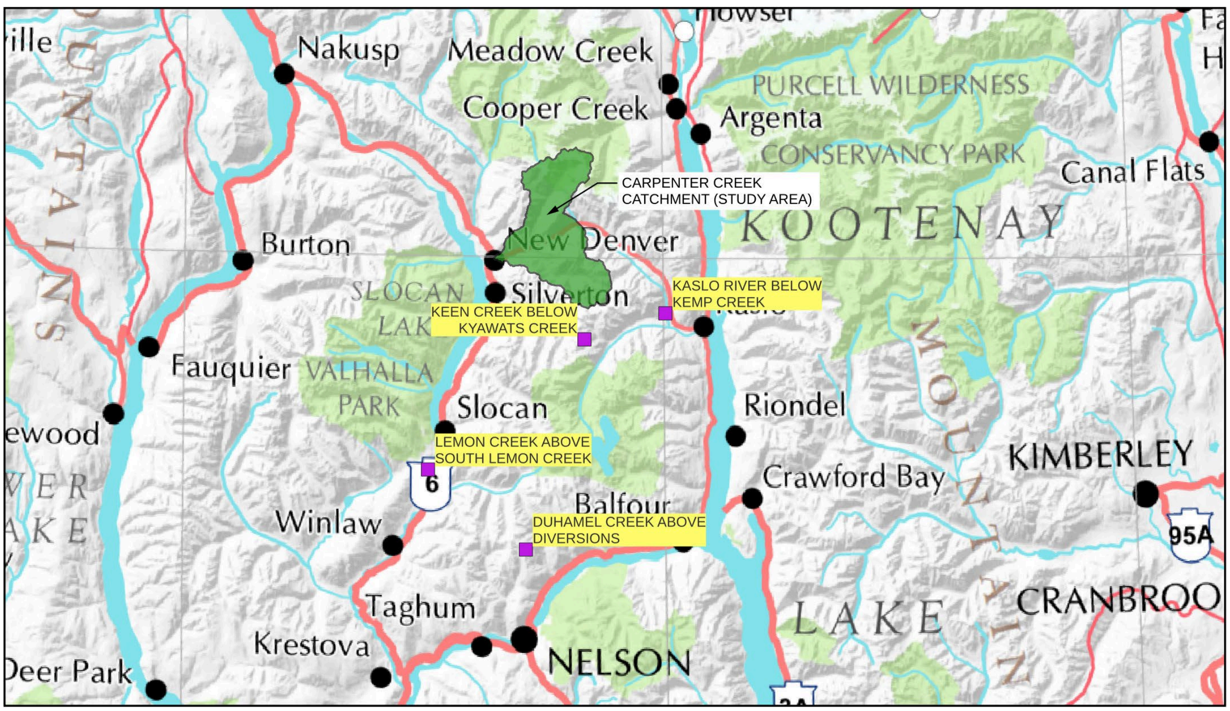


FIGURE 2-1: LOCATIONS OF STREAMFLOW GAUGES

A streamflow gauge at Nakusp was initially used in the analysis but was identified as having radically different hydrologic characteristics compared to the gauges above. For that reason, the streamflow gauge at Nakusp was excluded from this work.

2.1 Historic Streamflow Data

Daily and sub-daily historic data were obtained from WSC. Daily streamflow data was available for a longer period of historic record (starting from mid-1960's to early 1970's) compared to the sub-daily data (starting mid to late 1990's). The historic sub-daily data includes streamflow at 1-hr, 15-min, and 5-min intervals. The historic streamflow with irregular data intervals was converted to hourly intervals, and subsequently used in the analysis. Using a 1-hr interval is sufficient to characterize instantaneous peak flows in the study area.

The WSC makes publicly available select peak instantaneous flows along with its daily streamflow data. For the gauges in the study area, the select peak instantaneous data were inspected and found to be sufficient in capturing the historic record. Further, hourly streamflow records were used in certain frequency analyses methods (peak-over-threshold).

2.2 Relationship Between Daily and Instantaneous Data

Daily streamflow data for the gauges in Table 2-1 were used as the base data set in this work. The streamflow data was inspected and was found to be of high fidelity with minimal gaps in the historic record. The daily streamflow data did not require further processing, filtering or cleaning.

The sub-daily data, converted to 1-hr intervals, was used to define the relationship between daily to instantaneous peak flows along with the select instantaneous peak data available through WSC's HYDAT database. The 1-hr historic streamflow records were used in a peak-over-threshold analysis to extract events having peaks that exceed a set threshold, with at least 7 days between events. A further condition was imposed in the analysis that required a minimum difference in peaks between individual events. This condition was necessary as measurement uncertainty present in the 1-hr time series revealed small peaks on the rising/falling limb of the hydrograph (which should not be defined as events, even if more than 7 days passed between events). Imposing requirements for a minimum difference between peaks ensured that small (non-relevant) peaks were filtered out from the analyses.

The extraction of peaks was completed for the gauges in the study area. As the extraction procedure focused on events, the it was possible that multiple events could be extracted each year. Peak flow for each event was tagged with its date and time of occurrence and assigned its corresponding daily flow. A search procedure was implemented that investigated daily flows one day before and one day after the daily flow corresponding to the peak instantaneous flow. This search procedure ensured that the appropriate daily flow was tagged to peak instantaneous flows.

Once the events were assembled, peak flows were subdivided into freshet and winter seasons (see section below for definitions). The signal in the time series data identified that winter flow events are possible but have historically had much lower magnitudes compared to freshet events (where rain-on-snow typically occurs). The recent Atmospheric River of November 2021 (which caused record damage in Merritt and Princeton) was identified in the record, but did not have a significant peak in the gauges in the Kootenays.

For the purposes of this work, only the relationship between daily and instantaneous data for the freshet events are presented, as these events have the highest peaks. Relationships between daily and instantaneous flow for the freshet season are shown in Figures 2-2 to 2-5, which shall be used in subsequent section to establish flow characteristics at each gauge.

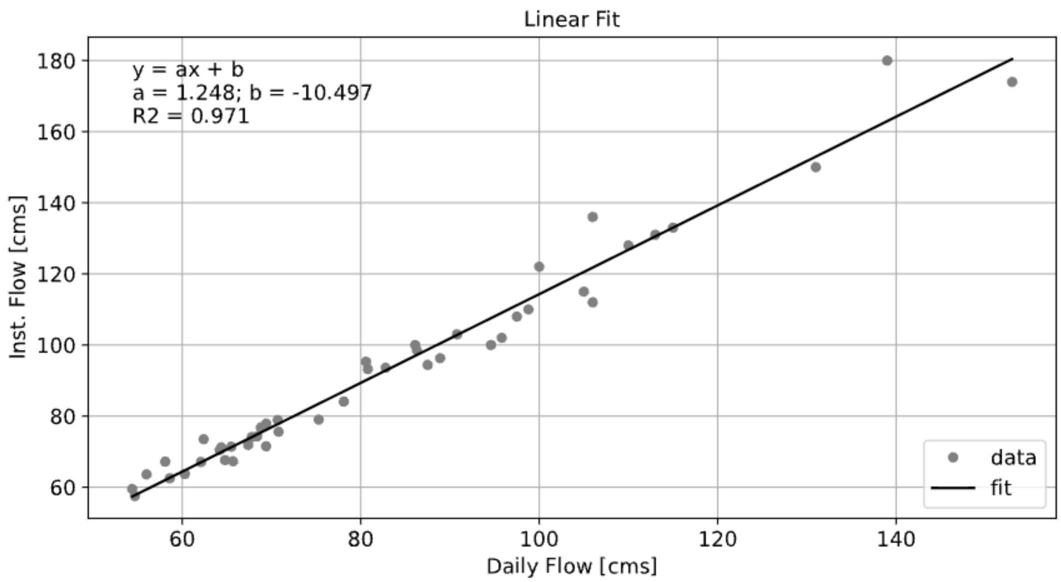


FIGURE 2-2: FRESHET DAILY TO INSTANTANEOUS RELATION FOR KASLO RIVER (08NH005)

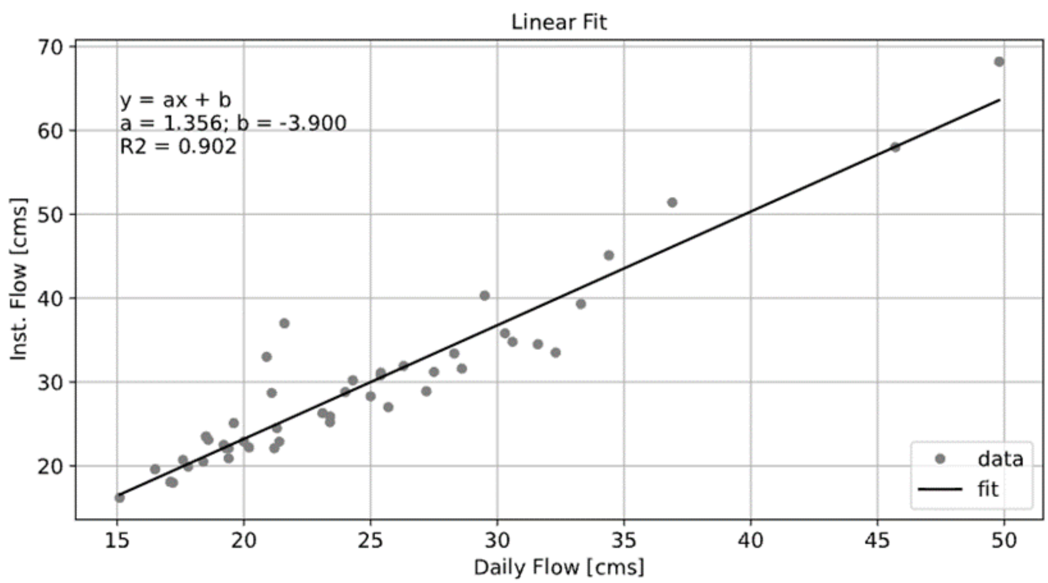


FIGURE 2-3: FRESHET DAILY TO INSTANTANEOUS RELATION FOR KEEN CREEK (08NH132)

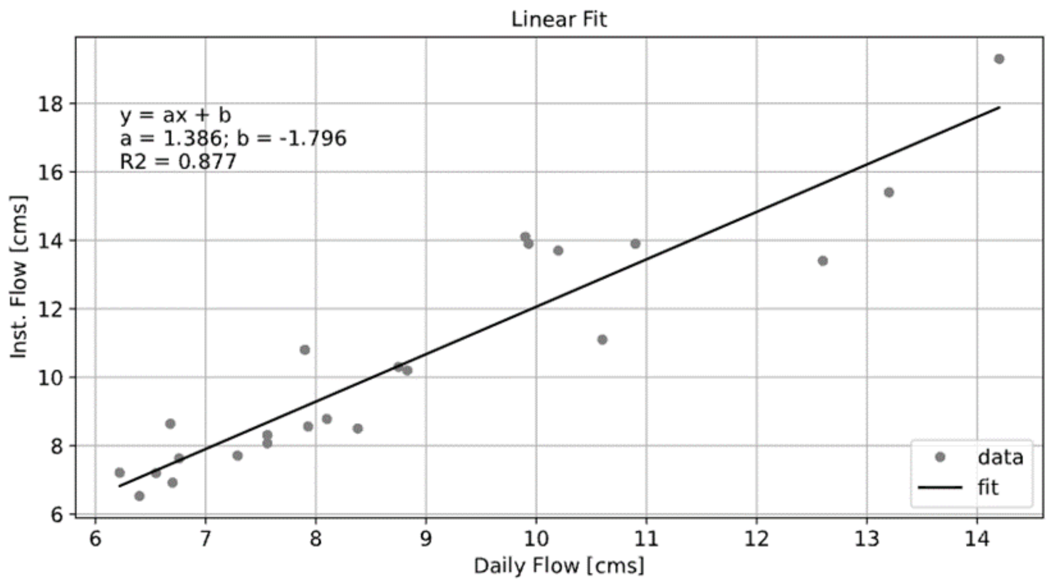


FIGURE 2-4: FRESHET DAILY TO INSTANTANEOUS RELATION FOR DUHAMEL CREEK (08NJ026)

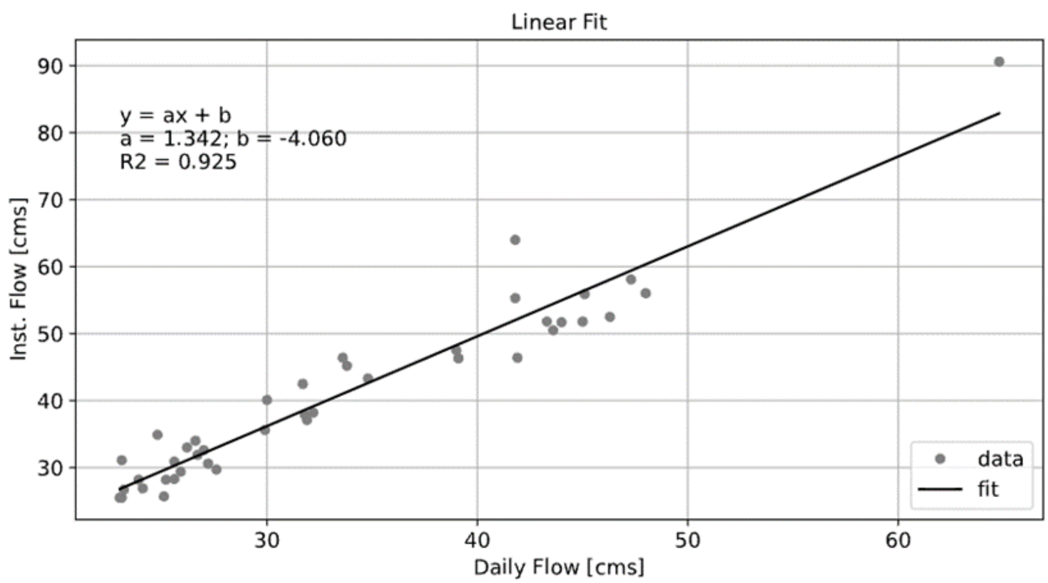


FIGURE 2-5: FRESHET DAILY TO INSTANTANEOUS RELATION FOR LEMON CREEK (08NJ160)

3.0 Methodology

This section presents the methodology that was used to quantify timing of freshet flows, flood frequency curves, climate change, and bulking factor applicable for steep creeks. Jointly these are referred to as flow characteristics. The flow characteristics are intended to be used in determination of design flows to support subsequent floodplain mapping, development of flood mitigation plans, and ultimately inform decisions regarding development activities within the floodplain.

3.1 Timing and Regularity of Freshet

The timing of freshet flows is measured between 1 and 365 (366 during a leap year), and points to the average day of year on which peak freshet flow occurs. In other words, it expresses the approximate day of year when annual flood peak occurs. If mean day of flood turns out to be 145, this means that, on average, the highest freshet flow is expected to occur on the 145th day of the year (May 25 for non-leap years).

The regularity indicator is a measure that indicates variability (or dispersion or standard deviation) of timing. Smaller values of the standard deviation mean that peak annual freshet flows are near, or at, the same time each year, while larger values suggest greater variability in terms of timing.

Timing and regularity indicators are applied for freshet flows and are used to comment on how peak freshet flows (timing), and how the spread around the peak (regularity) are changing with different periods. Both indicators are used to characterize observed (historic trends), as well as simulated records (long-term hydrologic model simulations that consider climate change).

3.2 Single Station Frequency Analysis

The index used to characterize stream flow magnitude is derived by carrying out flood frequency analysis. Standard practice in hydrologic frequency analysis takes a representative time series record, extracts annual maximum peak flows, fits a statistical distribution to the annual maxima series, and computes flows associated with various return periods. Such an approach is appropriate for basins where peak flows are driven by a single dominant process (like rainfall in the winter, or snowmelt during the freshet). For the gauges in the study area, the dominant flood generating process is snowmelt (with rain-on-snow also contributing).

Gauges with relatively small drainage areas closer to the coastal mountain ranges are more heavily influenced by winter rainfall (rainfall produced by atmospheric river events for example). Even though the signal from atmospheric rivers is identified in the streamflow gauges in the Kootenays, it has not been historically a contributing factor that produces high peak flows. For the catchments in the study area, highest peaks are generally produced by rapid snowmelt, or rainfall occurring during snowmelt periods.

Given that a single dominant flood generating mechanism occurs for the streamflow gauges in the study area (freshet floods, with rain-on-snow possible), block maxima methodology has been used to quantify flood characteristics. Rather than selecting annual maximums floods, block maxima methodology selects freshet maximums only.

Block maxima approach was used to extract maximum daily flows for each freshet season in the historic record. After the extraction of peak events, extracted data was fit using the three parameter Generalized Extreme Value (GEV) statistical distribution, with parameters estimated using the method of L-Moments. Flow frequencies are reported for return periods ranging from 2-year to 500-year. Zhang et al. (2020) identified that the GEV distribution outperformed other popular statistical distributions (like Log Pearson 3) in their study of many stations in Canada. The same study recommended GEV distribution for flood frequency analysis in Canada.

The last step in the analysis takes daily flow statistics and converts them to instantaneous flows by applying gauge specific relationships in Figure 2-6 to Figure 2-9. The product of the analyses were instantaneous flows for return periods ranging from 2 to 500-years.

3.3 Regional Flow Analysis

Regional analysis is a method used in hydrology to estimate streamflow characteristics at sites where streamflow observations do not exist. Regional methods work by aggregating relevant flow information from multiple neighbouring locations within a hydrologically similar region. This approach is often applied to estimate flow characteristics of an ungauged site (such as the outlet of Carpenter Creek) by using several sites that are in the same climatic zone with similar hydrologic response (i.e., freshet dominated, with rain-on-snow floods occurring often).

Regional analysis works by selecting streamflow gauges that are representative of the study area catchment. Next, single station frequency analysis is carried out to compute daily flow statistics for each gauge in the study. In this work, the Generalized Extreme Value (GEV) statistical distribution is used to fit the data, with distribution parameters estimated using the method of L-Moments. The daily statistics are adjusted to estimate instantaneous flood peaks, as documented above.

Regional curves were developed by making plots between drainage area and peak instantaneous flows from each gauge in the study area. One regional curve was generated for each return period (ranging from 2-yr to 500-yr). Having regional flow curves above, along with the drainage area of the catchment of interest, allows for peak flows to be computed in the study area.

3.4 Geomorphic Assessment of Fan Hazards

A geomorphologic assessment of the alluvial fan hazards at Carpenter Creek has been completed by SLR (2025) as part of this project. The SLR (2025) report has identified that clearwater and debris floods are possible for Carpenter Creek. A clearwater flood occurs when rainfall and/or snowmelt occur, where the water is the only medium transported by the stream. Debris floods occur when gravel, cobbles, and boulders from the bed and banks lifts within the water column, and is transported downstream during flood conditions. In addition to bed material, debris floods can carry woody debris (log jams). Evidence of riverbed reshaping is present in the main channel along the lower reach of Carpenter Creek at New Denver.

For the purposes of flood inundation, hazard, and development of Flood Construction Levels, SLR (2025) has recommended a 10% bulking factor should be added to the design flow to account for the increase in peak flow from sediment laden water during high flow events.

3.5 Climate Change Assessment

Climate change and its future impacts on the hydrologic flow regime requires assessment and quantification. Climate is defined as a long-term pattern in weather that is averaged over a period of 30 years. To represent a climate (whether in temperature, precipitation, or in riverine flow) a record of 30 years is required. The record can include measurements (from a streamflow gauge), or from synthetically generated quantities (from a simulation model).

Two different analyses methods were applied in this work to estimate flood flow characteristics from climate change. Each is described next.

3.5.1 PCIC Climate Change Simulations

Pacific Climate Impacts Consortium (PCIC) developed a large scale gridded hydrologic simulation model named Variable Infiltration Capacity (VIC) for British Columbia. The VIC model (PCIC, 2020) was discretized to roughly 30 km^2 grid cells on which simulations of streamflow were carried out. Input to the VIC hydrologic model included temperature and precipitation for 12 statistically downscaled Global Climate Model (GCM) projections, along with a baseline scenario. GCM projections were provided for two Representative Concentration Pathways (RCPs), namely RCP4.5 and RCP8.5 (six scenarios for each RCP). The RCP8.5 scenario represents a high emissions scenario, with greenhouse gas concentrations in 2100 rising to nearly three times those seen presently. The RCP4.5 scenario represents an intermediate emissions trajectory in which policies were implemented to reduce anthropogenic greenhouse gas emissions, with the goal of stabilizing radiative forcing by the year 2100.

The following GCMs were used in the PCIC simulations: ACCESS1, CanESM2, CCSM4, CNRN-CM5, HadGEM2-ES, and MPI-ESM-LR.

The Carpenter Creek catchment was included in the PCIC hydrology modeling. However, modeling outputs from PCIC did not include stream flow, but only un-routed values of gridded runoff and baseflow at discrete points in the catchment. The locations of the PCIC output nodes at and near the study area are shown in Figure 3-2.

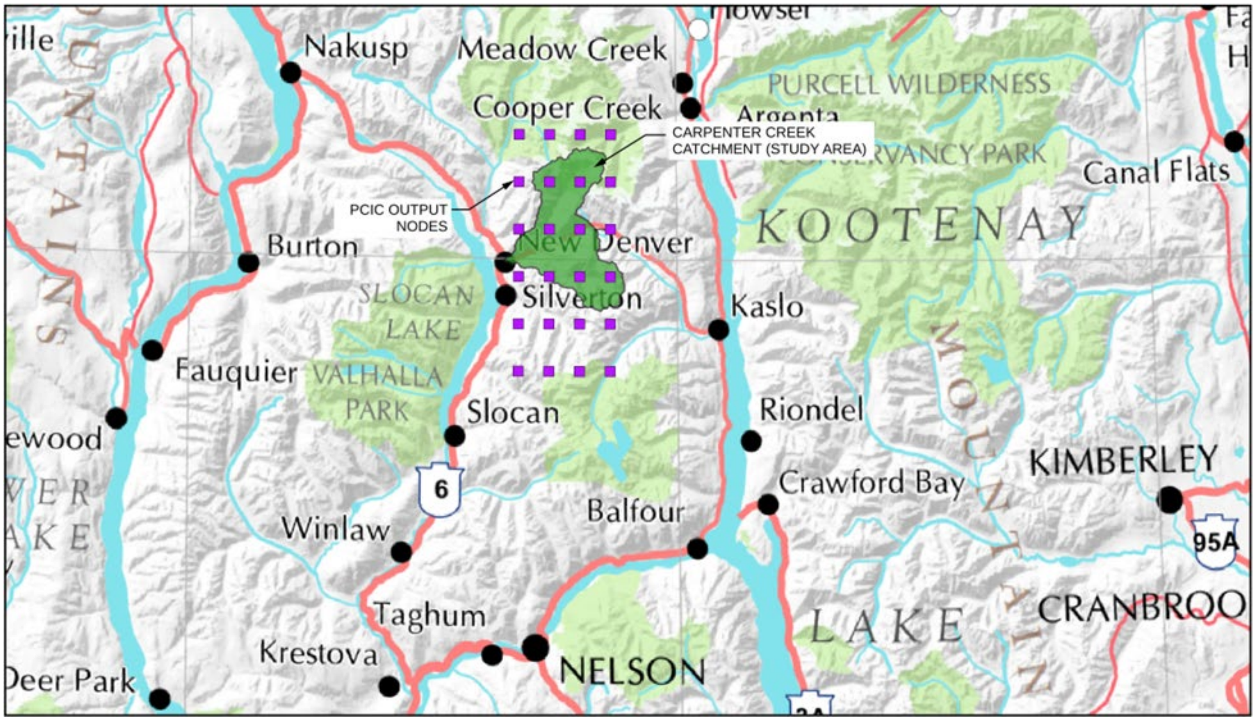


FIGURE 3-1: PCIC VIC HYDROLOGIC MODEL OUTPUT NODE LOCATIONS

The un-routed values mean the gridded modeling output of computed runoff and baseflow (in units of mm/day) for each cell in the VIC modeling domain. Consulting the lead hydrologist at PCIC revealed that it is not possible to post-process the VIC gridded modeling output to obtain streamflow at the catchment outlet. Instead, the PCIC hydrologist suggested that as an indicator of change runoff and baseflow be added and averaged for those nodes falling within the study area. Even though the resulting time series will not be streamflow, it may still be considered a valid indicator of future change. In this work, the average of runoff and baseflow (for the PCIC output nodes above) are referred as 'proxy flow.'

As per the recommendations made by the PCIC hydrologist, TRUE Consulting post-processed the available gridded data within Carpenter and Silverton Creek watersheds. The 'proxy flow' daily time series was generated for the historic and future projections based on the outputs of six global climate models. The data were processed to extract typical flow characterization statistics (return periods, timing, and regularity of flood peaks).

The PCIC modeling results include a long-term daily streamflow record from 1945-2100 for each of the six GCM scenarios, for two RCPs. The results from the RCP8.5 scenario were used, for each node in the study area. The ‘proxy flow’ was separated into following time periods: 2011-2040, 2041-2070, 2071-2100. Each of the above time periods represents a 30-year simulated record and is thus sufficient to characterize a given climate. Freshet timing and regularity indices have been computed for each of the above periods and compared for trends, as were frequency magnitude relationships (or other characteristic flows).

Results are summarized in the next chapter according to each period by averaging quantiles from each of the six GCM outputs. For example, a characteristic streamflow for 2011-2040 period is reported as a simple average of the characteristic streamflow from the six GCM simulations. This averaging ensures that a single result is reported for each period, which thus facilitates comparisons with other periods.

3.5.2 Rain-on-Snow Hydrologic Modeling

Visual analysis of sub-daily Water Survey of Canada streamflow records identified a strong pattern of rain-on-snow flooding in the region. This flood mechanism takes place during the freshet season as the snowpack starts to melt and generates surface runoff. Rainfall that occurs during the freshet season provides extra moisture to the hydrologic system, intensifies the melt process, and ultimately increases the resulting peak flows. Figure 3-3 shows a typical hydrograph plot in the study area where short duration peaks (caused by rainfall occurring during the freshet) are prominent.

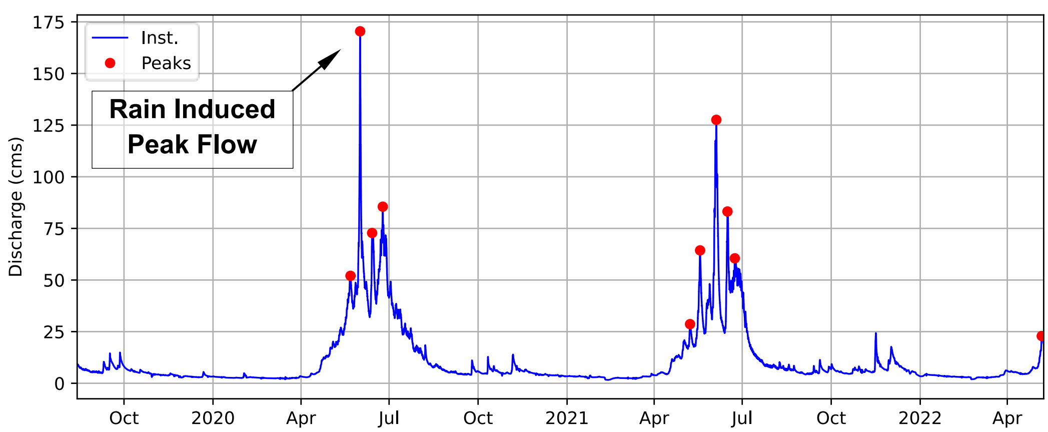


FIGURE 3-2: HYDROGRAPH PLOT AT OUTLET OF KASLO RIVER (08NH005) FOR 2020 AND 2021

PCIC’s hydrologic modeling has been developed for large drainage basins where the dominant pattern of flooding results from snowmelt only. As such, PCIC’s modeling cannot resolve the short-duration high-intensity rainfall processes for small (or medium) sized catchments like Carpenter Creek (having a catchment area of 204.5 km^2). The observed record suggests (see Figure 3-3) that rainfall is a relevant process that contributes to flooding during the freshet, and must be incorporated into the climate change assessment.

Assessing climate change indicators using modeling output from PCIC (which cannot accurately capture rainfall response of a small catchment) will inevitably lead to inaccurate climate change impacts on the hydrologic flow regime. To address this fact, a limited scope hydrologic modeling was carried to capture rainfall response during the freshet season. A simplified hydrologic model was developed using the US Army's Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS, 2024) for the Lemon Creek watershed. Lemon Creek watershed was selected for modeling as it is adjacent to the study area and has an active Water Survey of Canada streamflow gauge near its outlet, making model calibration possible.

The HEC-HMS hydrologic model of Lemon Creek was developed using physical parameters of the upland catchment (watershed area, slope, longest flow path lengths, stream slope, sub-basin elongation ratios, etc.). The said parameters were obtained from a watershed delineation exercise using Natural Resources Canada's CDEM digital elevation model. The hydrologic model was set up by splitting the catchment into 37 sub-catchments, each connected by flow paths (or stream segments). Model junctions were added at locations where two streams connected, or at locations where flow characteristics were required (such as at the streamflow gauge). The schematic of the HEC-HMS hydrologic model is shown in Figure 3-4.

For the purposes of this work, the Daymet library (Daymet, 2024) was used to obtain daily time series of snow water equivalent (SWE) for each sub-basin in the hydrologic model, which was then used to initialize the hydrologic model. Average basin coordinates were used to obtain a SWE time series from the Daymet library for each sub-basin in the model (as each sub-basin had a different mean elevation above sea level, and thus different SWE at typical freshet).

For calibration purposes, the freshet event of late May and early June 2020 was used in the simulations. The 2020 event was identified to have approximately 37 mm of rainfall occur during the freshet, in combination with temperatures spiking to approximately 25 degrees Celsius during the daytime periods. Increased temperatures caused the snow at higher elevations to melt, causing quick runoff, which was further exacerbated by the noted rainfall.

The hydrologic inputs to the HEC-HMS model included SWE and temperature (obtained for the 2020 flood event using the Daymet database), along with rainfall. As hourly rainfall is not available in the region, an exact rainfall input hyetograph could not be used as model input. Instead, a sensitivity analysis used several distributions typically used in hydrology that temporally distributes rainfall over the catchment. The event-based variant of the HEC-HMS hydrologic model was used in this work.

The HEC-HMS hydrologic model was set up to include sub-basins whose behaviour is captured using the SCS Curve Number loss method (which represents that portions of the precipitation that can be intercepted by vegetation, stored in surface depressions, and/or directly infiltrate in the soil). Transformation of excess rainfall (that volume of precipitation that is not intercepted nor infiltrated into the ground) was computed using the SCS Unit Hydrograph method. The catchment lag time was calculated using the SCS Lag Method, which is 0.6 times the basin's time of concentration. The lag time was calculated for each sub-basin based on average watershed slope, flow length, and the assumed CN number. The river reach in the hydrology model was set up with a Muskingum Kunge method, using a channel gradient derived from CDEM terrain data.

FIGURE 3-3: HEC-HMS HYDROLOGIC MODEL FOR LEMON CREEK

The hydrologic model was simulated for the 2020 flood event, and model parameters were adjusted until peak flows generated by the model reasonably matched observation. Then, rainfall input was adjusted to reflect the future under climate change, and the model was simulated again. The climate change factor was obtained by computing a ratio of future to existing peak flow generated by the hydrology model.

The main purpose of developing the HEC-HMS hydrologic model was to capture the rain-on-snow processes and test the system's behaviour using existing and future rainfall as input. As the focus was only on reasonably matching rain-on-snow peaks, the entire hydrograph shape during the freshet season has not been calibrated. As such, the hydrology model developed in this work cannot be used for any other purposes other than noted above.

4.0 Results

The methodology summarized in Section 3 was applied to the streamflow gauges in the study area. The analyses include characterization of flows and determination of anticipated change factors resulting from climate change.

4.1 Observed Data Analyses

4.1.1 Timing and Regularity

The historic data analyzed was divided into two distinct periods (1965-1994 and 1995-2021, when available) to identify the degree of change in the magnitude and timing of historic freshet flows. As only one out of three stations in the region have a record of sufficient length (Kaslo River gauge), that gauge was used to numerically quantify magnitude, timing and regularity indicators. For the gauges in the study area that had records in both periods, hydrograph plots are shown (Figures 4-1 and 4-2 for Kaslo River, Figures 4-3 and 4-4 for Keen Creek, and Figures 4-5 and 4-6 for Lemon Creek). Raster hydrograph plots are shown in Figures 4-7, 4-8 and 4-9 for Kaslo River, Keen and Lemon Creeks, respectively.

Magnitude, timing and regularity indices are summarized in Table 4-1 for the Kaslo River gauge.

TABLE 4-1: HISTORICAL FFA SUMMARY FOR KASLO RIVER (08NH005)

	FRESHET ANNUAL MAX		
PERIOD	Q200 DAILY (M^3/S)	TIMING (DAY OR YEAR)	REGULARITY (DAYS)
1965-1994	162	157.7	15.8
1995-2022	202	158.4	12.6

By inspecting the results in Table 4-1 and plots in Figures 4-1 and 4-2 for the Kaslo gauge it is evident that peak freshet flows have increased. The peak flow magnitude has increased (resulting from sudden temperature increases, rainfall events, or both) occurring during the freshet season. The average timing of the floods has generally remained unchanged, with the regularity being marginally decreased. The Kaslo gauge also shows the occurrence of more winter rainfall events in 1995-2022 compared to the 1965-1994 period, even though these winter events are generally smaller than the freshet events.

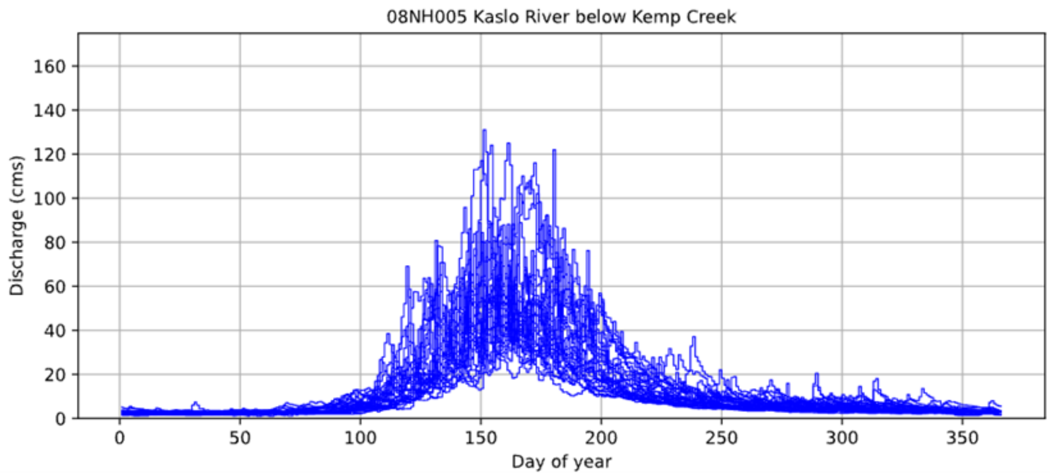


FIGURE 4-1: KASLO RIVER BELOW KEMP CREEK (1965-1995)

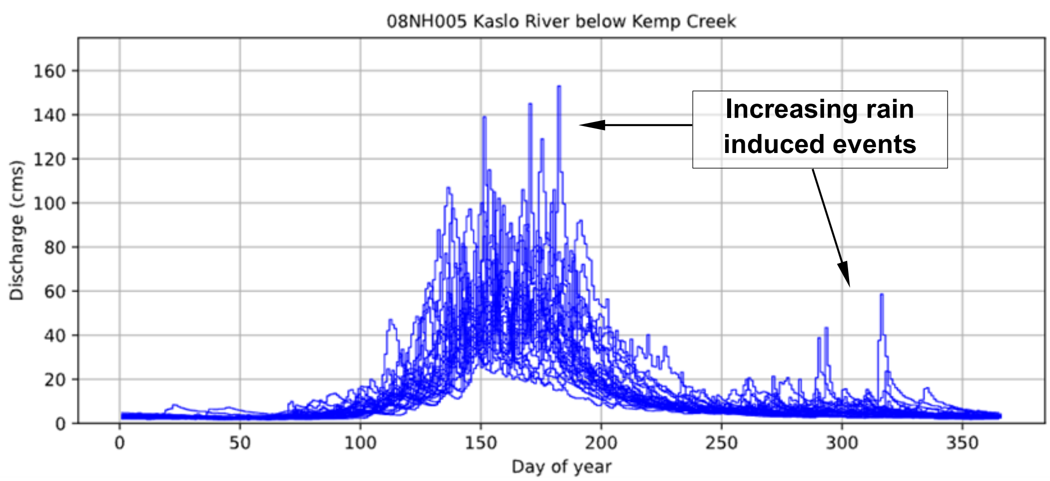


FIGURE 4-2: KASLO RIVER BELOW KEMP CREEK (1996-2022)

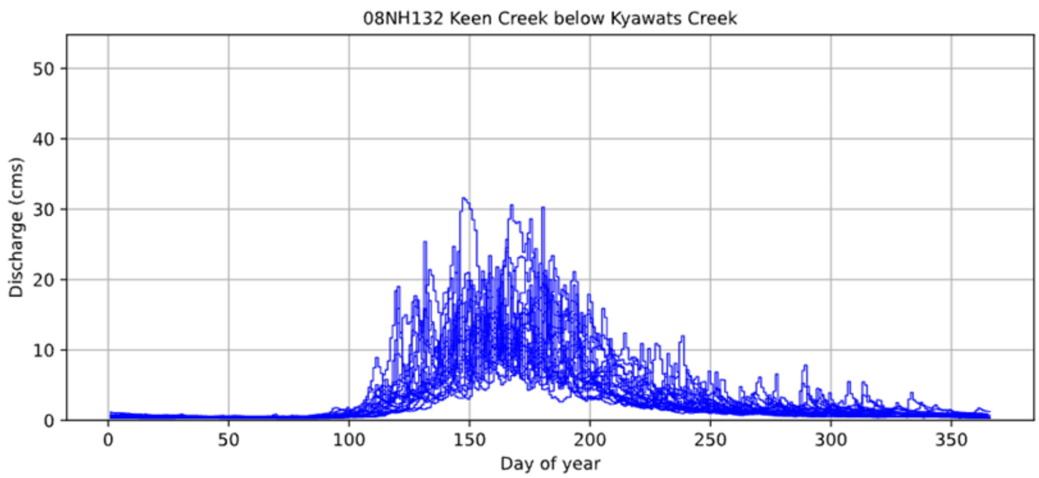


FIGURE 4-3: KEEN CREEK BELOW KYAWATS CREEK (1973-1995)

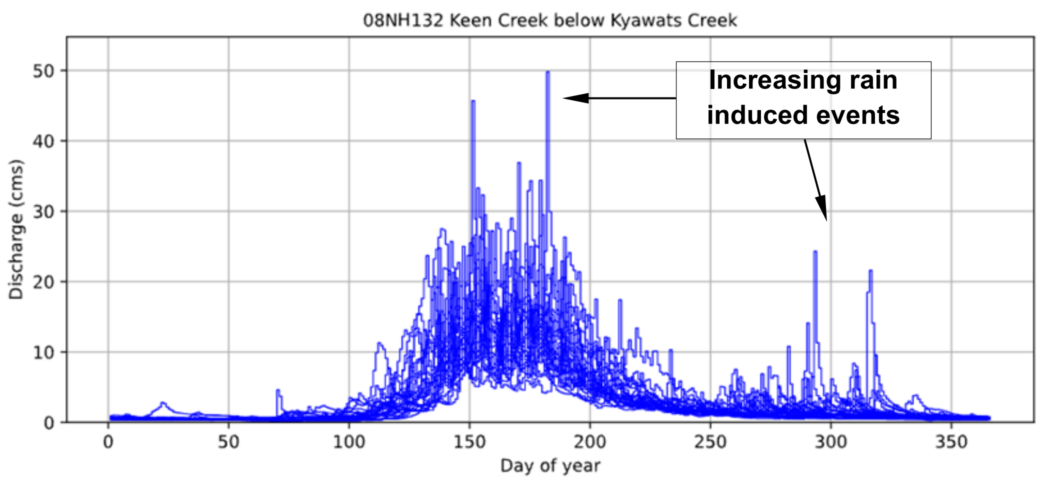


FIGURE 4-4: FIGURE 4-4: KEEN CREEK BELOW KYAWATS CREEK (1996-2022)

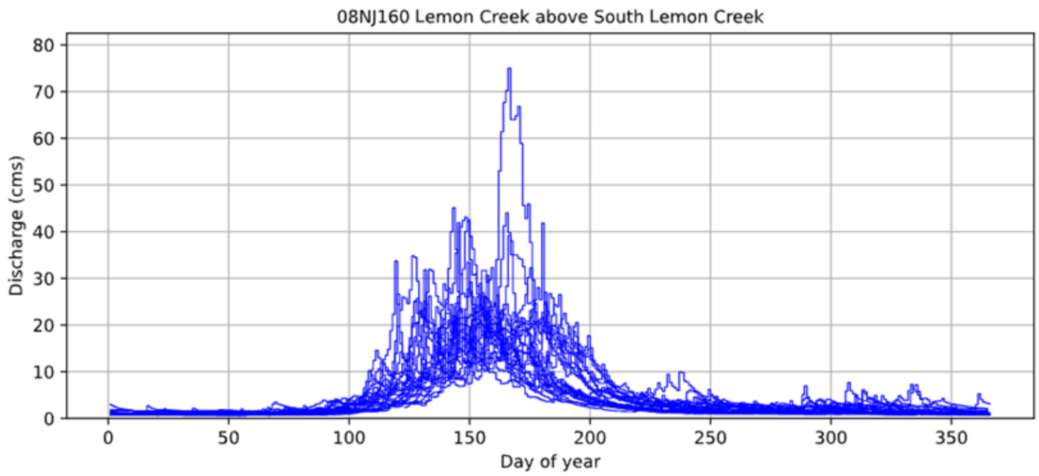


FIGURE 4-5: LEMON CREEK ABOVE SOUTH LEMON CREEK (1973-1995)

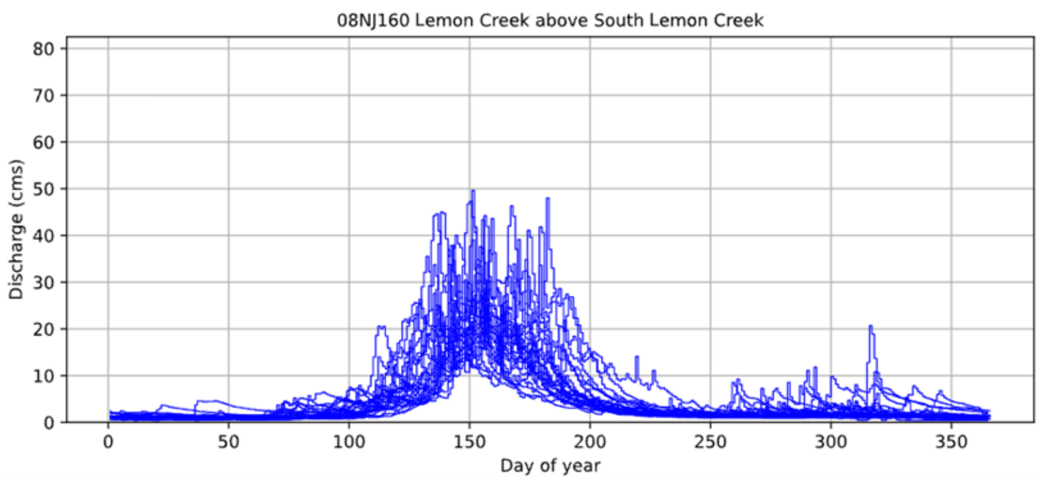


FIGURE 4-6: LEMON CREEK ABOVE SOUTH LEMON CREEK (1996-2022)

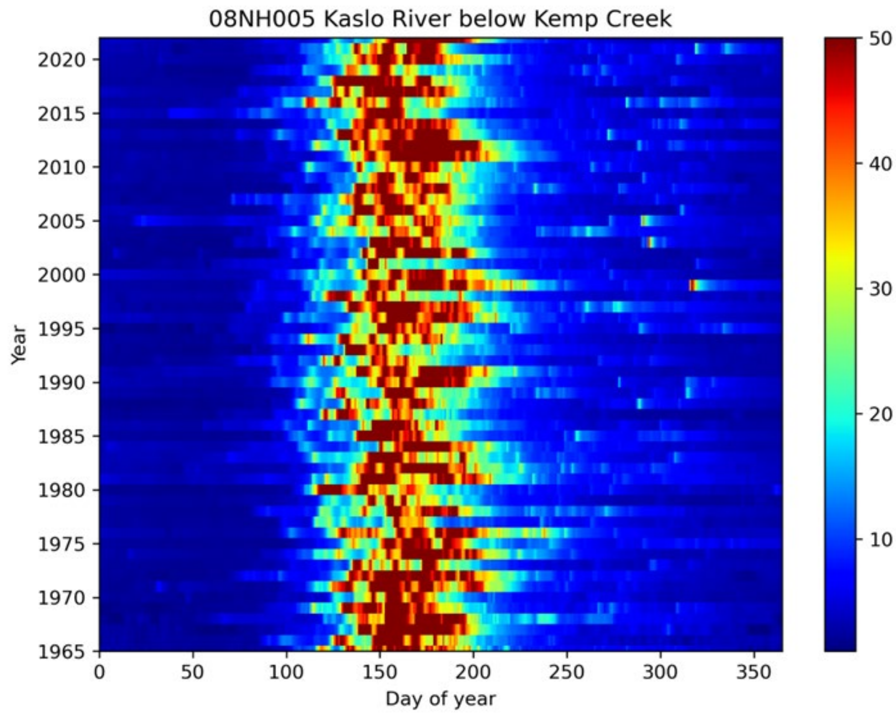


FIGURE 4-7: KASLO RIVER RASTER HYDROGRAPH PLOT (FLOWS IN M^3/S)

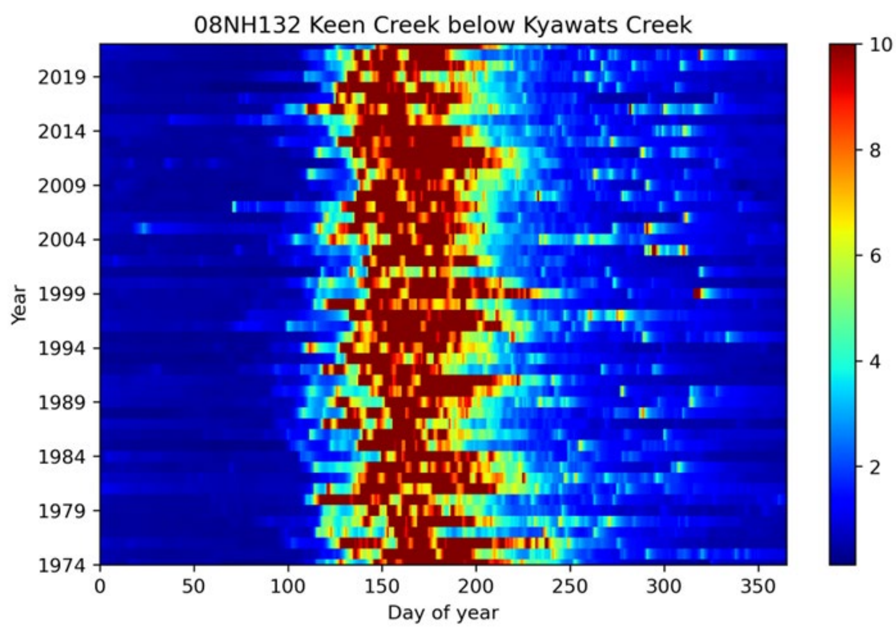


FIGURE 4-8: KEEN CREEK RASTER HYDROGRAPH PLOT (FLOWS IN M^3/S)

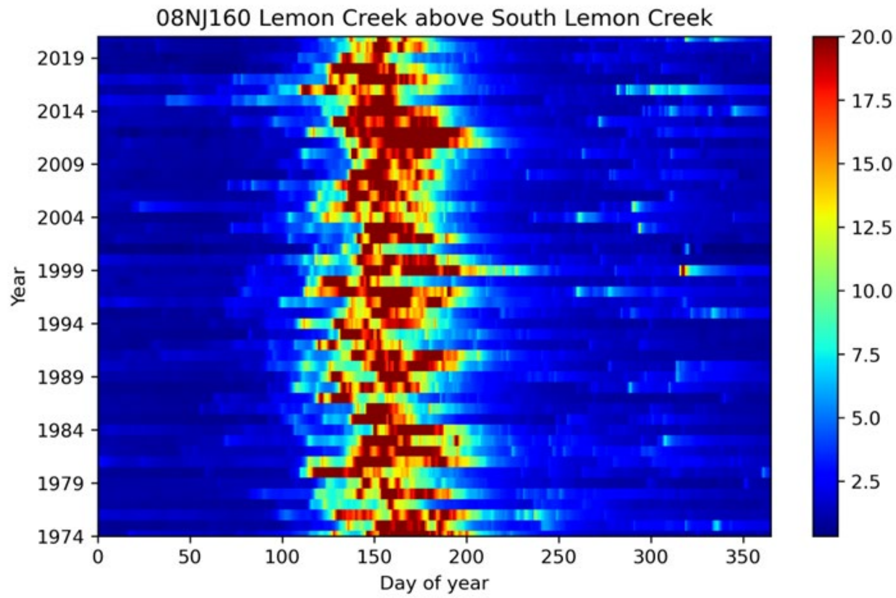


FIGURE 4-9: LEMON CREEK RASTER HYDROGRAPH PLOT (FLOWS IN M^3/S)

For the smallest watershed in the study area (Keen Creek), the hydrograph plots visually indicate that timing and regularity have not changed generally, but the rainfall induced peaks have experienced changes in the last thirty years. Since small catchments have a more drastic response to rainfall compared to larger watersheds, the changes in the rain signal are more pronounced. Higher occurrence of rainfall events (during the freshet and winter seasons) is observed in the latter period (1995-2022) compared to the earlier period (1973-1994). The raster hydrograph plots (Figure 4-8) for Keen Creek show a much greater intensity of rainfall events from early June to mid-December (day of year 150 to 300), indicating greater occurrence of flooding from rainfall events in the recent past compared to earlier periods.

The hydrographs for Lemon Creek (Figures 4-5 and 4-6) show a smaller increase in peak flows during the freshet (and winter) seasons from either rapid thaw, rainfall, or both. The change is dampened as the Lemon Creek catchment is greater in size compared to Keen Creek, where the changes in the rain signal is clearer. Timing and regularity for Lemon Creek are generally unchanged in the two time periods evaluated. The large freshet flood from 1974 has been significant and is likely skewing the statistics of the 1973-1994 period.

Changes in the historic streamflow record suggest that rainfall will become a more relevant factor in the future. Changes during the freshet season (when the snowpack is melting) will be most pronounced and have the chance of being most impacted.

4.1.2 Frequency Magnitude Relationships

Daily data is used in statistical analyses to carry out single station statistical analyses of streamflow records. Results are summarized below.

Daily data was filtered for the freshet season, from which annual maximums were extracted and used to fit the GEV statistical distribution. Daily flows were converted to instantaneous flows via relationships presented above. Flow characteristics were computed for each gauge. The entire available record is used in the statistics for each gauge.

Freshet block maxima analysis results are shown in Table 4-2 for the four gauges within the study area. Individual statistical fits (using the GEV distribution with parameters estimated using L-Moments) are shown in Figures 4-10 to 4-13.

TABLE 4-2: SINGLE STATIONS FREQUENCY ANALYSIS WITHIN STUDY AREA

			Peak Instantaneous Freshet Flow (m^3/s) / Return Period (Yrs)							
Gauge ID	Gauge Name	DA (km^2)	2	5	10	20	50	100	200	500
08NH005	Kaslo River below Kemp Creek	442	92.1	120.5	139.5	158.0	182.3	200.7	219.2	244.0
08NH132	Keen Creek below Kyawats Creek	92.3	27.7	36.7	42.4	47.8	54.5	59.5	64.3	70.5
08NJ026	Duhamel Creek above Diversions	52.9	10.4	13.8	16.3	19.0	22.8	26.0	29.4	34.4
08NJ160	Lemon Creek above South Lemon Creek	181	39.8	52.0	60.2	68.1	78.5	86.4	94.4	105.1

DA = Drainage Area as reported by Water Survey of Canada

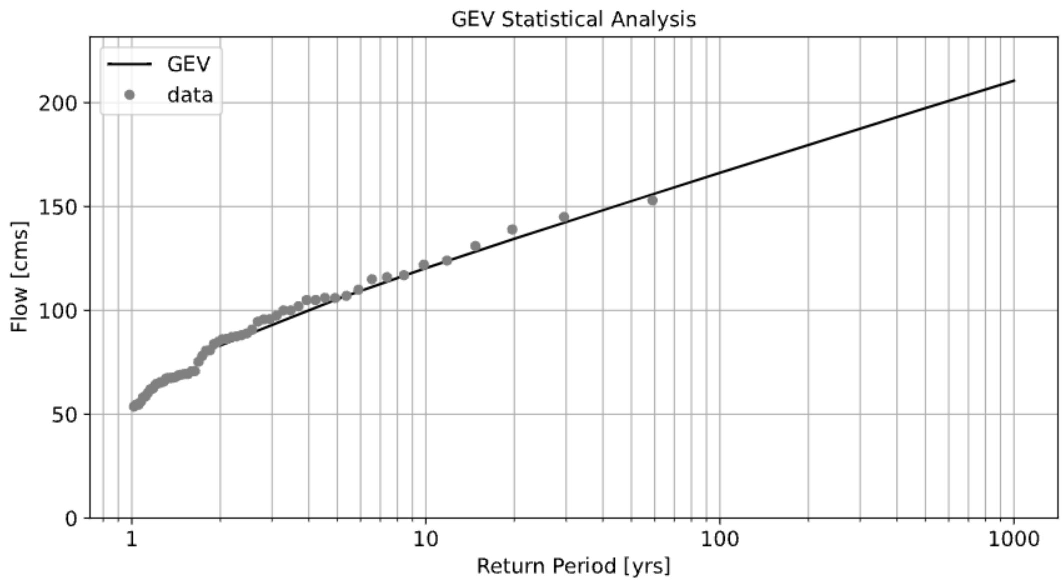


FIGURE 4-10: FREQUENCY CURVE FOR KASLO RIVER (08NH005)

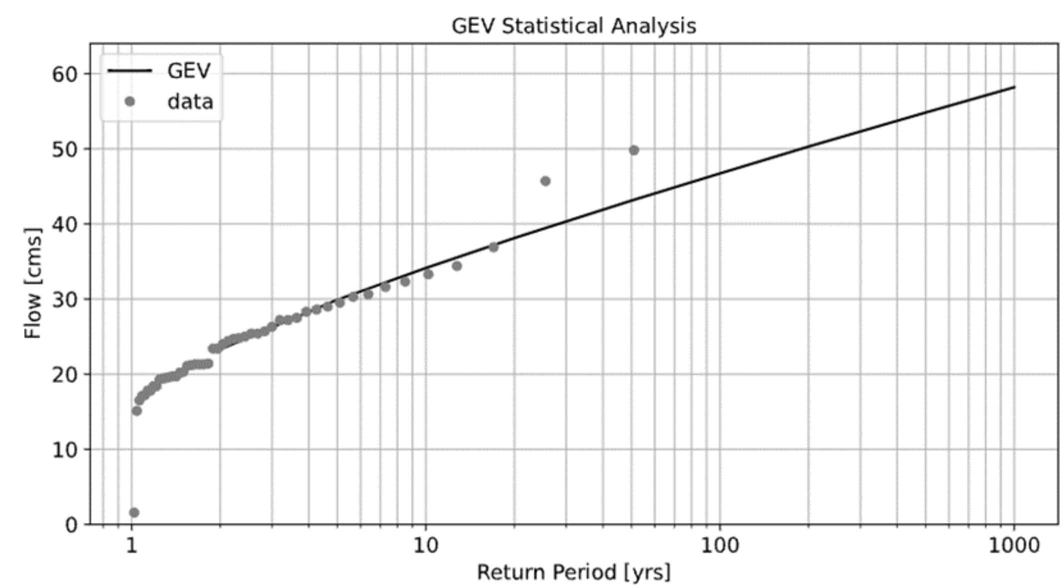


FIGURE 4-11: FREQUENCY CURVE FOR KEEN CREEK (08NH132)

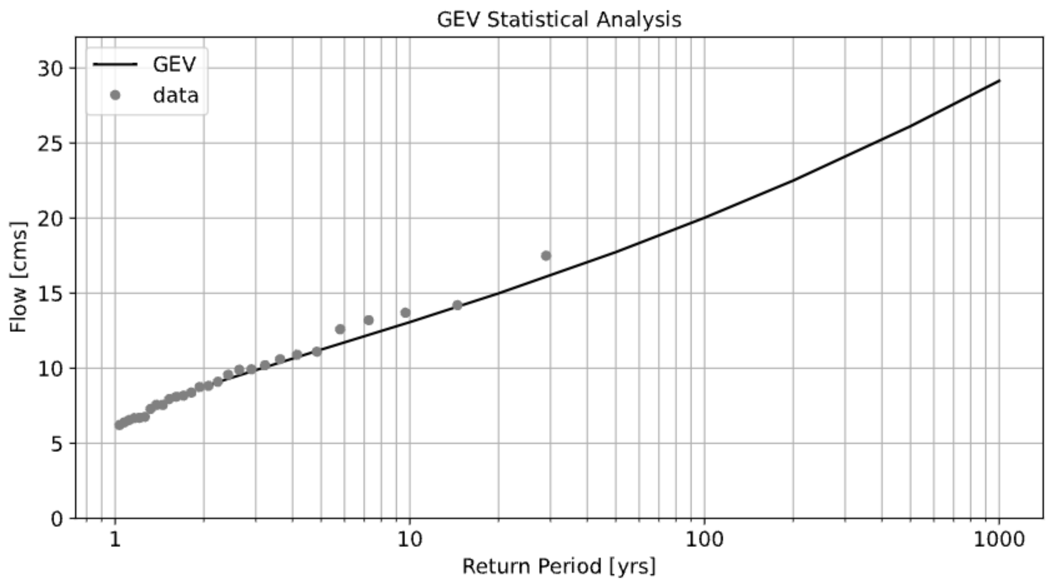


FIGURE 4-12: FREQUENCY CURVE FOR DUHAMEL CREEK (08NJ026)

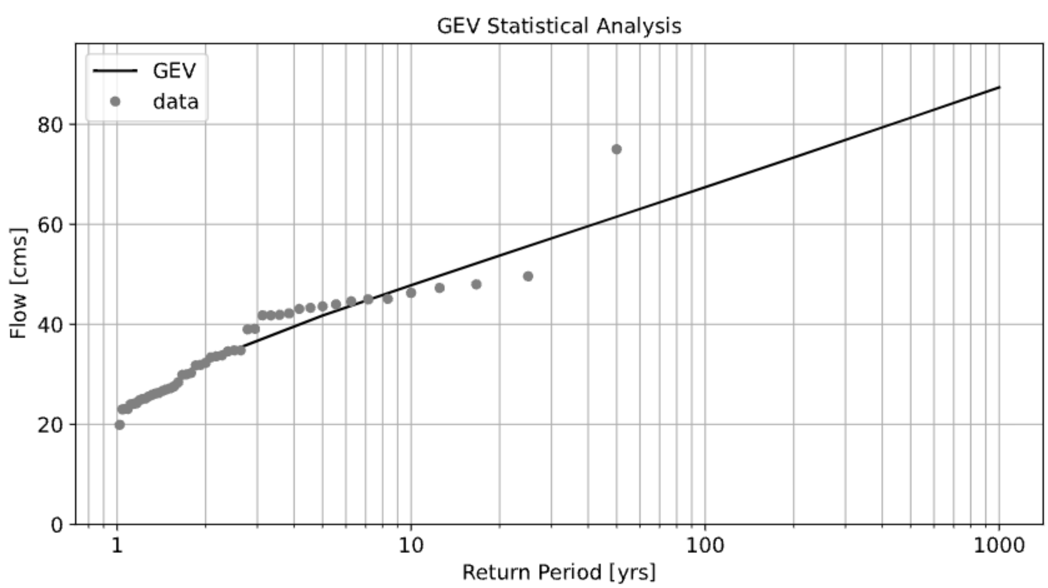


FIGURE 4-13: FREQUENCY CURVE FOR LEMON CREEK (08NJ160)

4.1.3 Regional Analyses

Relationships between drainage area and peak freshet flow are often used in BC for regional analysis as they are generally acceptable practice. Using data provided from known streamflow gauges, a relationship between drainage area and peak flow was established for each return period interval ranging from 2-yr to 500-yr. A linear model for the regional analysis was found to have sufficient accuracy.

Developing regional curves requires establishing drainage areas at locations where flows are known (at existing streamflow gauges). Relationships between peak flows and drainage area allow estimation of peak flow characteristics for any catchment in that region. The regional curves developed are shown in Figures 4-14 to 4-21 for return periods ranging from 2-yr to 500-yr. Applying the regional curves to Carpenter Creek at New Denver results in the flow characteristics developed in Table 4-3.

TABLE 4-3: PEAK FLOW CHARACTERISTICS FOR CARPENTER CREEK AT NEW DENVER

			PEAK INSTANTANEOUS FRESHET FLOW (M^3/S) / RETURN PERIOD (YRS)							
GAUGE ID	GAUGE NAME	DA (KM^2)	2	5	10	20	50	100	200	500
-	Carpenter Creek at New Denver	204.5	45.0	59.0	68.4	77.5	89.4	98.5	107.7	120.0

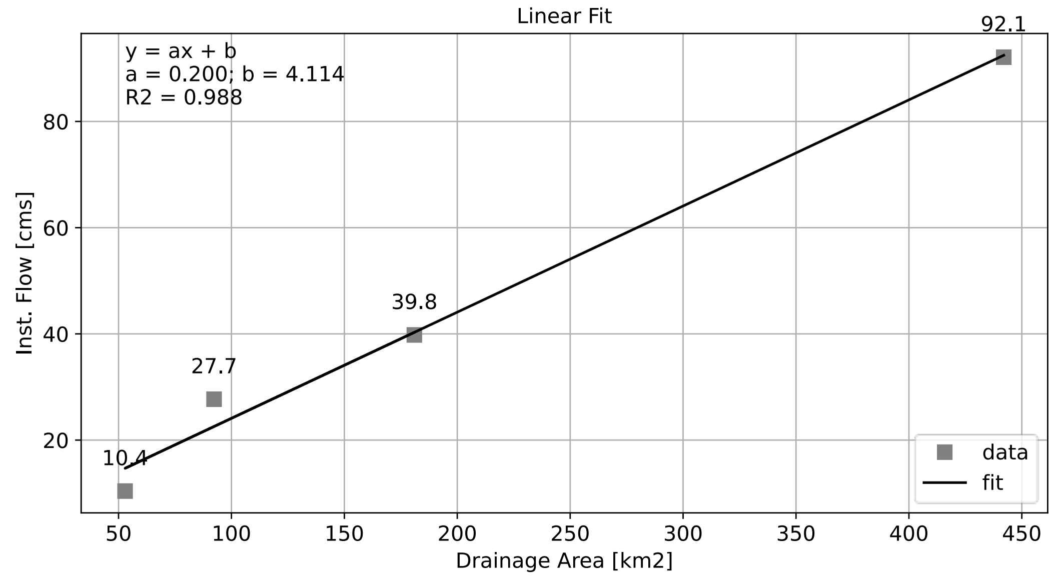


FIGURE 4-14: REGIONAL CURVE FOR 2-YR PEAK FLOW

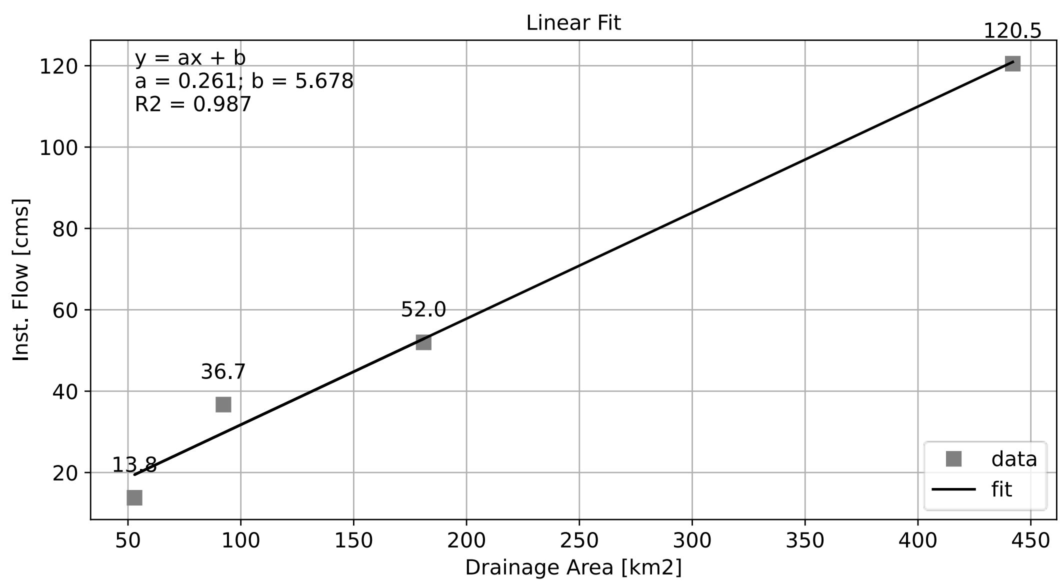


FIGURE 4-15: REGIONAL CURVE FOR 5-YR PEAK FLOW

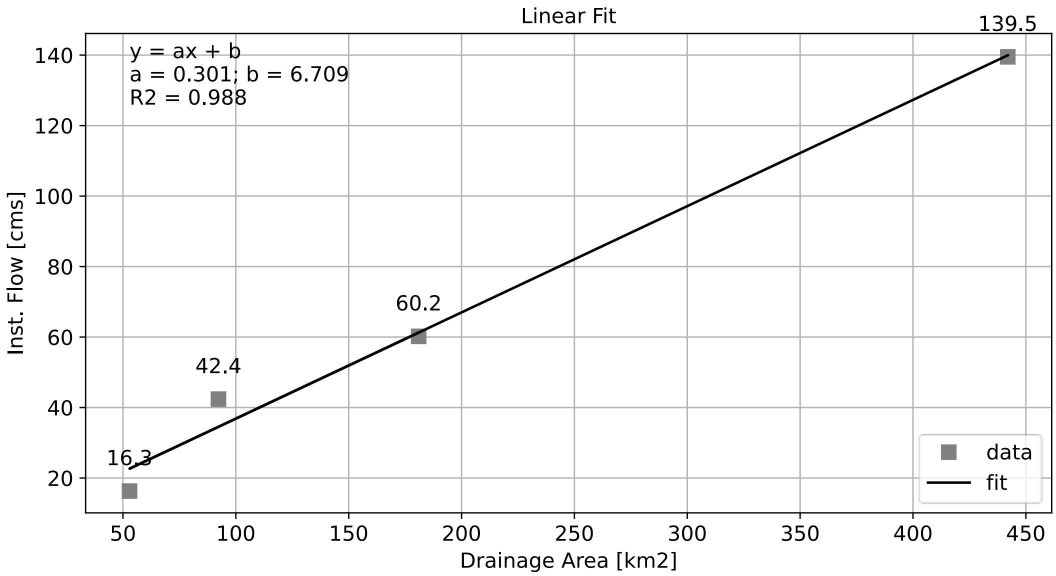


FIGURE 4-16: REGIONAL CURVE FOR 10-YR PEAK FLOW

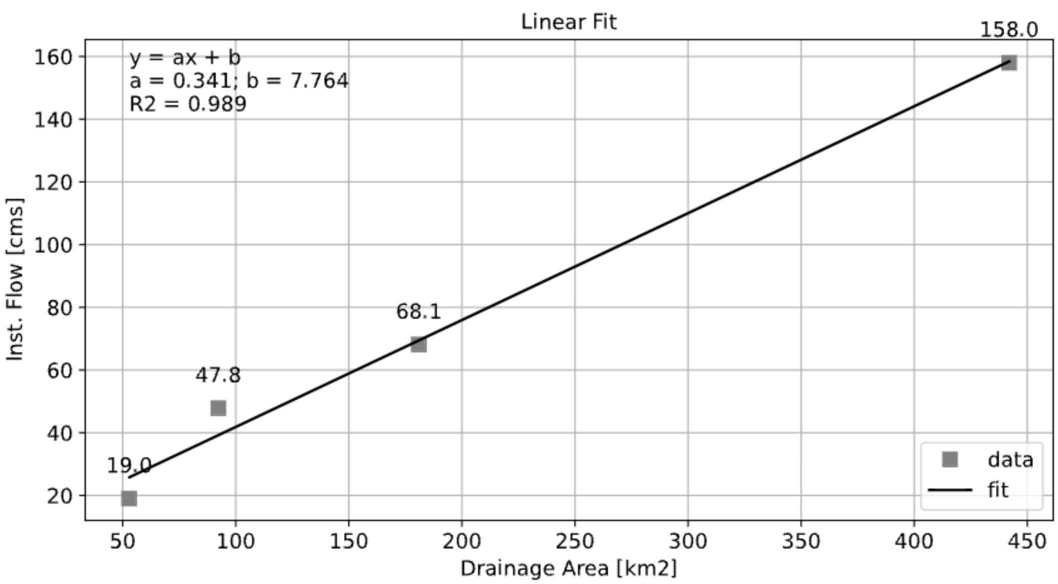


FIGURE 4-17: REGIONAL CURVE FOR 20-YR PEAK FLOW

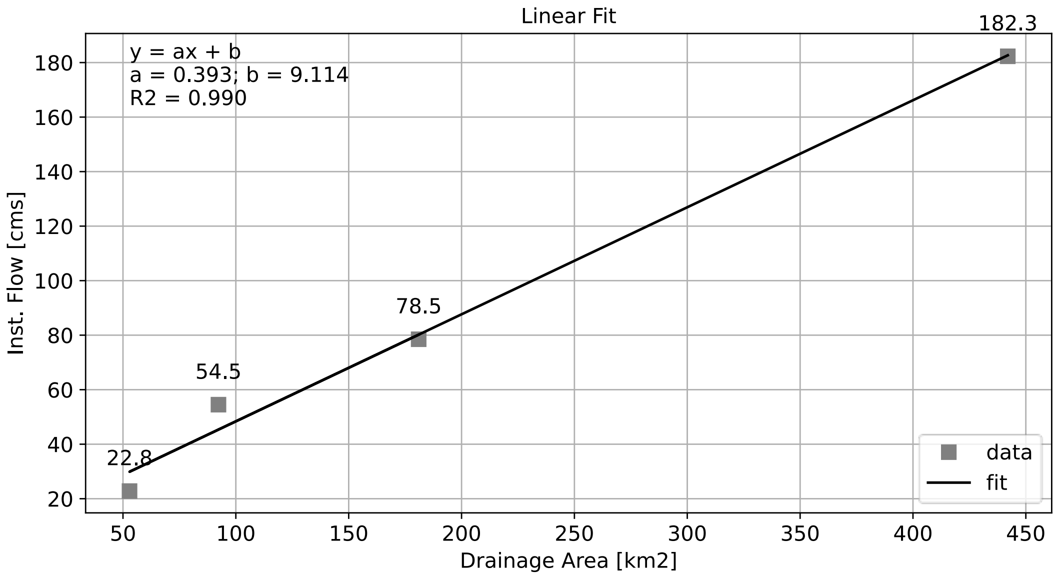


FIGURE 4-18: REGIONAL CURVE FOR 50-YR PEAK FLOW

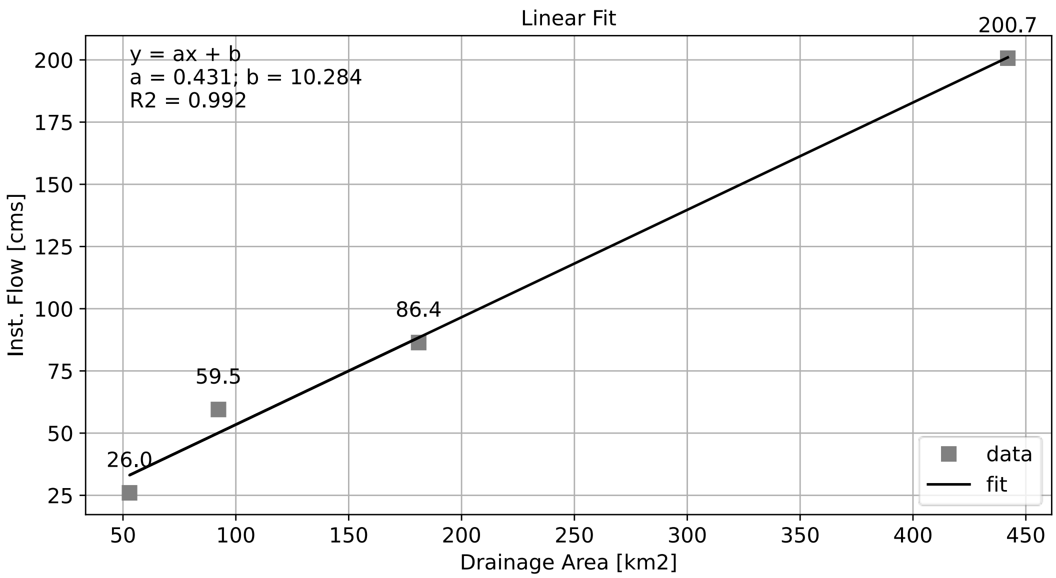


FIGURE 4-19: REGIONAL CURVE FOR 100-YR PEAK FLOW

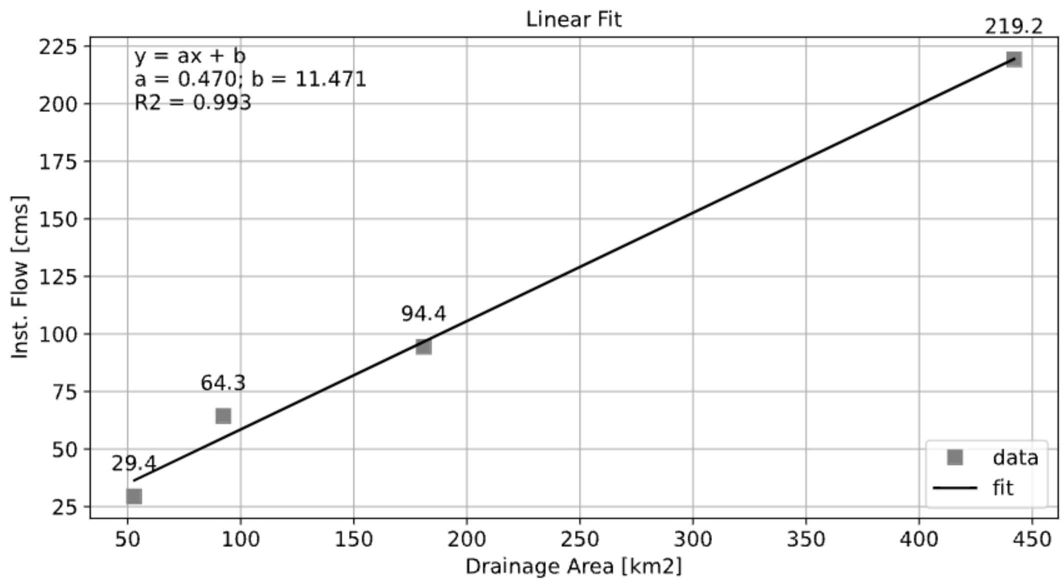


FIGURE 4-20: REGIONAL CURVE FOR 200-YR PEAK FLOW

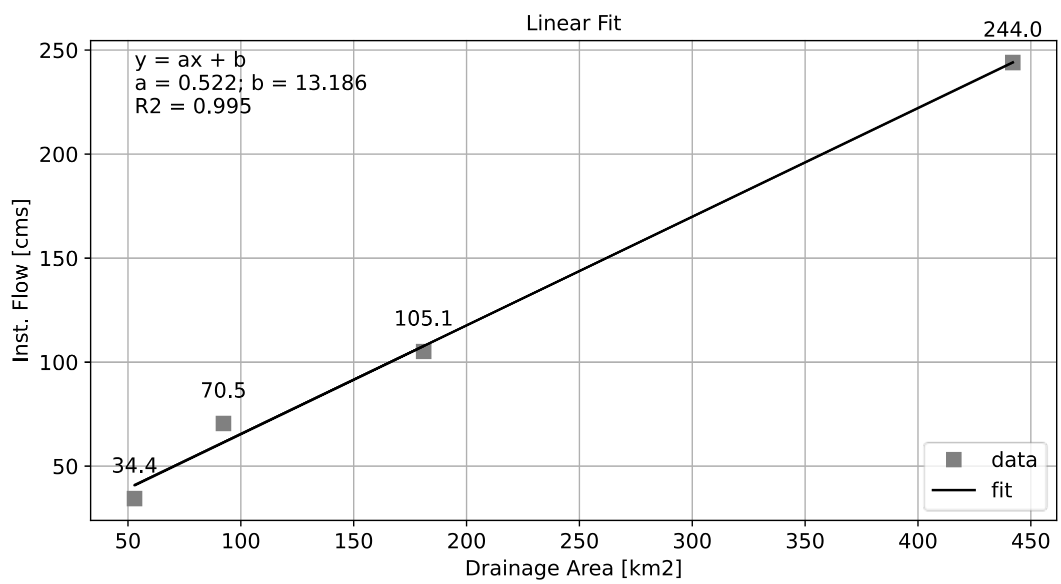


FIGURE 4-21: REGIONAL CURVE FOR 500-YR PEAK FLOW

4.2 Climate Change Data Analyses

This section presents a summary of climate change analyses carried out in the study.

4.2.1 PCIC Climate Change Analyses – Magnitude, Timing and Regularity

The analysis of PCIC's 'proxy flow' timeseries is summarized in this section, noting that PCIC's data can not capture magnitudes of short-intensity rainfall events. However, the PCIC 'proxy flow' data can be used to quantify general patterns of change when it comes to snowmelt. The 'proxy flow' variable was extracted as a daily timeseries, upon which analysis was carried out. Note that as this variable is a proxy, its absolute magnitudes are meaningless. However, the proxy flow could be used as a valid indicator of change when snowmelt flows are considered.

The 'proxy flow' variable was assessed for magnitude, timing and regularity. The results presented in Table 4-4 show the 200-yr 'proxy flow' magnitude (averaged among the six climate change model outputs), as well as timing and regularity.

TABLE 4-4: PCIC CLIMATE CHANGE SUMMARY FOR THE STUDY AREA

	FRESHET SEASON		
PERIOD (-)	Q200 FLOW PROXY (MM/DAY)	TIMING (DAY OF YEAR)	REGULARITY (DAYS)
2011-2040	18.6	155.3	13.7
2041-2070	20.0	151.8	13.1
2071-2100	19.2	136.8	14.3

The PCIC results suggest that freshet's peak flow (snowmelt only) is anticipated to only marginally change in future periods. Results also suggest that by the end of the century, the shape of the annual hydrograph is anticipated to shift, with the peak occurring almost three weeks earlier compared to present conditions. The regularity generally remains similar, with little anticipated change.

A sample of the year-over-year hydrograph plots from the CanESM2 model, for the RCP 8.5 scenario, is shown in Figures 4-16 to 4-19 for the 'proxy flow' variable. The raster hydrograph is shown in Figure 4-20 for the same variable and model simulation.

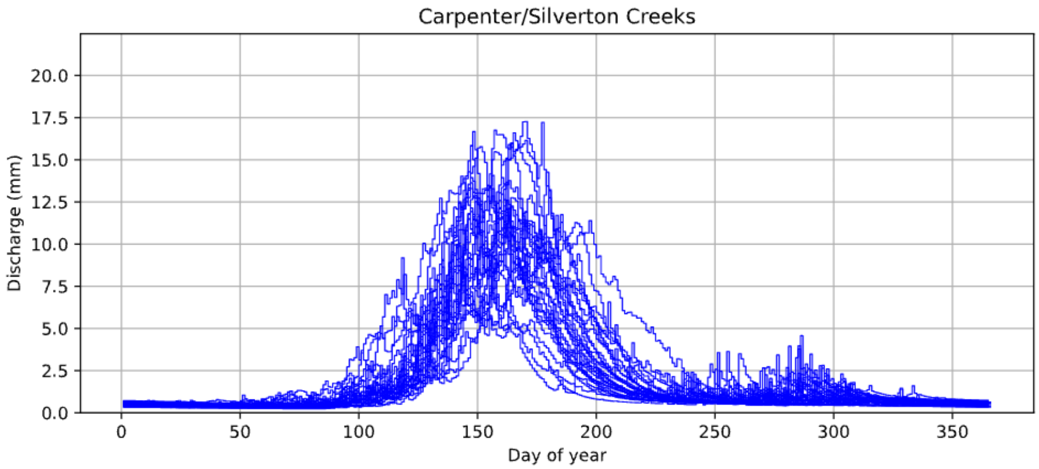


FIGURE 4-22: PROXY FLOW HYDROGRAPH FOR 1981-2010, CANESM2 MODEL

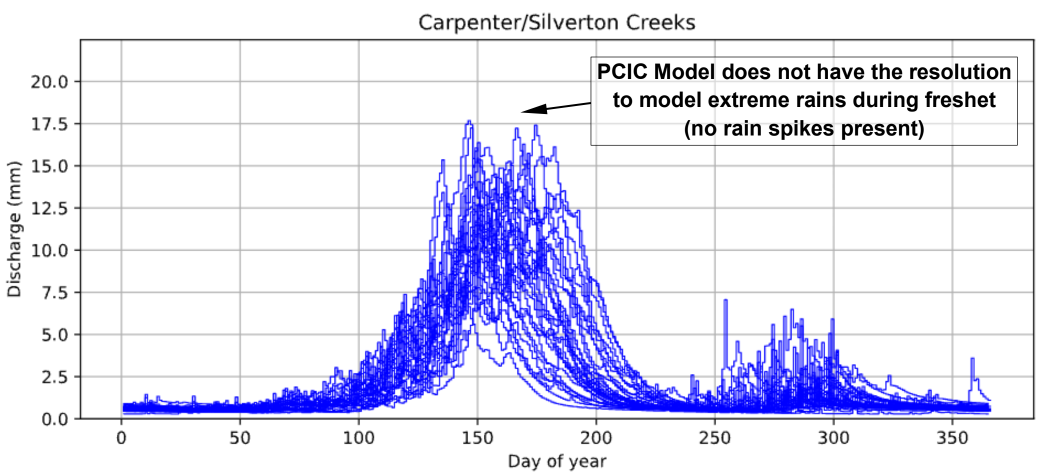


FIGURE 4-23: PROXY FLOW HYDROGRAPH FOR 2011-2040, CANESM2 MODEL

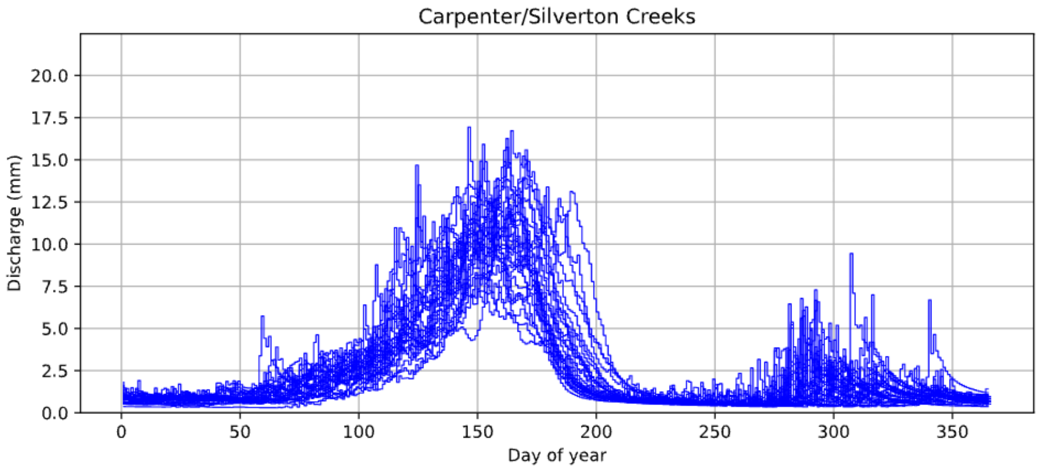


FIGURE 4-24: PROXY FLOW HYDROGRAPH FOR 2041-2070, CANESM2 MODEL

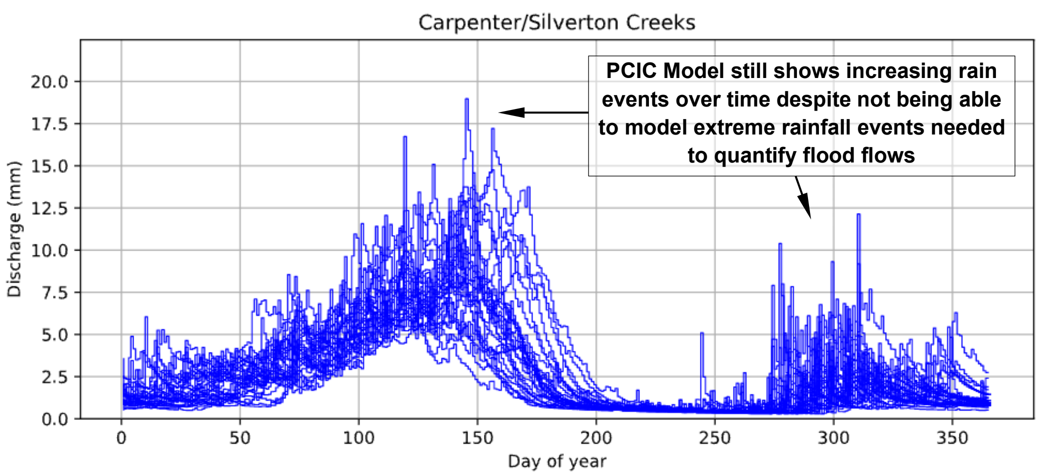


FIGURE 4-25: PROXY FLOW HYDROGRAPH FOR 2071-2100, CANESM2 MODEL

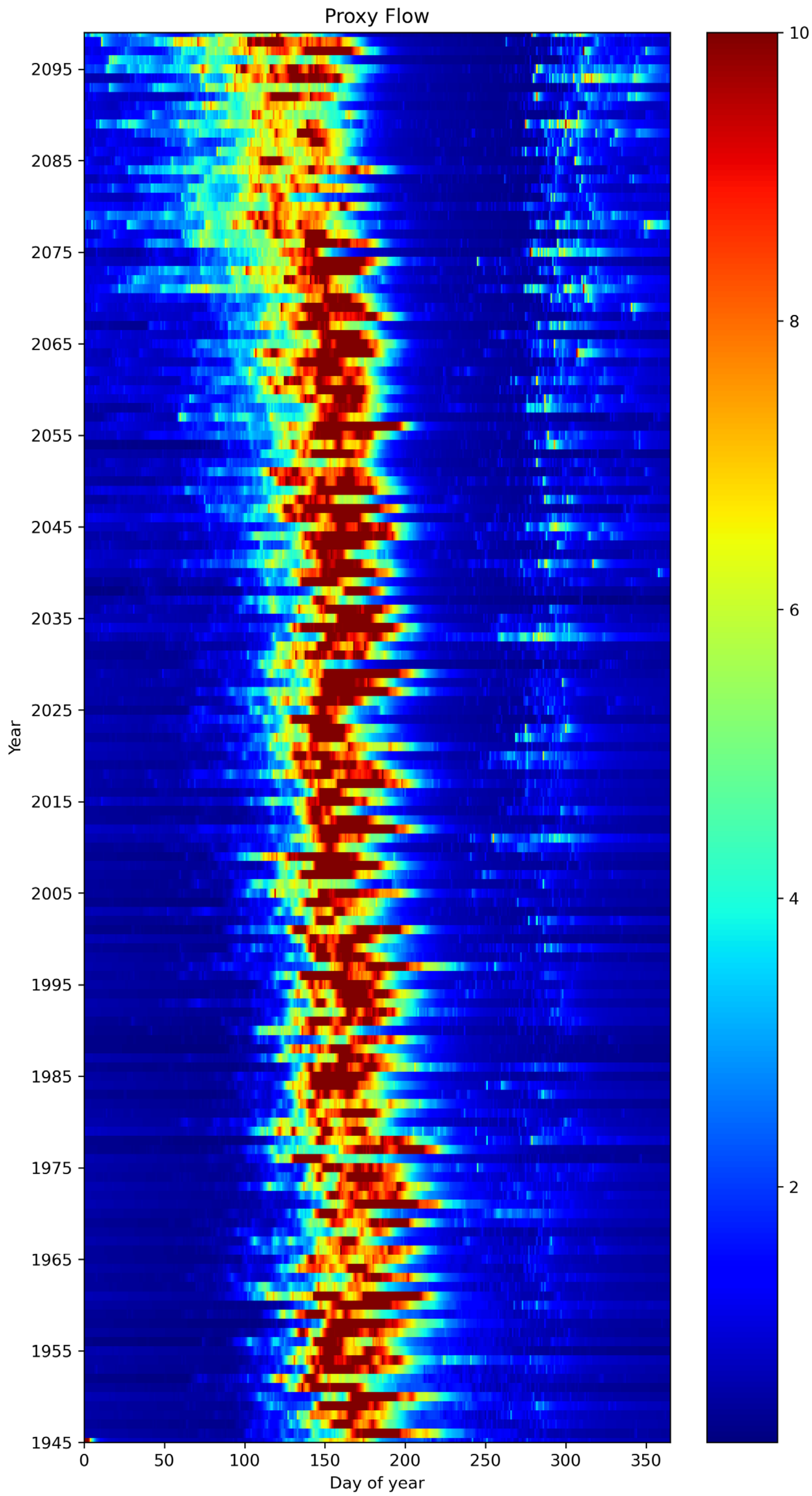


FIGURE 4-26: PROXY FLOW RASTER HYDROGRAPH FOR 1945-2100 (FLOWS IN M^3/S)

The proxy flow hydrograph plots for different 30-year time periods show a shift in the annual hydrograph, with the melt anticipated to occur earlier. The peak magnitude of the snowmelt is not anticipated to change according to the PCIC simulations (which do not include short-duration high-intensity rainfall). Winter rainfall is, however, expected to increase significantly, but is anticipated to remain at or below the snowmelt peaks.

The raster hydrograph plot in Figure 4-20 shows that seasonally the hydrologic response will likely change by the end of the century, which will see earlier snowmelt, and significantly more rainfall (especially during the winter months). The winter rainfall, even though significantly increased, is still expected to be less than peaks that could be generated by the rain-on-snow processes.

4.2.2 Short-Duration High-Intensity Rainfall

Short-duration high-intensity rainfall under the effects of climate change is needed to quantify how rain-on-snow flows will change in the future. To do this, rainfall characteristics under climate change is needed. In Canada, this data is available through the ClimateData.ca online web portal. The ClimateData.ca is a collaboration between Environment and Climate Change Canada (ECCC) and several Canadian non-profit organizations (including PCIC in British Columbia) that specialize in dissemination and processing of data under changed climatic conditions.

Intensity-Duration-Frequency (IDF) curves synthesize short-duration rainfall characteristics for a particular location. The curves provide information on magnitude (how much), duration (how long) and frequency (return period) of rainfall. IDF data are available at the ClimateData.ca portal, which were last updated in 2022. For this work, IDF data stations at Duncan Lake Dam, Fauquier and Nelson were obtained and used.

For the climate change adjusted rainfall, the SSP5.85 scenario was used (next iteration of the RCP8.5 scenario). The SSP5.85 scenario assumes minimal global climate change mitigation measures are applied by the end of the century, with greenhouse gas emissions generally increasing (business as usual scenario). The use of the SSP5.85 scenario represents the currently accepted standard practice for evaluation and design of flood management infrastructure in BC.

Future rainfall rates were obtained by ECCC by scaling the historic IDF values based on the temperature scaling technique using the Clausius-Clayperon relationship. The said relationship states that the water carrying capacity of the atmosphere increases by about 7% for every 1°C of warming. Annual mean temperature projections for a particular climate scenario (i.e., SSP5.85) over a period (2070-2100) were used to develop climate adjusted rainfall, which were then synthesized as IDF curves.

In this work, the Pacific Climate Impacts Consortium (PCIC) bias adjusted CMIP6 global model was used, alongside of the SSP5.85 scenario for the 2070-2100 period to obtain climate adjusted rainfall. The rainfall data is summarized in Table 4-5 for historic and climate adjusted rainfall.

TABLE 4-5: RAINFALL CHARACTERISTICS UNDER CLIMATE CHANGE FOR STUDY AREA

LOCATION (-)	HISTORICAL 200-YR 24-HR RAINFALL (MM)	2071-2100 200-YR 24-HR RAINFALL (MM)	CHANGE FACTOR (-)
Duncan Lake Dam	66.8	95.2	1.42
Fauquier	66.9	99.8	1.49
Nelson	69.1	98.6	1.43
		Average	**1.45**

Based on the above, the peak rainfall characteristics are anticipated to change by an average factor of 1.45 (or 45% higher) by the end of century compared to present conditions.

4.2.3 Rain-on-Snow Climate Change Factor Estimate

The HEC-HMS hydrologic model developed for Lemon Creek was used to simulate the flood peaks during the 2020 freshet event. This event included a rapid melt of the snowpack during several days when the temperature spiked to a daily high of 25 degrees Celsius. On top of the rapid snowmelt, a rainfall event occurred that added approximately 37 mm of rainfall over the same period, producing a rain-on-snow induced flood.

The HEC-HMS model was simulated using the best representation of the existing conditions (where the model was initialized using snow water equivalents obtained from the Daymet database, and forced with observed temperature record, along with rainfall). The hydrologic model was considered semi-calibrated as the simulated peak flow reasonably matched observed peaks at the Lemon Creek gauge.

To assess the rain-on-snow climate change factor, the rainfall in the hydrologic model was increased by a factor of 1.45 (see Table 4-5), and simulations repeated for the same event. The peak flow obtained can be considered representative of conditions under climate change for the end of century period. The simulations were repeated using several sub-daily rainfall distributions, with each distribution producing a slightly different peak value for the 2071-2100 time period. This is to be expected, as changes in temporal rainfall distribution has the effect of producing different peak flow magnitudes. Based on the sensitivity tests carried out, a rain-on-snow climate change factor of 1.7 (or 70% increase from base case) was identified as reasonable under climate change.

The climate adjusted factor of 1.7 shall be used to scale historic peak flows in this work.

4.2.4 Climate Change Uncertainty

Climate change introduces significant uncertainties into our understanding of future environmental conditions. One of the primary challenges is the difficulty in accurately capturing extreme weather events within climate models. These models, which are designed to simulate long-term climate patterns, often struggle with predicting localized extreme phenomena, such as intense storms or prolonged droughts.

Rainfall is notably one of the most uncertain parameters in climate modeling. Unlike temperature, which tends to follow more predictable patterns, precipitation is influenced by complex atmospheric dynamics and topographical features. This variability makes it challenging to project future rainfall amounts and intensities with high confidence. Localized events, such as extreme rainfall driven by Atmospheric Rivers, are particularly difficult to model accurately, adding another layer of uncertainty to flood risk projections.

Uncertainty in climate projections also varies by spatial scale. Regional models may offer more detailed insights than global models, but they are still limited by the quality of input data and the inherent unpredictability of weather systems. This spatial uncertainty is especially pronounced in mountainous regions, where topography plays a crucial role in weather patterns.

To address and mitigate these uncertainties, various approaches are employed. One method is to use a range of scenarios and models to capture a spectrum of possible future conditions. Taking an ensemble approach and using multiple climate models helps to better understand and quantify the uncertainty, providing a more comprehensive view of potential outcomes. Tools such as temperature scaling recommended by Environment and Climate Change Canada provide effective ways to project future rainfall intensities. Event-based methods and fine-scale climate data also help refine estimates based on recent extreme events. These strategies emphasize the importance of adaptive management, which involves continually updating and refining methodologies as new data and techniques emerge.

Incorporating uncertainty into decision-making is crucial for effective climate change adaptation. By acknowledging the limitations of current models and projections, decision-makers can develop more robust plans that are flexible and responsive to new information. This adaptive approach ensures that flood risk assessments and infrastructure designs remain relevant and resilient under varying future scenarios.

It is essential to recognize that climate science is an evolving field, and many questions remain unanswered. Embracing uncertainty and adopting an adaptive management strategy allows us to navigate the complexities of climate change more effectively. As we improve our understanding and modeling capabilities, we must remain open to revising our approaches and assumptions, ensuring that we are prepared for a range of possible futures.

4.3 Steep Creek Hazards

A geomorphologic assessment at Carpenter Creek completed by SLR (2025) has identified that clearwater and debris floods are possible at the project site. Staff from SLR observed that lower reaches of Carpenter Creek were noted to have mobile sediment during flood events, where gravel, cobbles and boulders resting on the riverbed can be transported during floods. The process where sediment (and woody debris) become entrained in the flow leads to an increase in the volume of organic and mineral debris being transported downstream. Sediment bulking is represented by applying a factor to peak flow derived from hydrologic analyses of clearwater flows.

A bulking factor of 10% was identified by SLR (2025) to apply for the lower reaches of Carpenter Creek. A bulking factor accounts for the increase in peak flow from sediment laden water during high flow events.

Note that BGC used a bulking factor of 20% on Duhamel Creek (a smaller catchment in a neighbouring watershed) when estimating 200-yr flow (BGC, 2020b). At Wilson Creek, a larger catchment in the Regional District of Central Kootenays, BGC used a bulking factor of 10% (BGC, 2020c).

4.4 Design Flows

For the purposes of floodplain mapping for Carpenter Creek at New Denver flow characteristics are identified in Table 4-6:

TABLE 4-6: END OF CENTURY DESIGN FLOWS FOR CARPENTER CREEK AT NEW DENVER

COMPONENT	FLOW (m^3/s)
200-yr Peak Clearwater Flow	107.7
Climate Change Adjustment (70%)	75.4
Sediment Bulking Adjustment (10%)	10.8
200-yr Peak Design Flow	**193.9**

The peak design flows identified above include a significant climate change factor that considers impacts of more intense rainfall during the freshet season. It is recognized that a climate change factor significantly increases the peak flows, but such factor is required for a robust estimate required for floodplain mapping that are going to be relied upon for decades in the future.

5.0 Summary of Findings

Findings made in this section are based on analyses, assessments, and interpretations of:

- Historic sub-daily and daily streamflow records obtained from Water Survey of Canada,
- Long-term hydrologic model outputs produced by Pacific Climate Impacts Consortium (PCIC),
- Short-duration high-intensity rainfall characteristics anticipated in the future, and developed by Environment and Climate Change Canada along with several Canadian non-profit organizations which includes PCIC,
- Simplified hydrologic model of the rain-on-snow processes for a proxy watershed (at Lemon Creek, which responds similarly to Carpenter Creek), and
- Geomorphology processes (entrainment of sediment and woody debris during flood events) that are identified to operate in steep mountainous watersheds.

The main study findings include the following:

1. Present day Carpenter Creek watershed is classified as having a hydrologic regime that is freshet dominated, meaning that annual floods typically occur from the melting of the snowpack in the spring.
2. Current streamflow records in the region suggest that watersheds routinely experience rainfall during the freshet season, where the snowmelt flooding is intensified by the contribution of rainfall. Rainfall on top of already melting snowpack further accelerates the melt process, and thus contributes to more intense catchment response (i.e., quicker flooding).
3. Analysis of changes in regional hydrologic characteristics was completed using the long-term streamflow record that includes nearly 60 years (1965-2022 for the Kaslo gauge). Change analysis suggests that peak flow characteristics have generally increased, with timing (average day of freshet's peak) and regularity (spread around the mean) generally remaining unchanged.
4. Inspection of the year-over-year hydrograph plots clearly indicate larger frequency of rainfall induced peaks (short-duration high-intensity spikes) during the freshet and winter seasons.
5. Changes in the historic record indicate that rainfall will become a critical factor in the future, especially when rainfall occurs during the freshet season (when the snowpack melts).
6. Frequency-magnitude relationships were developed using representative streamflow gauges in the region. Regional analysis synthesized the historic flow characteristics and estimated curves that relate peak flow with catchment area, which allowed for estimation of flows for Carpenter Creek at New Denver.
7. Climate change analyses were completed using results of PCIC's long-term hydrologic model simulations. Analyses of the model outputs identified that annual hydrograph

shape will have an earlier melt of the snowpack (in the order of two to three weeks earlier compared to present conditions). Peak flow magnitudes from the snowmelt will remain at their present values.

8. PCIC's hydrologic model simulations are suggesting earlier occurrence of the snowmelt on average, and significantly more rainfall during the winter seasons.
9. PCIC's hydrologic model was unable to capture the behaviour and response from short-duration high-intensity rainfall (as the model was not designed for this purpose). As such, conclusions drawn from PCIC's model are most accurate when referring to melting of the snowpack only.
10. Changes to short-duration high-intensity rainfall characteristics were obtained from ClimateData.ca database for several meteorologic stations in the region. Peak rainfall characteristics (for 24-hour rainfall magnitude having a 200-year return period) are showing an increase by 45% compared to current values.
11. To estimate impacts of increased rainfall (which can occur during the freshet season) a limited scope event based hydrologic model was developed for the Lemon Creek watershed. Lemon Creek watershed was used in the modeling as it had a long-term streamflow record and similar hydrologic response to Carpenter Creek.
12. Hydrologic simulations of the Lemon Creek catchment were set up for the rain-on-snow event that occurred during the 2020 freshet season (where rainfall occurred during a period of rapid thaw). The hydrologic model simulations were carried out using existing rainfall, and rainfall factored for climate change (future conditions). The changes to the hydrologic response were evaluated by comparing present and future peak flows. The ratio of the future to present-day peaks is defined as the climate change factor.
13. A climate change factor of 1.7 (70% increase) was identified from outputs of hydrologic modeling and is recommended for application for floodplain mapping.
14. Steep creek hazards were assessed which identified that clearwater and debris floods are possible, and as such application of the bulking factor is required.
15. SLR (2025) has identified that a bulking factor of 1.1 (10% increase) is applicable for lower reaches of Carpenter Creek at New Denver.
16. Design flow was established for the purposes of floodplain mapping, which includes 200-yr clearwater peak flow, a factor for climate change (1.7), and a factor for sediment bulking (1.1). The resulting 200-year peak design flow for Carpenter Creek 193.9 m^3/s.
17. The above estimates of design flows are believed to be robust in light of the fact that floodplain mapping and its products will be in use for several decades in the future.

Although the above estimates of design flows are believed to be robust, it is important to acknowledge the tremendous uncertainty introduced by climate change. The unpredictable nature of future climate conditions, including variations in precipitation patterns and snowmelt timing, poses significant challenges for accurate hydrologic modeling. As such, it is crucial for floodplain mapping and related products to remain adaptable and subject to regular updates, ensuring they reflect the latest scientific insights and data to safeguard communities effectively.

References

BGC (2020a). Steep Creek Assessment Methodology. Report prepared by BGC Engineering Inc. on behalf of the Regional District of Central Kootenay, Vancouver, BC, March 2020.

BGC (2020b). RDCK Floodplain and Steep Creek Study, Duhamel Creek. Report prepared by BGC Engineering Inc. on behalf of the Regional District of Central Kootenay, Vancouver, BC, March 2020.

BGC (2020c). RDCK Floodplain and Steep Creek Study, Wilson Creek. Report prepared by BGC Engineering Inc. on behalf of the Regional District of Central Kootenay, Vancouver, BC, March 2020.

BGC (2023). Fraser Valley Regional District Hazard Report, prepared by BGC Engineering Inc., on behalf of the Fraser Valley Regional District, Vancouver, BC, October 2023.

CCAP (2024). Climate Change Adaptation Program, Regional Adaptation for the Kootenay & Boundary. Source: https://www.bcclimatechangeadaptation.ca/regional-adaptation/kootenay-boundary/, accessed July 22, 2024.

Church, M, and Jakob, M. (2020). What is a debris flood? Water Resources Research, Vol 56.

ClimateData.ca (2024). Downloaded from https://climatedata.ca/ on June 29, 2024.

Daymet (2024). Daymet: Annual Climate Summaries on a 1-km Grid for North America, Version 4R1, Downloaded from https://daymet.ornl.gov/getdata on June 29, 2024.

EGBC (2018) Legislated Flood Assessments in a Changing Climate in BC, Engineers & Geoscientists British Columbia (EGBC) – Professional Practice Guidelines, Version 2.1, August 2018.

HEC-HMS (2024). Hydrologic Engineering Center, Hydrologic Modeling System, Technical Reference Manual, Davis, California, June, 2024.

Madsen, H. et al (1997). Comparison of annual maximum series and partial duration series methods for modeling extreme hydrologic events, 1. At-site modeling, Water Resources Research, Volume 33, No. 4, April 1997.

Moase, E., Strouth, A., and Matthias, J. (2018). Steep creek hazard mitigation case studies: some lessons learned from past events. 7th Canadian Geohazards Conference, Canmore, AB, June 2018.

NHC (2021). British Columbia Extreme Flood Project, Bulletin 2020-1-RFFA, Regional Flood Frequency Analysis, Technical development report and manual to complete a regional flood frequency analysis, report by Northwest Hydraulic Consultants, Vancouver, March, 2021.

PCIC (2020). Pacific Climate Impacts Consortium, University of Victoria, (January 2020). VIC-GL BCCAQ CMIP5: Gridded Hydrologic Model Output. Downloaded from https://data.pacificclimate.org/portal/hydro_model_out/map/ on June 29, 2024.

SLR (2025). Geomorphological Assessment of Carpenter Creek Fan Hazards, prepared by SLR Consulting (Canada) Ltd., Kamloops, BC, February 2025.

Zhang et al. (2020). Identification of a preferred statistical distribution for at-site frequency analysis in Canada. Canadian Water Resources Journal, Vol 45, Issue 1.

APPENDIX B

Lake Level and Wind Speed Analysis at Slocan Lake

Lake Level and Wind Speed Frequency Analysis at Slocan Lake

Village of New Denver

February 2025

Project No. 1479-111

TRUE

ENGINEERING ■ PLANNING ■ URBAN DESIGN ■ LAND SURVEYING

2089 Falcon Rd | Kamloops BC | V2C 4J2 | true.ca | tel 250.828.0881

Revision Log

Revision #	*Revised by*	*Date*	*Issue / Revision Description*
1	PP	Feb 12, 2025	Issued to Client

Report Submission

Report Prepared By:

PROFESSIONAL ENGINEER, PROVINCE OF BRITISH COLUMBIA
P. PRODANOVIC
52340
Permit to Practice
No. 1000129
2025-02-13

Pat Prodanovic, Ph.D., P. Eng.
Sr. Water Resources Engineer

Report Reviewed By:

Permit to Practice No. 1000129
PROFESSIONAL ENGINEER, PROVINCE OF BRITISH COLUMBIA
J. P. WELKE
35705
2025-02-13

Jonathan Welke, P. Eng.
Sr. Water Resources Engineer

R:\Clients\1400-1499\1479\1479-111\05 Reports\Lake Level and Wind Speed Frequency Report\1479-111-Village of New Denver-Lake Level Flood Frequency and Wind Speed Analysis-February 2025.docx

Table of Contents

1.0 Introduction **1**
1.1 Lakeshore Hazards at Inland Lakes 2
1.2 Study Objectives and Scope of Work 2
1.3 Vertical Datum 2
2.0 Background Review **4**
2.1 Floodplain Mapping Study, Slocan River (NHC, 1989) 4
2.2 RDCK Floodplain and Steep Creek Study, Slocan River (BGC, 2020) 5
3.0 Historic Water Level Analyses **7**
3.1 Slocan Lake Water Levels 7
4.0 Historic Wind Speed and Direction Analysis **10**
4.1 Wind Observations 10
4.1.1 BC Data Portal (PCIC) 10
4.1.2 Canadian Weather Energy and Engineering Datasets (CWEEDS) 11
4.2 Wind Directional Statistics 13
5.0 Climate Change Assessment **15**
5.1 Impact of Climate Change on Water Levels 15
5.2 Impact of Climate Change on Wind Speeds 18
5.3 Design Parameters for Floodplain Mapping Assessment 18
5.3.1 Water Levels for Slocan Lake 18
5.3.2 Wind Speed and Directional 18
6.0 Summary of Findings **19**
7.0 References **21**

List of Tables

Table 3-1: Daily Lake Level Characteristics at Slocan City (1945-1968) 9
Table 4-1: BC Data Portal Stations Closest to Project Site..10
Table 4-2: Castlegar CWEEDS Station Directional Statistics (1954-2017) 14
Table 5-1: Slocan River at Crescent Valley Summary, CanESM2 Model 17

List of Figures

Figure 1-1: Project Location 1
Figure 3-1: Slocan Lake at Slocan Water Levels, 1945-1968 8
Figure 3-2: Statistical Fit for Daily Lake Levels at Slocan City (1945-1968)............................... 9
Figure 4-1: Definition Sketch of the Nautical Direction Convention..11
Figure 4-2: CWEEDS Wind Rose at Castlegar (May-July, 1954-2005) 12
Figure 4-3: CWEEDS Wind Rose at Nelson (May-July, 1998-2017)..12
Figure 5-1: PCIC Simulations for Slocan River at Crescent Valley 16

1.0 Introduction

This report provides a summary of technical analyses undertaken to characterize water levels of Slocan Lake and regional wind speed for the purpose of completing lakeshore floodplain mapping for the Village of New Denver and Village of Silverton (See Figure 1-1). As both communities lie on the eastern shoreline of Slocan Lake and are relatively close together, the same analyses apply. The lakeshore flooding assessment is part of the overall floodplain mapping assignment for each community, where both lakeshore and riverine floods are being mapped.

FIGURE 1-1: PROJECT LOCATION

Characterization of lake levels and wind speeds is accomplished by carrying out a frequency analysis of historic data. Frequency analysis is a technique used to establish various return periods of a variable in question (water level, wind speed, streamflow, etc.). In BC, the 200-yr lake levels factored for climate change represent the standard that required for lakeshore floodplain mapping, in conjunction with 200-yr wind speeds and directions.

Up to date floodplain maps are required to support future land use planning, assist with emergency response efforts, and ultimately inform design of municipal infrastructure for decades into the future.

1.1 Lakeshore Hazards at Inland Lakes

Being an inland lake surrounded by mountains on all sides, Slocan Lake's hazards are affected by the lake's upstream hydrology (long-term variation of water levels) and its regional wind climate (which generates waves and lead to short-term wave uprush and overtopping of low-lying shoreline). For floodplain mapping purposes, both long-term variation of water levels and short-term impacts from windstorms are required (the subject of this work).

Greatest lakeshore flood hazards are caused by high lake levels and strong windstorms occurring jointly. High lake level causes flooding and inundation of low-lying areas near the lake's shoreline, while winds blowing over open fetches of water generate waves which cause shoreline hazards. For inland lakes the longest open water fetch is measured along the lake's long axis (which for Slocan Lake is approximately 17 km). Winds blowing over a lake with such a fetch can generate significant wave magnitudes and contribute to lake's hazards near its margins.

Wind generated waves propagate inland and eventually reach and interact with the shoreline. As waves propagate to the shoreline, they cause wave energy to run up the shoreline. The magnitude of the wave uprush depends on the magnitude of the incident wave height, the foreshore slope, and its surface treatment (grass, riprap rock, vertical wall). For example, a shallow slope shoreline absorbs much of the incoming wave energy and thus causes small wave up-rush heights (which are measured above the peak stillwater level). In contrast, steep foreshore slopes with structures (such as vertical walls) cause highest wave uprush heights as there is no mechanism to absorb the incoming wave energy.

1.2 Study Objectives and Scope of Work

Peak stillwater levels and winds are main driving hydro-climatic factors that cause lakeshore hazards at Slocan Lake and are the focus of this report. More importantly, the driving hydro-climatic factors could be influenced by climate change in the future. Knowing how much the driving factors change is required for floodplain mapping purposes. The scope of work in this report is therefore to characterize peak stillwater levels and wind characteristics and estimate lake levels and winds for return periods ranging from 2-yr to 500-yr conditions that are factored for climate change.

1.3 Vertical Datum

In this assignment the horizontal reference plane used is NAD83(CSRS)/UTM Zone 11N. The vertical datum used is the Canadian Geodetic Vertical Datum 2013 (CGVD2013). All levels, topographic and bathymetric surveys, maps, inundation boundaries, flood elevations and all other references are made to the above noted standard. This project uses SI units, with dimensions reported in meters (m), and discharges reported in meters cubed per second (m^3/s).

Other floodplain mapping studies in the area completed by RDCK consistently use the above referenced horizontal and vertical control, thus further warranting its use.

2.0 Background Review

This section documents previous studies that have characterized lake levels and/or winds at Slocan Lake, and form background reports for the present assignment. Research has identified two floodplain mapping studies for the Slocan River that are relevant. Each study is summarized below.

2.1 Floodplain Mapping Study, Slocan River (NHC, 1989)

As part of the original floodplain mapping study, NHC (1989) completed detailed hydrologic and hydraulic assessment of 56 km of the Slocan River. The same study includes an assessment of design lake levels for the southern portion of Slocan Lake (the headwaters of the Slocan River).

All hydrologic analyses of water levels were carried out by staff of the BC Ministry of Environment (MoE), Water Management Branch and were used in the 1989 floodplain mapping. The data used for frequency analyses included the available historic water level data.

The previous floodplain mapping assignment used a calibrated HEC-2 hydraulic model (best available at the time) to estimate water surface profiles along the Slocan River from its outlet to its headwaters at the Village of Slocan. Computed 200-yr discharge for Slocan River was imposed in the HEC-2 model, which allowed estimation of a water surface profile along the study reach (which included the lower portion of Slocan Lake). The computed water surface elevation at Slocan Lake were ultimately adopted and used in the 1989 floodplain mapping.

The NHC (1989) report also documents analyses of wind generated waves. Two different wind stations were used, including those at Castlegar Airport and at a BC Hydro dam near Castlegar. The report points out that winds are highly impacted by topography surrounding the lake, where the highest winds align with the long axis of the lake. Directional statistics were not provided, as it was assumed that winds will blow over the long axis of the lake. Estimates of wind magnitudes for 1-yr, 2-yr, 10-yr, and 20-yr were provided in the report.

Wave runup height were not estimated in the NHC (1989) work. The study authors note that wave runup depends not only on offshore wave characteristics, but on local factors such as foreshore slopes, surface treatment (grass, rock) and type of structure (grassed slope, riprap, wall). Rather than estimating a range of wave uprush heights for different local conditions, NHC (1989) opted to combine lake level and wave height to estimate a joint water surface elevation of the lake. This approach is rather unusual, and did not represent standard practice at the time.

Instead of assessing a range of wave uprush heights during high water levels, a comparison was made between the Slocan Lake backwater level computed using the HEC-2 hydraulic model, and the sum of lake level plus wave heights. NHC (1989) found that water level at Slocan Lake computed using the backwater calculation was higher compared to a sum of lake level and wave height, and for that reason used the computed backwater level for the lakeshore floodplain mapping (i.e., the river backwater dictates the lake level).

The NHC (1989) estimated the 200-yr water level as 538.55 m CGVD28, on top of which 0.6 m freeboard was applied to produce a Slocan Lake Flood Construction Level (FCL) of 539.2 m CGVD28. For comparison to current analysis, the NHC (1989) data can be converted to the current CGVD2013 datum by adding 0.28 m (as per National Resources of Canada published conversions), resulting in a 200-yr water level of 538.83 m CGVD2013, and an FCL of 539.48 m CGVD2013.

2.2 RDCK Floodplain and Steep Creek Study, Slocan River (BGC, 2020)

A floodplain mapping update study for Slocan River was completed by BGC (2020) which provides an update to the previous mapping work. The BGC (2020) study re-assessed hydrology of Slocan River and included a factor to account for future impact of climate change. Note that previous mapping work did not include a factor for climate change, as that was not typically included in studies from the 1980’s.

BGC (2020) used statistical and process-based methods to assess changes in peak streamflow characteristics resulting from climate change. The statistical modeling carried out showed a small decrease in the flood magnitude with climate change, while the process-based methods showed an increase. BGC (2020) reported that trend analysis on streamflow data produced inconclusive results. For the floodplain mapping work, BGC (2020) decided to increase flows in the Slocan River by 20% to account for uncertainty in climate change. A 20% increase in peak flows means that flows of 476 m^3/s (used in 1989) were increased to 575 m^3/s (used in 2020).

The above flows were used in hydraulic modeling of the Slocan River from its headwaters at Slocan Lake to its outlet at Kootenay River. The modeling was conducted using the HEC-RAS 2D hydraulic model (best available presently). Similar to the original mapping from 1989, Slocan Lake levels were estimated using backwater calculations using the hydraulic model. *Since higher flows were used compared to the previous work, the backwater calculation yielded a correspondingly higher water level for Slocan Lake*.

The BGC (2020) computed 200-yr water level at Slocan Lake was 539.58 m CGVD2013, to which a 0.6 m freeboard was added to produce a Slocan Lake FCL of 540.2 m CGVD2013 (which does not include wave runup). These results are much higher than those used previously.

Even though analysis of the hydrologic signal under climate change yielded inconclusive results for the Slocan River, a 20% increase in streamflow was used by BGC (2020) to account for future uncertainties in climate change. This assumption has direct consequences for the estimation of water levels in Slocan Lake.

Shoreline hazards for Slocan Lake were not mapped in BGC (2020), and wave runup was not included in their flood hazard assessment.

3.0 Historic Water Level Analyses

A search of historic data for Slocan Lake was carried out. This search identified that Water Survey of Canada HYDAT database is the only source where multi-decade high fidelity streamflow and water level data exists for the study area. Relevant data from HYDAT includes the streamflow gauge Slocan River at Slocan City (id 08NJ014, period 1916-1968), and a water level gauge Slocan Lake at Slocan City (id 08NJ137, period 1916-1968). Both sets include data on a daily time step. An inspection of the dataset identified that period between 1916-1944 had much of the record missing, and was thus discarded.

A non-profit organization named Living Lakes Canada has recently started collecting hydrometric data through its Columbia River Basin Water Monitoring Framework. As of this writing (October 2024), temperature and water level observations since 2022 are available at Slocan Lake (from the floating pier at New Denver). Living Lakes Canada data was not used, as its record was too short for use in frequency analysis.

3.1 Slocan Lake Water Levels

Water level data from the Slocan Lake at Slocan City gauge is shown in Figure 3-1, for the period from 1945-1968. The observed data suggests that lake levels vary seasonally by 1.5 m. During the freshet season (when the snowmelt generates runoff) data shows lake levels increase, and then lower to its normal range during the summer and fall. Note the missing period exists (shown as blanks in the record) in the late 1940’s and early 1950’s, and between 1964-1968. The HYDAT data, available in the CGVD28 vertical datum, was converted to CGVD2013 to align with current project requirements.

As the data has been collected on the daily interval, variations from short-term windstorms are not visible in the data record.

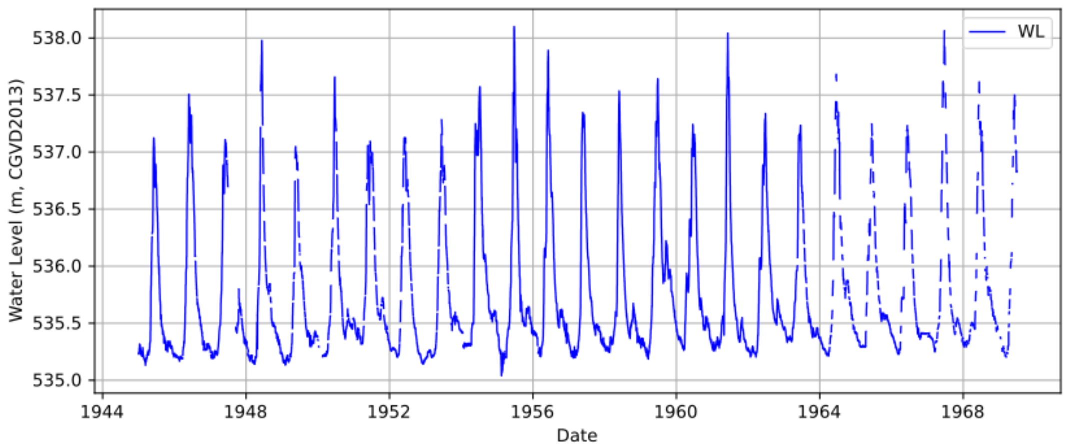


FIGURE 3-1: SLOCAN LAKE AT SLOCAN WATER LEVELS, 1945-1968

Statistical analyses of the historic lake level records were carried out. The historic record of water levels was used to extract annual maximum levels from the historic record. Next, the annual maximum levels were used to fit the data to several statistical distributions commonly used in hydrology. Outputs from such analyses identify a range of quantiles (ranging from 2-yr to 500-yr return periods). Table 3-1 shows results from the Generalized Extreme Value (GEV) statistical distribution, whose parameters were computed using the Method of L-Moments (L-MOM). The statistical fit is shown in Figure 3-2.

Adjusting the 200-yr peak daily water level to peak instantaneous water level requires addition of 0.1 m to the values in Table 3-1 (same as used in NHC, 1989).As such, the 200-yr peak instantaneous water level, based on the analysis of historical records, is 538.80 m CGVD2013.

TABLE 3-1: DAILY LAKE LEVEL CHARACTERISTICS AT SLOCAN CITY (1945-1968)

RETURN PERIOD [YRS]	DAILY WATER LEVEL [M CGVD2013] @ 08NJ137, GEV L-MOM	INST. WATER LEVEL [M CGVD2013] @ 08NJ137, GEV L-MOM
2	537.44	537.44
5	537.75	537.85
10	537.95	538.05
20	538.13	538.23
50	538.37	538.47
100	538.54	538.64
200	538.70	538.80
500	538.92	539.02

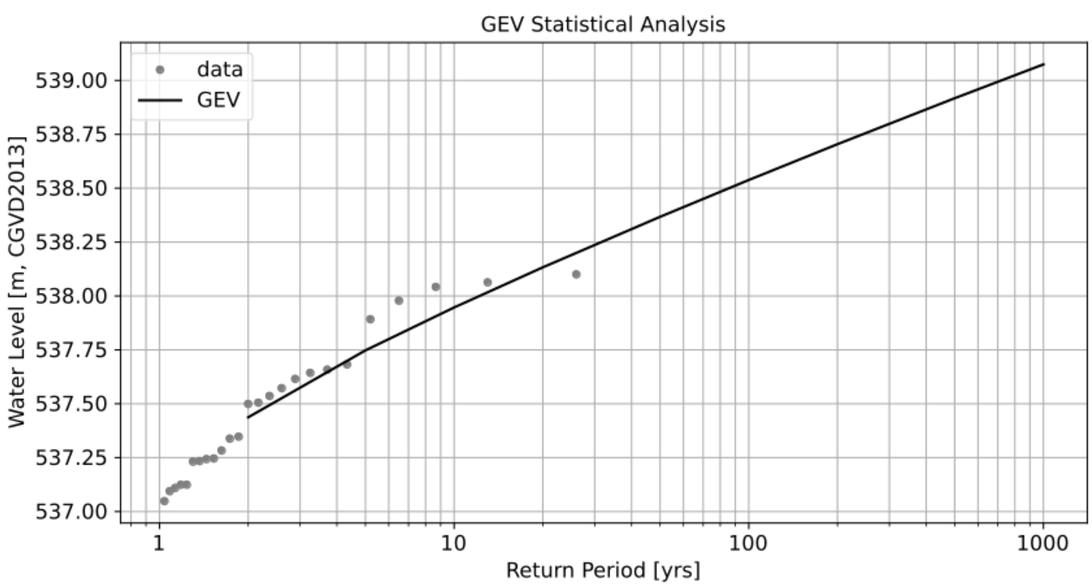


FIGURE 3-2: STATISTICAL FIT FOR DAILY LAKE LEVELS AT SLOCAN CITY (1945-1968)

4.0 Historic Wind Speed and Direction Analysis

Wind climate characteristics are necessary for the computation of waves on inland lakes. Local winds blowing over a fetch of open water of Slocan Lake will generate waves, which will propagate to the shoreline and induce wave effects (wave runup). The wave effects require quantification for the lakeshore floodplain mapping. This section presents the analyses of regional wind data, for the purposes of defining design wind speed and direction for use in lakeshore floodplain mapping.

4.1 Wind Observations

Several sources of wind records are investigated in this work (mostly at local airports). Each data source is described below.

4.1.1 BC Data Portal (PCIC)

The data portal hosted by Pacific Climate Impacts Consortium (PCIC) includes a toolset that allows access to British Columbia Meteorologic Station Data. The data from the portal includes measured data from various public and private sources, including federal and provincial departments, including:

- Environment Canada,
- BC Hydro,
- BC Ministry of the Environment and Climate Change Strategy,
- BC Ministry of Transportation and Infrastructure,
- BC Ministry of Forests, Lands, Natural Resources Operations and Rural Development, and
- BC Ministry of Agriculture.

Table 4-1 lists the two stations closest to the project site.

TABLE 4-1: BC DATA PORTAL STATIONS CLOSEST TO PROJECT SITE

STATION NAME	NETWORK NAME	NATIVE ID	LAT (DEG)	LON (DEG)	ELEV (MSL)	DATE RANGE
New Denver	FLNRO-WMB	936	117.3749W	49.984N	549	2006-05-26 to 2026-05-31
New Denver	MoTI	34101	117.35833W	49.995N	640	1976-2004

Statistical analyses require high fidelity wind records. The FLNRO-WMB gauge at New Denver has record length that spans less than one week and is thus not appropriate for statistical analyses. The MoTI gauge has a longer record but is located higher up the mountain side and is not representative (i.e., Slocan Lake is much lower in elevation than the gauge). Further, much of the wind record of the MoTI gauge is missing, and thus not appropriate for long-term statistics. Metadata and/or quality control of the wind data for the above two gauges is not available. For these reasons, the BC Data Portal data was not adopted in this work.

4.1.2 Canadian Weather Energy and Engineering Datasets (CWEEDS)

A high-fidelity data source from the Canadian Weather Energy and Engineering datasets (CWEEDS) is a collection of processed historic weather data by staff at Environment Canada and Climate Change. The CWEEDS dataset was last updated in July 2020 and includes files for a total of 564 stations at Canadian locations (with records extending up to the end of 2017). Various data is available through CWEEDS, of which the wind speed and direction were extracted for use in this work.

The CWEEDS database was used to extract hourly averaged wind speed and direction data for the stations in Castlegar (1954-2005), Nelson (1998-2017) as these stations are in relatively close proximity to Slocan Lake and would be expected to be influenced by similar topographic factors. The analyses that follow quantify wind characteristics that occur during the flood season only (using winds from the months of May, June, and July). This data filtering is necessary as the intention of the exercise is to estimate lake induced hazards during times when peak stillwater levels are highest (the freshet season). Using annual maximum winds is not appropriate for delineation of lakeshore flood hazards for systems where freshet flooding dominates, as over estimation of effects would result (and would be physically unrealistic). For example, combining winds from January would not be reasonable with peak water levels that occur between May to July. For this reason, wind data between May and July are retained and used in the remaining analyses in this work (as that is the period when freshet flooding typically occurs on Slocan Lake).

Wind data is shown graphically with wind rose plots, which show the percentage of wind blowing from each of the 16 cardinal wind directions. All wind data is plotted according to the nautical direction convention, where angles are measured clockwise from north (see Figure 4-1). Figures 4-2 and 4-3 show the wind rose plots for Castlegar and Nelson respectively (data filtered to include the freshet season only).

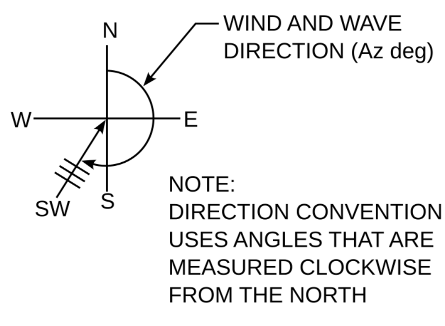


FIGURE 4-3: DEFINITION SKETCH OF THE NAUTICAL DIRECTION CONVENTION

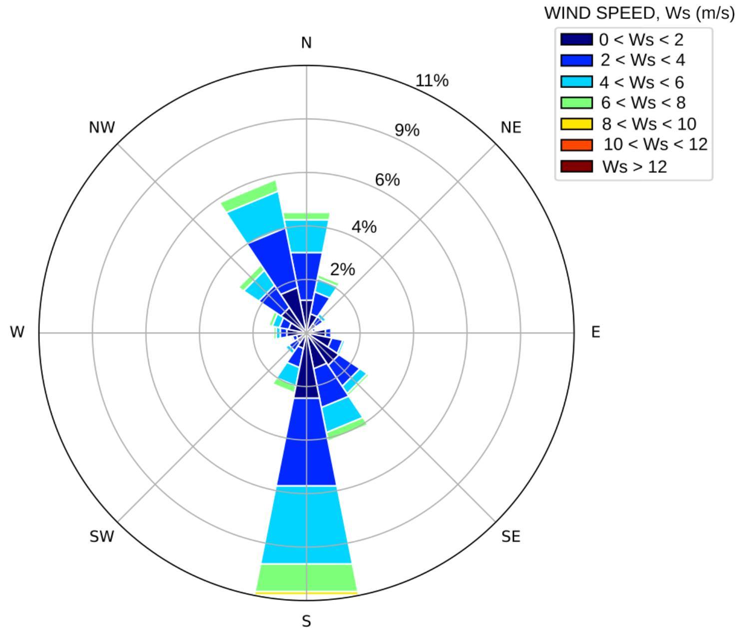


FIGURE 4-4: CWEEDS WIND ROSE AT CASTLEGAR (MAY-JULY, 1954-2005)

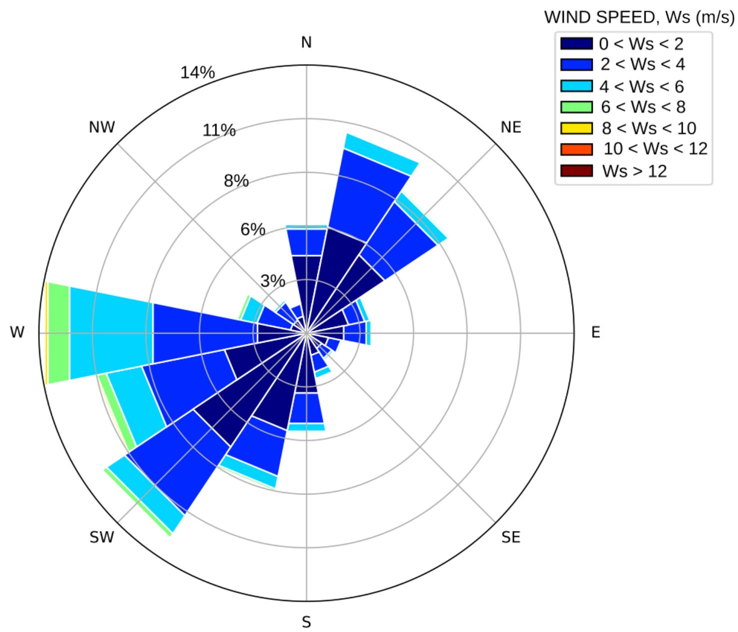


FIGURE 4-5: CWEEDS WIND ROSE AT NELSON (MAY-JULY, 1998-2017)

For the Castlegar wind rose data, it is readily apparent that dominant wind direction aligns with the open fetch of the Columbia River (north-south). Surrounding mountains funnel winds through the river valley, which is wind's path of lowest resistance.

The wind rose at Nelson likewise shows that the dominant wind direction aligns with the Kootenay River/Lake, where dominant winds generally blow along the longest fetch of open water. The mountains surrounding open water act to funnel the winds along the lake's long axis, thus generating maximum wave effects.

Castlegar observations of wind speed and direction span a longer period than the station at Nelson, and is relatively close to the project site. The Castlegar station is believed to be representative of regional wind conditions for Slocan Lake and is therefore selected for use in this project.

4.2 Wind Directional Statistics

Directional wind statistics are typically developed by extracting and analyzing hourly annual maximum wind speeds for each of the 16 cardinal directions. In this project, however, a different procedure was adopted as the intention was to seek appropriate wind speeds (and directions) to apply during times of flooding on the Slocan Lake. Analyses of flows and water level observations (see previous section) suggests that peak water levels at Slocan Lake occur during freshet season (May to July). For this work the historic CWEEDS data at Castlegar was therefore filtered to retain data only for months of May, June, and July. This is appropriate as only winds during the freshet season are to be applied on top of flood water levels at Slocan Lake to estimate wave effects.

The filtered CWEEDS hourly wind data was therefore analyzed using directional statistical analysis, where hourly observations were first separated into 16 cardinal directions. Then, extreme annual maximum wind speed was extracted from each cardinal direction and were fit using Gumbel statistical distribution (with parameters estimated using the Method of Moments). Results of the statistical analyses provided quantities for wind speed, for each direction, ranging from 2-yr to 200-yr. Results of the filtered Castlegar wind gauge are presented in Table 4-2

It is acknowledged that wave effects may be more extreme during non-freshet conditions, but would occur during periods of normal (i.e., non flood) water levels. Such conditions would be relevant for the design of shoreline protection, and/or planning, evaluation, and design of municipal infrastructure. However, as the subject of this assignment is lakeshore floodplain mapping, conditions that apply during the freshet season are considered.

For the estimation of the design wind for Slocan Lake, the Table 4-2 suggests that 200-yr return period wind speed for the period between May to July is in the 16.0 m/s range, factored for the maximum fetch (which for Castlegar is in the north-south direction).

TABLE 4-2: CASTLEGAR CWEEDS STATION DIRECTIONAL STATISTICS (1954-2017)

WIND DIR	WIND DIR	WIND SPEED [M/S] / RETURN PERIOD [YRS]						
[-]	[AZ DEG]	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
N	0	8.0	9.4	10.3	11.4	12.3	13.2	14.0
NNE	22.5	7.4	8.6	9.3	10.3	11.1	11.8	12.5
NE	45	6.0	7.7	8.9	10.3	11.4	12.5	13.6
ENE	67.5	4.3	5.9	6.9	8.3	9.2	10.2	11.2
E	90	4.8	6.9	8.3	10.1	11.5	12.8	14.1
ESE	112.5	5.9	7.7	8.9	10.4	11.5	12.6	13.7
SE	135	6.8	8.9	10.3	12.1	13.4	14.8	16.1
SSE	157.5	8.0	9.9	11.1	12.6	13.7	14.9	16.0
S	180	9.2	10.3	11.0	11.8	12.5	13.1	13.7
SSW	202.5	7.9	9.5	10.6	12.0	13.0	14.0	15.0
SW	225	6.2	8.3	9.6	11.4	12.7	14.0	15.3
WSW	247.5	5.2	6.9	8.1	9.5	10.5	11.6	12.6
W	270	6.8	9.7	11.6	14.0	15.7	17.5	19.3
WNW	292.5	7.2	9.4	10.9	12.7	14.0	15.4	16.7
NW	315	7.8	9.7	10.9	12.4	13.5	14.7	15.8
NNW	337.5	7.9	9.6	10.7	12.1	13.2	14.2	15.2

Using the Castlegar windrose (Figure 4-2) it is observed that dominant wind directions are from the north and from south. In selecting the design wind speed for use in this project, several wind directions were considered. When evaluating winds from the north, directions NNW, N, and NNE were considered (15.2 m/s as maximum). Likewise, when evaluating winds from the south, direction from SSE, S, and SSW were considered (16.0 m/s as maximum). The highest wind speed among the two was selected (16.0 m/s), and thus used in the analysis.

5.0 Climate Change Assessment

BC Provincial regulations require that floodplain mapping assignments consider climate change. This section presents a summary of the climate change assessment as it pertains to water levels and regional wind characteristics applicable to Slocan Lake. Climate is defined as a long-term pattern in weather that is averaged over a period of 30 years. To represent a climate (whether in temperature, precipitation, water level, wind or in riverine flow) a record of approximately 30 years is required from which characteristics are determined. The record can include measurements (from a gauge), or from synthetically generated quantities (from a computer simulation model).

5.1 Impact of Climate Change on Water Levels

To estimate changes to water levels at Slocan Lake, this work analyzes outputs from long-term hydrologic modeling. Pacific Climate Impacts Consortium (PCIC) developed a large scale gridded hydrologic simulation model named Variable Infiltration Capacity (VIC). The VIC model was discretized to roughly 30 km^2 grid cells on which simulations of streamflow were carried out. Input to the VIC hydrologic model included temperature and precipitation for 12 statistically downscaled Global Climate Model (GCM) projections, along with a baseline scenario. GCM projections were provided for two Representative Concentration Pathways (RCPs), namely RCP4.5 and RCP8.5 (six scenarios for each RCP). The RCP 8.5 scenario represents a high emissions scenario, with greenhouse gas concentrations in 2100 rising to nearly three times to what they are presently. The RCP 4.5 scenario represents an intermediate emissions trajectory in which policies are implemented to reduce anthropogenic greenhouse gas emissions, with the goal of stabilizing radiative forcing by year 2100.

The RCP8.5 scenario includes more intense hydrologic signal (for the size of watershed in the study area) compared to the RCP4.5.

Water levels in Slocan Lake are not available directly from the PCIC's hydrologic modeling; instead, modeling output includes streamflow at Slocan River at Crescent Valley (located downstream of Slocan Lake) and can be considered as a proxy indicator to Slocan Lake levels. If the flow in Slocan River changes because of climate change, so will Slocan Lake water levels.

A plot of the hydrographs (river discharge vs time) at Slocan River at Crescent Valley is shown in Figures 5-1, for a total of five 30-yr climate periods ranging from 1980's to 2100. A raster hydrograph plot (where each row shows a year's worth of flows, which are displayed as a heat map) is shown for the same gauge in Figure 5-1.

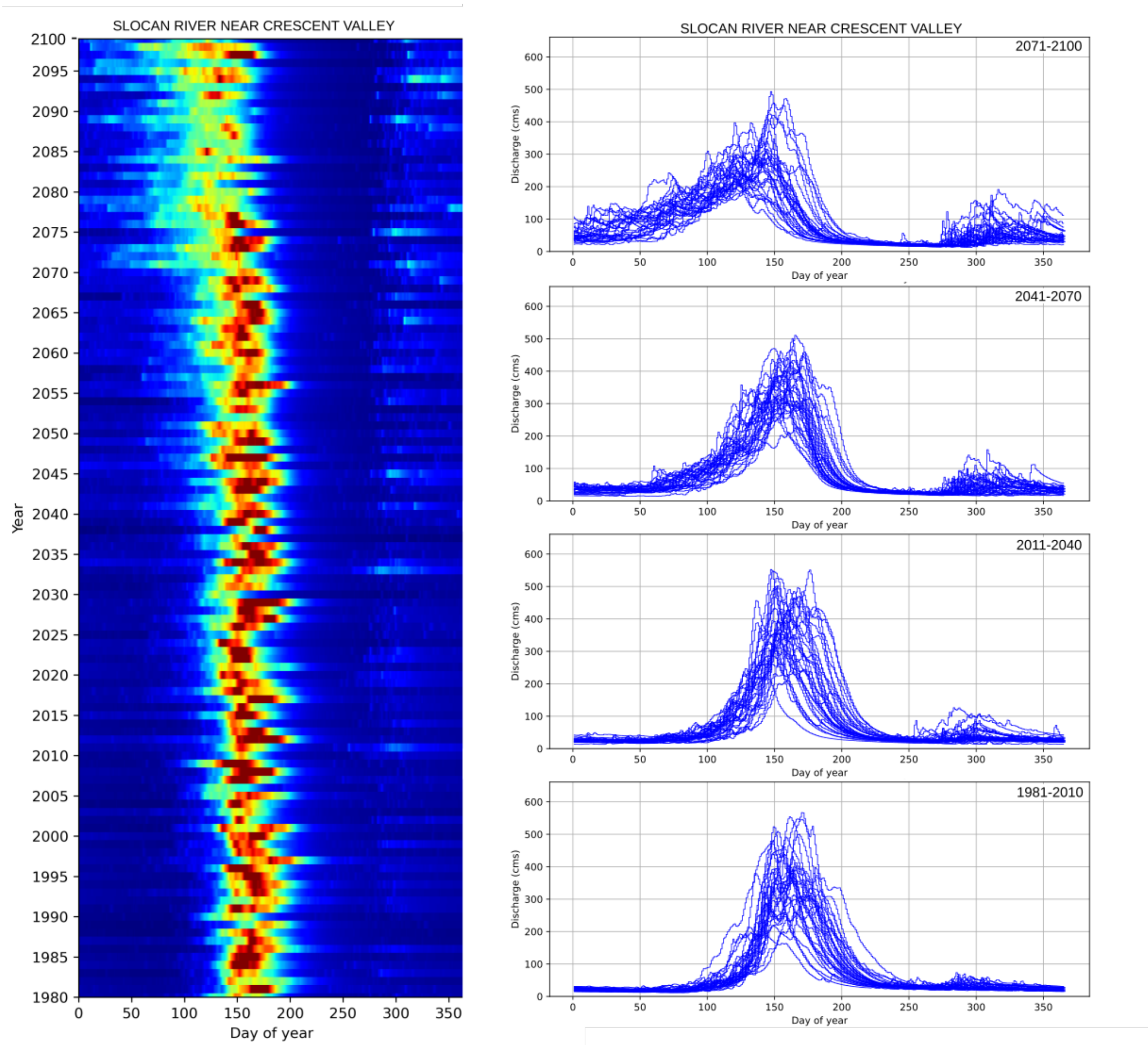


FIGURE 5-1: PCIC SIMULATIONS FOR SLOCAN RIVER AT CRESCENT VALLEY

TABLE 5-1: SLOCAN RIVER AT CRESCENT VALLEY SUMMARY, CANESM2 MODEL

	FRESHET ANNUAL MAX		
PERIOD [-]	Q200 DAILY [M³/S]	TIMING [DAY OF YEAR]	REGULARITY [DAYS]
1981-2010	614	162	13.0
2011-2040	586	156	11.9
2040-2070	610	151	12.0
2071-2100	550	137	13.2

The PCIC's hydrologic model output data was analyzed by extracting annual maximum peak flow for each year (for each climate period, scenario, and global climate model). A summary of the analyses is shown in Table 5-1, where 200-yr peak daily flows are shown for the four climate periods, along with timing (average day of year when peak freshet occurs) and regularity (the spread of the day of year when peak freshet occurs). The data suggests that peak freshet flows are not anticipated to increase as a result of climate change in the Slocan River. Further, the data also shows a trend that peak flows will generally occur earlier in the year (average day of year when peak flows occur will be almost a month earlier by the end of the century). The regularity (spread around the peak) is anticipated to stay roughly the same.

The above analysis and visuals demonstrate that peak freshet flows in the Slocan River (which also control levels in Slocan Lake) are not anticipated to increase in response to climate change. Visual inspection of the year-over-year hydrograph plots for different climate periods show that while winter flows will increase, they are not anticipated to have significant magnitudes to compared to peak freshet flows. In other words, the freshet conditions are anticipated to stay dominant up to year 2100.

The data, however also shows a glimpse of the start of a changing hydrologic regime where winter flows increase. Such behaviour stems from the decline in the snowpack, along with a shift in timing of the freshet (which is expected to occur some weeks earlier compared to present conditions).

A finding that peak flows are not anticipated to increase was also made in BGC (2020) in the floodplain mapping update for Slocan River, where the study authors noted that changes in peak freshet flows were not detected in the hydrologic signal investigated.

Although winter rainfall is anticipated to increase in the region, it is not a driving factor that is responsible for generating flows at Slocan River at Crescent Valley (which has a drainage area of 3300 km^2). For such large catchments, the melt of the snowpack is the dominant mechanism that causes flooding, and this will remain in the future. Changes to high-intensity short-duration rainfall are extremely relevant to smaller catchments in the region (up to a few hundred squared kilometers in size) and will be responsible for changes to peak flows resulting from climate change. Flow frequency analysis reports for Carpenter Creek in New Denver, and Silverton Creek in Silverton, also prepared as part of this floodplain mapping assignment, document changes to flow characteristics from changes to the rainfall signal.

5.2 Impact of Climate Change on Wind Speeds

Climate change is anticipated to alter global weather patterns, which may alter regional winds in the future. How future climate change will alter wind patterns is unknown at the present time. A study by Ausenco-Sandwell (BC MoE, 2011) analyzed local weather and wave data against a calibrated global and regional atmospheric-oceanographic model and found no significant changes to wind for coastal waters in BC.

To the best knowledge of the authors of this work, there is no presently available studies (or precedent in BC) that would justify increasing or decreasing design wind speeds to account for climate change. Therefore, no changes to the wind forcing have been applied in this work.

As more information on impacts of climate change on regional wind patterns becomes available, the above statement may need to be revised and/or updated in the future.

5.3 Design Parameters for Floodplain Mapping Assessment

5.3.1 Water Levels for Slocan Lake

Climate change analysis using PCIC's hydrologic model output at Slocan River at Crescent Valley was used as a proxy gauge to assess water levels in Slocan Lake in the future. Analyses of the long-term hydrologic signal obtained from modeling data suggests that peak flows at Slocan River at Crescent Valley are not anticipated to increase with climate change. Since flow in Slocan River determines water levels in Slocan Lake, a conclusion is drawn that water levels characteristics at Slocan Lake will remain unchanged in the future.

For the purposes of lakeshore floodplain mapping at Slocan Lake, it is recommended that 200-yr peak water level of 538.8 m CGVD2013 be used (daily 200-yr level statistic adjusted to instantaneous level), described in Section 3.1.

5.3.2 Wind Speed and Directional

Based on the wind rose plots and above analyses, it is recommended that a 200-yr wind speed of 16.0 m/s (taken as the 200-yr wind speed during the freshet) be applied during the 200-yr peak stillwater level at Slocan Lake. The design direction for the noted wind speed is taken as the long axis of Slocan Lake. The same speed is to be applied for winds blowing from the north, and south directions, depending on the maximum exposure.

6.0 Summary of Findings

The focus of this document is to characterize water levels at Slocan Lake and regional wind speeds (and factoring each for climate change). This characterization is made to facilitate lakeshore floodplain mapping for the communities of New Denver and Silverton. As both communities are close together and share the same lake and regional wind characteristics, a single report is prepared.

The findings in this report are based on analyses, assessment, and interpretation of:

- Historic water level and streamflow records of Slocan Lake at Slocan City from Water Survey of Canada's HYDAT database,
- Historic wind speed and direction records at Castlegar from Environment Canada and Climate Change CWEEDS database, and
- Long-term hydrologic model outputs from Pacific Climate Impacts Consortium VIC hydrologic model output of Slocan River at Crescent Valley.

The main study findings are the following:

1. Two previous floodplain mapping studies are available for the Slocan River between its headwaters at Slocan Lake and its outlet at the Kootenay River. The original study was carried out by NHC (1989), while the recent updates were completed by BGC (2020).
2. The BGC (2020) study analyzed changes to the hydrologic signal of the Slocan River from climate change but did not find evidence of increases to peak streamflow using two different methodologies. For the purposes of updating floodplain mapping BGC (2020) increased 200-yr peak flows in Slocan River by 20% to account for uncertainties from climate change.
3. Given that Slocan Lake water levels are directly related to flows in Slocan River, the 20% increase in flows used by BGC (2020) resulted in an increase of the computed water level at Slocan Lake.
4. The 200-yr lake level at Slocan Lake reported by BGC (2020) is 539.56 m CGVD2013 and is higher the 200-yr water level of 538.83 m CGVD2013 identified in NHC (1989).
5. Analysis of the historic water levels demonstrates that 200-yr instantaneous lake level in Slocan Lake is 538.8 m CGVD2013 (nearly identical to value reported by NHC, 1989).
6. Analyses of wind speed and directions for various climate stations surrounding water bodies in Kootenay region were carried out. It was identified that regional wind climate is heavily influenced by the surrounding terrain, where mountains on all sides of a water body act as a funnel and lead local increases in wind speed. This was confirmed with data at Castlegar and Nelson.
7. For lakeshore flood hazard identification and floodplain mapping, winds occurring during the freshet season (May to July) were extracted from the observed record and used in directional statistical analysis.

8. Wind data for the Castlegar station is selected for use in this study, as it included a high fidelity record that spans decades. 200-yr freshet season wind speed of 16.0 m/s was identified for use in estimation of wave related hazards during the freshet season.
9. Impact of climate change of water levels of Slocan Lake were assessed using PCIC's hydrologic model output at Slocan River at Crescent Valley. The analyses carried out confirm that peak flows in Slocan River are not anticipated to increase because of climate change.
10. The above finding implies that Slocan Lake levels are likewise not anticipated to increase because of climate change. 200-yr design lake level of 538.8 m CGVD2013 is recommended to be used in lakeshore floodplain mapping and represents lake level that is climate adjusted (but where the adjustment factor is 1.0).
11. Lakeshore flood hazards are to be characterized for the 200-yr climate adjusted design condition. The design condition includes winds having a magnitude of 16.0 m/s (and blowing over the long axis of the lake), in combination of Slocan Lake water level 538.8 m CGVD2013.

7.0 References

BGC (2020). RDCK Floodplain and Steep Creek Study, Slocan River. Report prepared by BGC Engineering Inc. on behalf of the Regional District of Central Kootenay, Vancouver, BC, March 2020.

NHC (1989). Floodplain Mapping Study, Slocan River. Report prepared by Northwest Hydraulic Consultants Ltd. on behalf of the Ministry of Environment, Province of British Columbia, BC, February 1989.

BC MoE (2011a). Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use - Draft Policy Discussion Paper (Project No. 143111 Rev. 0). Report prepared by Ausenco-Sandwell for BC Ministry of Environment (BC MoE). 45 pp.

APPENDIX C

Geomorphological Assessment of Carpenter Creek Fan Hazards

Geomorphological Assessment of Carpenter Creek Fan Hazards

Village of New Denver, British Columbia

TRUE Consulting

2089 Falcon Road,
Kamloops, BC
V2C 4JC

Prepared by:

SLR Consulting (Canada) Ltd.

200 - 887 Great Northern Way, Vancouver, BC, Canada V5T 4T5

SLR Project No.: 233.V24454.00000

Client Reference No: 1479-111

February 13, 2025

Revision: A

Revision Record

Revision	Date	Prepared By	Checked & Authorized By
A	February 13, 2025	Michael Brierley and Robin McKillop	Roberta Adams

Statement of Limitations

This report has been prepared by SLR Consulting (Canada) Ltd. (SLR) for TRUE Consulting Limited (Client) in accordance with the scope of work and all other terms and conditions of the agreement between such parties. SLR acknowledges and agrees that the Client may provide this report to government agencies, interest holders, and/or Indigenous communities as part of project planning or regulatory approval processes. Copying or distribution of this report, in whole or in part, for any other purpose other than as aforementioned is not permitted without the prior written consent of SLR.

Any findings, conclusions, recommendations, or designs provided in this report are based on conditions and criteria that existed at the time work was completed and the assumptions and qualifications set forth herein.

This report may contain data or information provided by third party sources on which SLR is entitled to rely without verification and SLR does not warrant the accuracy of any such data or information.

Nothing in this report constitutes a legal opinion nor does SLR make any representation as to compliance with any laws, rules, regulations, or policies established by federal, provincial territorial, or local government bodies, other than as specifically set forth in this report. Revisions to legislative or regulatory standards referred to in this report may be expected over time and, as a result, modifications to the findings, conclusions, or recommendations may be necessary.

Executive Summary

A geomorphological assessment of steep creek processes and associated hazards has been completed for the fan at the mouth of Carpenter Creek, in New Denver, British Columbia. Carpenter Creek and its two major tributaries, Kane Creek and Seaton Creek, drain a mountainous watershed rimmed by alpine peaks above Slocan Lake. Consideration was given to processes including clearwater floods, debris floods, debris flows, bank erosion and avulsions. In clearwater (regular) floods, sediment comprises less than 20% of the discharge by weight (Wilford et al., 2004). Debris floods are a channelized flood of sediment-laden water, where sediment concentrations can range from 20-47% by volume (Wilford et al., 2004). Debris flows are rapid, high-density mass movements of saturated debris that can have peak discharges up to 40 times greater than clearwater floods (Hunger er al., 2001). This assessment is part of a larger flood hazard mapping project led by TRUE Consulting (2025).

Findings from desktop study and field reconnaissance informed understanding of the nature and extent of exposure of New Denver to steep creek processes. Historical aerial photography, recent satellite imagery and LiDAR data available for the watershed enabled review of the types and distribution of key sediment sources, extraction of longitudinal profiles and identification of pertinent slope-breaks, mapping of landforms providing insight into fan evolution, comparative analysis of channel planforms over time, calculation of watershed morphometrics, and assessment of in-stream sediment mobility along lowermost Carpenter Creek. One day of field work on May 14, 2024, provided an opportunity to 'ground truth' desktop-based interpretations, examine natural and anthropogenic exposures of sediments comprising the fan and its confining slopes, characterize bed and bank material, and determine the extent of riprap protection of flood/erosion control dikes.

A synthesis of findings indicates that lowermost Carpenter Creek exhibits a wandering to braided, gravel-bed channel that is susceptible to clearwater floods and debris floods, largely in association with widespread mobilization of the bed and/or rapid erosion of confining glaciofluvial and till scarps. There is no evidence of debris flows directly affecting lowermost Carpenter Creek or the adjacent community of New Denver. Outburst floods from natural dams formed by beavers or small landslides are also possible, but there is no evidence of such past events. Land adjacent to lowermost Carpenter Creek is also susceptible to bank erosion, as demonstrated by migration of channel positions over time and repeated efforts to repair a riprapped dike immediately upstream of the Union Street bridge. Although unlikely, an avulsion could occur during a major flood in response to at least partial obstruction of the channel or bridge opening by sediment and/or woody debris. The potential for an avulsion to affect a portion of the contemporary fan decreases away from the active channel.

A bulking value of 0.1 is best applied to modelling of clearwater floods along lower Carpenter Creek, based on the types and distribution of opportunities for sediment recruitment and regional analyses by BGC Engineering Inc. (2020) and Church and Jakob (2020). As a means of managing risks associated with steep creek processes, recommendations are made to regularly update topographic/bathymetric surveys and modelling on which flood hazard limits are based, periodically inspect watershed conditions to identify any new impoundments or instabilities alongside the channels, and undertake sensitivity analyses of avulsion potential and pathways.

Table of Contents

Statement of Limitations ii
Executive Summary iii
Table of Contents iv
Acronyms and Abbreviations viii
1.0 Introduction 1
1.1 Objectives 1
2.0 Study Area 1
2.1 Physiography 3
2.2 Quaternary History and Surficial Geology 4
2.3 Flooding History 4
3.0 Methods 4
3.1 Background Review 5
3.2 Watershed Review 5
3.3 Mapping of Fan Geomorphology 6
3.4 Historical Planform Assessment 6
3.5 Longitudinal Profiles 7
3.6 Field Reconnaissance 7
3.7 In-stream Sediment Mobility 8
4.0 Results 9
4.1 Watershed Characterization, Sediment Sources and Implications for Flooding 9
4.1.1 Outburst Flood Potential 15
4.2 Evolution of the Carpenter Creek Fan Complex 16
4.3 Morphology and Dynamics of the Contemporary Channel Corridor of Lowermost Carpenter Creek 19
4.3.1 Channel Morphology 19
4.3.2 Historical Planform Changes 23
4.3.3 In-stream Sediment Mobility 27
5.0 Discussion 28
5.1 Implications for Flood-related Hazards in New Denver 28
5.1.1 Flood Process Considerations 28
5.1.2 Bed and/or Bank Erosion 29
5.1.3 Rapid Sedimentation and Avulsion 31
5.2 Recommendations 32

6.0 Summary **33**
7.0 Closure **34**
8.0 References **35**

Tables in Text

Table 1: Aerial and satellite imagery utilized for the historical planform assessment 7

Table 2: Grain sizes used for the sediment transport assessment and their associated critical shear stresses along lowermost Carpenter Creek... 8

Table 3: Watershed morphometrics for Carpenter Creek and its two major tributaries...........11

Table 4: Modelled shear stresses for lowermost Carpenter Creek for the estimated 2-year return flow (m^3/s) and 200-year return flow (m^3/s) 28

Figures in Text

Figure 1: Study area location and key features 2

Figure 2: Longitudinal Profiles of Carpenter Creek and its two major tributaries, extracted from 20 m contours along the 1:20,000-scale BC freshwater Atlas stream linework. Note that gradients upstream and downstream of the Three Forks remain similar (approx. 3.4%). 10

Figure 3: Distribution of dominant flood types based on watershed morphometrics (adapted from Church and Jakob, 2020). In this case, the term “floods” is specific to “clearwater floods.” The plotted positions of Carpenter Creek (CU: upper; CL: lower), Seaton Creek (S) and Kane Creek (K) indicate a propensity for clearwater floods and debris floods. 12

Figure 4: Examples of the dominant types of sediment sources to lower Carpenter Creek. A) Incised colluvial fan with eroded toe, about 1.5 km upstream of Sandon. B) Partially revegetated road embankment failure, about 3 km upstream of the Three Forks. C) Ravelling glaciofluvial terrace scarp about 0.7 km upstream of the Union Street bridge. D) Sloughing cut-bank into till about 0.4 km upstream of the Three Forks....14

Figure 5: Geomorphology and evolution of the Carpenter Creek fan complex 18

Figure 6: Longitudinal profile of lowermost Carpenter Creek (~water surface), derived from TRUE’s ground-based survey data with blended LiDAR data (2018). Note the relative uniformity of the channel gradient, until the widening near the creek mouth. Sediment

mobility analysis was completed based on two cross-sections (vertical red lines) and corresponding pebble counts (PC-1 and PC-2)...21

Figure 7: Grain size distribution of bed material along lowermost Carpenter Creek. PC-1 is near the creek mouth; PC-2 is immediately upstream of the Bridge. Bed material slightly fines downstream..21

Figure 8: Historical channel planforms of lowermost Carpenter Creek 24

Figure 9: Historical positions of Carpenter Creek fan front 25

Figure 10: Comparison of historical imagery at the Bridge from 1981 (first available image following dike construction) to 2023. The channel thalweg has shifted northward to the dike, where it has remained in contact for approximately 40 years.....................26

Figure 11: Generalized zones of relative avulsion potential on the contemporary fan of Carpenter Creek (south of the active channel corridor), based on consideration of potential initiation mechanisms, effects of existing dikes, and surface topography. Dashed black lines depict extent of flood/erosion mitigation dikes. Base image: Hillshaded 2018 LiDAR (GeoBC) with 1 m contours. 32

Photos in Text

Photo 1: Oblique aerial view of New Denver and the fan complex on which it is situated at the mouth of Carpenter Creek (photo credit: J. Roberts).. 3

Photo 2: Typical exposure (~1.2 m high) of clast-supported, rounded gravels and cobbles comprising the contemporary fan of Carpenter Creek. Such materials indicate deposition primarily from clearwater floods. 13

Photo 3: Upstream view of eroding scarp of remnant glaciofluvial (fan) terrace along the southern bank of lower Carpenter Creek, about 0.7 km upstream of the Bridge. 19

Photo 4: Upstream view from the Bridge at a sinuous, single-thread planform Carpenter Creek (left). Upstream view of a multi-thread planform of Carpenter Creek near its mouth (right)...20

Photo 5: Overview of bed material (gravels and cobbles) at the edge of an active bar upstream of the Bridge (left; PC-2; note 60 cm steel folding rule for scale) and near the mouth of Carpenter Creek (right; PC-1). Note the slightly greater proportion of sand and pebbles nearer the mouth. 22

Photo 6: Upstream view of large wood jam opposite the recently repaired section of dike upstream of the Bridge (left) and downstream view of mid-channel jam downstream of the Bridge that is bifurcating flow (right). 22

Photo 7: Recently placed rip-rap following scour during the 2020 flood (orangey tan colour). Rip-rap repaired upstream of the bridge (left, upstream view) has larger material (up to 1,200 mm), whereas the downstream portion (right, downstream view) has smaller material (up to 400 mm). The smaller material has a higher chance to be displaced based on the sediment mobility analysis. 30

Photo 8: Northeast view along the upstream portion of the dike protecting the Bridge, looking toward the intersection of Slocan Avenue and Columbia Street. Note this section of dike, although locally set back from the active channel, is constructed of erodible, cobbly fan deposits. 30

Acronyms and Abbreviations

°C	degrees Celsius
cm	centimetre
D	grain size diameter
DEM	digital elevation model
g	gravitational acceleration
kg/m^3	kilogram per cubic metre
km	kilometre
km^2	square kilometers
m	metre
m^2	square metre
m asl	metres above sea level
mm	millimetre
m/s	metres per second
m/s^2	metres per squared seconds
m^3/s	cubic metres per second
Mt.	Mount
ρ	water density
ρ_s	sediment density
SLR	SLR Consulting (Canada) Ltd.
TRUE	TRUE Consulting Ltd.
τ_c^*	dimensionless shear stress

1.0 Introduction

Palmer, recently acquired by SLR Consulting (Canada) Ltd. (hereafter "SLR"), is pleased to provide TRUE Consulting (TRUE) on behalf of the Village of New Denver (New Denver), with the results of our geomorphological assessment of steep creek processes and associated hazards with the potential to affect people, property and/or infrastructure in New Denver, British Columbia. Steep creek processes include clearwater floods[1], debris floods and debris flows, each of which is defined in Section 3.2, as well as bank erosion and avulsions. New Denver is situated on an alluvial fan at the mouth of Carpenter Creek, which drains a mountainous watershed. The assessment, completed as part of a larger flood hazard mapping project led by TRUE (2024), considers the potential implications of geomorphological processes on and upstream of the fan.

This report provides an overview of project objectives (Section 1.1) and study area characteristics (Section 2.0), outlines our desktop and field methods (Section 3.0), describes the results (Section 4.0), discusses the implications and a few recommendations (Section 5.0), and concludes with a brief summary (Section 6.0).

1.1 Objectives

The overall objective of this geomorphological assessment is to improve understanding of the flood-related geomorphological processes to which people, property and/or infrastructure on the Carpenter Creek fan may be exposed and to ensure that flood hazard mapping completed by TRUE considers these processes. Achievement of these objectives involved the completion of several main tasks:

- Characterization of the Carpenter Creek watershed, including its morphometrics and key sources of sediment to Carpenter Creek and its tributaries;
- Evaluation of the evolution of the fan complex at the mouth of Carpenter Creek, based on interpretation of surficial geology and landforms, historical trends in channel and fan-front position, and documentation in previous reports; and
- Assessment of the longitudinal profiles and in-stream sediment mobility of Carpenter Creek, especially along its lowermost reaches, and the associated implications for erosion, transport and deposition of sediment and woody debris during floods.

2.0 Study Area

The study area is focused on the community of New Denver, in the broader context of the surrounding 204.5 km^2 Carpenter Creek watershed, in the West Kootenays of British Columbia (**Figure 1**). New Denver is situated on a fan complex at the mouth of Carpenter Creek (**Photo 1**). Much of the Carpenter Creek watershed is drained by three prominent creek valleys that join at a triple confluence known as the "Three Forks," about 5 km upstream of the apex of the Carpenter Creek fan on which New Denver is situated. Kane Creek is the northern branch, Seaton Creek is the middle branch, and Carpenter Creek is the southern branch. The sections of Carpenter Creek upstream and downstream of the Three Forks are hereinafter referred to as "upper Carpenter Creek" and "lower Carpenter Creek," respectively. The term, "lowermost Carpenter Creek," is more specifically used to refer to the section of Carpenter Creek that descends the fan complex at its mouth.

[1] The term "clearwater flood" is only used in this report in place of the more general "flood," in accordance with definitions in Section 3.2, where a specific distinction is necessary.

CLIENT
TRUE Consulting

PROJECT
New Denver Fan Hazards

TITLE
Study Area Location and Key Features

Palmer. PART OF SLR

REF. NO. 2304301-1-2

Figure 1

Document Path: G:\Shared drives\Projects 2023\23085 - TRUE Consulting\2308501 - Silverton and New Denver Fan Hazards\GIS\1_Workspace\Task 6 - SG and Study Area Figure\2308501 SG Figure.aprx

Photo 1: Oblique aerial view of New Denver and the fan complex on which it is situated at the mouth of Carpenter Creek (photo credit: J. Roberts).

2.1 Physiography

The Carpenter Creek watershed is mountainous, with a dendritic drainage pattern eroded deeply into metamorphosed shale and sandstone bedrock comprising much of the Selkirk Mountains (Turner et al., 2009). Alpine peaks and steep slopes prone to snow avalanches and debris slides and flows occupy the headwaters. Carpenter Creek and its two major tributaries exhibit V- to U-shaped valleys. Elevations range from 2,798 m above sea level (m asl) at the summit of Mt. Dryden to 537 m asl at the mouth of Carpenter Creek, along the eastern shore of Slocan Lake. The community of New Denver extends from the shoreline of Slocan Lake up to approximately 610 m asl on an ancient portion of the fan at the mouth of Carpenter Creek (Section 4.2).

Climate within the study area is continental, with cool winters and hot, dry summers. At nearby Nakusp, average July temperatures were 20.0°C and average January temperatures were - 1.7°C, between 1991 and 2020 (Climate Normals, Environment and Climate Change Canada). Annual precipitation is approximately 705 mm, which falls as rain and snow. Rain-on-snow events, in spring, are responsible for some of the most significant flooding (Section 2.3). Most lower- to mid-elevation slopes in the watershed are covered by mixed coniferous forests, except where interrupted by shrubby vegetation along avalanche paths.

2.2 Quaternary History and Surficial Geology

The study area was subjected to the most recent Wisconsinan glaciation, beneath glacial ice of the Cordilleran Ice Sheet, which reached its maximum extent about 14,500 years BP (Ryder et al., 1991). Till was deposited beneath the ice on most gentle to moderate slopes, deeply along some valley bottoms. Deglaciation of the region occurred mainly through thinning and downwasting. The first areas to become ice-free were the highest uplands as the ice margin moved to lower elevations in valleys (Clague and Ward, 2011). Continued ablation stranded glacial ice within valleys, where it could no longer flow, and led to the formation of ice-stagnation features (e.g., glaciofluvial fans). South-flowing glaciers carved deep ‘U’ shaped troughs, which now hold Kootenay, Arrow and Slocan Lakes. Remnant ice blocking drainages resulted in lake levels approximately 150 m higher than present, and the deposition of silts and clays preserved in isolated terraces near the lake shores (BGC Engineering Inc., 2020). Colluvial and fluvial erosion reworked glacial sediments and deposited them along, and at the mouths of, stream valleys during an early Holocene paraglacial period (Church and Ryder, 1972). Colluvium is now the most extensive surficial material in the watershed (Clover Point Cartographics, 1980).

Anthropogenic disturbance in the watershed is modest, relative to its size, largely from forestry activities, mineral exploration and silver mining along upper Carpenter Creek. Roads constructed for forest harvesting and for exploration in some of the alpine basins switchback up the steep mountainsides. In New Denver itself, riprapped dikes/embankments constructed to help control flooding and erosion (hereafter referred to as “dikes”) directs high flows beneath a single bridge crossing of Union Street (hereafter referred to as “the Bridge”).

2.3 Flooding History

New Denver’s susceptibility to, and history of, flooding spurred this study. Floods generated by spring snowmelt (freshet), particularly when combined with intense or prolonged rainfall, are responsible for the largest discharges (TRUE, 2024). Atmospheric rivers in the fall are increasingly recognized as a source of floods. Routing of flood water from surface runoff in the watershed is rapid due to the predominance of moderate to steep slopes with relatively thin surficial materials overlying bedrock.

Floods also typically involve considerable erosion, transport and deposition of sediment and woody debris, which have affected portions of the community. Notable floods occurred in 1973, 2013, 2017, and 2020, resulting in erosion of a dike along Carpenter Creek and reworking of alluvial deposits (WSA Engineering, 2012; SNT Geotechnical Ltd, 2020; 2022a, 2022b). Changes to climatic conditions, such as an increase in temperature, precipitation, and/or snowpack, could result in an increase in flooding and flood frequency in the region (Climate Change Adaptation Program, 2024).

The lowest elevations of New Denver may also be susceptible to flooding and erosion along the shoreline of Slocan Lake.

3.0 Methods

SLR applied a systematic desktop and field-based approach for assessing geomorphological processes and associated hazards potentially affecting the Carpenter Creek fan on which New Denver is located. The following subsections outline the main tasks completed in support of the assessment.

3.1 Background Review

SLR compiled and reviewed a variety of background information pertinent to understanding the geomorphology of the study area and the potential flood-related hazards associated with Carpenter Creek and its alluvial fan. High-resolution LiDAR from 2018 was available from GeoBC (western portion of watershed), various years of historical aerial photography from 1939 to 1998 was provided by the UBC Geographic Information Centre (entire watershed), and satellite imagery from Esri World Imagery for the years 2014 to 2022 was viewed in GIS software (entire watershed). Key reports, including geotechnical assessments and hydrological studies, were reviewed and referenced where applicable in this report. Terrain stability mapping (1:20,000-scale; Surewood Forest Consultants Ltd., 2000) was available for a portion of the watershed, within the broader context of terrain mapping coverage (1:50,000; Clover Point Cartographics, 1980). Only regional-scale (1:1,000,000) surficial geology mapping was available for the study area (Fulton et al., 1984). The flood hazard studies completed by WSA Engineering Ltd. (2017) and by BGC Engineering Inc. (2019), for the entire Regional District of Central Kootenay, provided important context on flood hazards and history within New Denver.

3.2 Watershed Review

A desktop-based review of the Carpenter Creek watershed was completed to gain an understanding of its geomorphology and identify the primary sources of sediment to Carpenter Creek, given their potential influence on observed and potential dynamics of the fan on which New Denver is situated. LiDAR data (2018), historical aerial photography 1939 to 1998 (Section 3.1), and recent satellite imagery (2014 to 2022, Section 3.1) were systematically examined. The distribution and main types (e.g., prominent debris flow gullies, persistent slumps, undercut terrace scarps) of sediment sources actively contributing sediment to Carpenter Creek were noted.

A preliminary understanding of the propensity for one or more types of flooding along Kane Creek, Seaton Creek and lowermost Carpenter Creek was gained through calculation of the Melton (1957) ratios for their respective catchments. The Melton ratio provides a measure of catchment ruggedness and is defined as the watershed relief in kilometres divided by the square root of watershed area in kilometres (Melton, 1957; Wilford et al., 2004). The Melton ratio provides an indication of whether clearwater floods, debris floods or debris flows, as defined below, are likely dominant within a particular watershed:

- **Clearwater flood** – An extreme hydrologic event where sediment comprises less than 20% of the discharge by weight (Wilford et al., 2004). These events are commonly caused by moderate to heavy or prolonged rainfall, melting snow, or a combination of the two. As noted above, the distinction of “clearwater flood” is only made in this report from the broader term, “flood,” where necessary.
- **Debris flood** – A channelized flood of sediment-laden water, where sediment concentration can range from 20-47% by volume (Wilford et al., 2004). Peak discharges of debris floods can be twice that of clearwater floods within the same hydrologic setting (Hungr et al., 2001). Debris floods are not considered a type of landslide.
- **Debris flow** – A rapid, high-density mass movement of saturated debris. Debris flows are channelized events, typically within steep gullies, channels, or established flow paths (Hungr et al., 2013). A debris flow may initiate once a debris slide or rockslide on an open slope becomes channelized in a gully, for example, and enlarges through entrainment of surficial material, organic debris and water. Debris flows are commonly triggered by intense or prolonged precipitation and can have peak discharges up to 40 times

greater than those of clearwater floods within the same hydrologic setting (Hungr et al., 2001). Debris flows may transition to debris floods through addition of water in tributaries (Wilford et al., 2009).

3.3 Mapping of Fan Geomorphology

Detailed mapping of the geomorphology of the Carpenter Creek fan complex was prepared to help document how its evolution influences, and limits the extent of, flood-related hazards to which New Denver is currently exposed. Mapping of surficial materials and surface expressions was completed based on the interpretation of available aerial/satellite imagery (**Table 1**) and a digital elevation model (DEM) blending TRUE's ground-based topographic survey of the main channel (October 2023) with the 2018 LiDAR data. Interpretations were aided by a historical planform assessment, described in Section 3.4. The mapping was completed in ArcMap at a scale of 1:5,000 in general accordance with the *Terrain Classification System for British Columbia* (Howes and Kenk, 1997). The focus was differentiation of fluvial (active and inactive) and glaciofluvial landforms comprising the Carpenter Creek fan complex.

3.4 Historical Planform Assessment

In order to strengthen our understanding of the locations, mechanisms, and implications of planimetric changes along lowermost Carpenter Creek, a systematic comparative overlay was completed using aerial photographs from 1939, 1951, 1966, 1981, 1990, and 1997; Esri World Imagery satellite imagery from 2014, 2017, and 2022; and 2021 and 2023 orthophotography (acquired by an unmanned aerial vehicle) from TRUE (**Table 1**). The aerial photographs were georeferenced to the 2022 Esri base image using standard georeferencing tools in ArcMap. A minimum of five control points were used to optimize the spatial match within the floodplain area, where relief and relative image distortion are low. Resultant errors in comparison to the ortho-imagery were generally <1 m, although locally greater for the older 1939 and 1951 images.

Three types of planform delineations were completed based on interpretation of the imagery and topographic data sources:

- **Banks of active channel** – Defined by the limits of the unvegetated, flood-prone width of the bankfull channel. Flooding and avulsions are still possible beyond this zone of frequent inundation and scour.
- **Thalwegs** – The portion of a channel that conveys most of the flow (i.e., the deepest area within a given cross-section).
- **Side channels** – Secondary channels that convey smaller portions of flow, at least during flood conditions.

The position of the shoreline of Slocan Lake, along the alluvial fan front, was also delineated and compared over time using the same aerial and satellite imagery as was used for the channel delineations (**Table 1**). Changes in the position and configuration of fan fronts can provide insights into the relative contributions of sediment output and shoreline erosion.

Table 1: Aerial and satellite imagery utilized for the historical planform assessment

Type	Year	Roll Number	Source
Colour orthophotography (unmanned aerial vehicle)	2023	N/A	TRUE
Satellite imagery	2022	N/A	Esri World Imagery
Colour orthophotography (unmanned aerial vehicle)	2021	N/A	TRUE
Satellite imagery	2017	N/A	Esri World Imagery
Satellite imagery	2014	N/A	Esri World Imagery
Black-and-white aerial photography	1997	BCB97110	UBC Geographic Information Centre
Black-and-white aerial photography	1990	BCB90143	UBC Geographic Information Centre
Black-and-white aerial photography	1981	BC81111	UBC Geographic Information Centre
Black-and-white aerial photography	1966	BC4382	UBC Geographic Information Centre
Black-and-white aerial photography	1951	BC1341	UBC Geographic Information Centre
Black-and-white aerial photography	1939	BC155	UBC Geographic Information Centre

3.5 Longitudinal Profiles

Two longitudinal profiles of Carpenter Creek (~water surface) were extracted from available topographic data to help identify slope-breaks, establish channel gradients, and provide insights on channel stability and differences in aggradation and degradation potential. Channel gradients were also used to inform analysis of sediment mobility (Section 4.3.3). A detailed longitudinal profile was extracted from TRUE's merged DEM along the active channel corridor descending the fan complex along lowermost Carpenter Creek. A watershed-scale longitudinal profile, for broader context, was extracted from 20 m contours along the 1:20,000-scale BC Freshwater Atlas stream linework.

3.6 Field Reconnaissance

Field reconnaissance was completed within the lower portion of the Carpenter Creek watershed by two SLR geoscientists on May 14, 2024. The weather was clear and warm (18°C), with no antecedent precipitation, and Carpenter Creek was below bankfull level. Desktop-based interpretations were 'ground-truthed' and additional information that could not be determined remotely was collected.

Sediments comprising the Carpenter Creek fan were examined in natural and anthropogenic exposures, giving particular attention to any evidence of debris flood or debris flow deposits. The approximate grain size distribution of channel bed materials was estimated based on Wolman (1954) pebble counts, whereby the intermediate (b-axis) of 200 randomly selected gravels to boulders were measured using a metric folding rule. Bank characteristics, bar morphology and distribution, and in-stream and channel-edge woody debris were observed and photographed. The nature and extent of anthropogenic alteration to Carpenter Creek's lower reach were documented. Any sites that may be susceptible to debris jam formation or avulsion were noted for subsequent review based on the results of desktop analyses. Anthropogenic disturbance of the alluvial fan surface precluded assessment of historical overbank flooding and/or deposition based on soils or dendrochronology, for example.

3.7 In-stream Sediment Mobility

To better understand the ability of lower Carpenter Creek to entrain and transport sediments it receives from upstream reaches, a basic, 1-dimensional hydraulic modelling exercise was undertaken. Two representative locations were selected for analysis to evaluate sediment mobility along the active channel descending the fan: 1) upstream of the Bridge, and 2) near the mouth of Carpenter Creek where thalweg position changes frequently. Representative channel cross-sections were extracted from TRUE's merged 2023 DEM.

At both cross-sections, a Manning's 'n' of 0.035 was applied to the cobble-boulder bankfull channel and a Manning's 'n' of 0.050 to 0.080 was applied to the overbank and partly vegetated floodplain areas. Critical shear stresses (τ_c), the hydraulic condition at which particles are in a state of incipient motion, were estimated for grain sizes ranging from very fine sand (0.062 mm) to boulders (256 mm) using Shields' (1936) equation, as outlined by Church (2006) (**Table 2**):

$$\tau_c = \tau_c^* \cdot (\rho_s - \rho) \cdot g \cdot D$$

Where τ_c^* is the dimensionless critical shear stress, ρ_s is the sediment density (2,650 kg/m^3), ρ is the water density (1,000 kg/m^3), g is the acceleration due to gravity (9.81 m/s^2), and D is the grain size diameter. τ_c^* was set at 0.04 due an observed mixture of cobble and boulders on the bed surface (Wilcock and Crowe, 2003). The hydraulic modelling results for multiple return-period flows (2- to 200-year) were provided by TRUE (2024).

For this assessment, a given grain size was considered 'partially mobile', a condition at which some particles are in a state of incipient motion, when the shear stress exceeded the critical shear stress. A given grain size was considered 'fully mobile', a condition at which all particles are in a state of incipient motion, when the shear stress was two times the critical shear stress (Wilcock and McArdell, 1993).

Table 2: Grain sizes used for the sediment transport assessment and their associated critical shear stresses along lowermost Carpenter Creek

Grain Description	Grain Size (mm)	Partial Mobility Critical Shear Stress (N/m^2)	Full Mobility Critical Shear Stress (N/m^2)
Very Fine Sand	0.062	0.0	0.1
Medium Sand	0.25	0.2	0.3
Coarse Sand	1	0.7	1.3
Very Fine Gravel	2	1.3	2.6
Fine Gravel	4	2.6	5.2
Medium Gravel	8	5.2	10.4
Coarse Gravel	16	10.4	20.7
Very Coarse Gravel	32	20.7	41.4
Fine Cobble	64	41.4	82.9

Grain Description	Grain Size (mm)	Partial Mobility Critical Shear Stress (N/m^2)	Full Mobility Critical Shear Stress (N/m^2)
Coarse Cobble	128	82.9	165.8
Boulders	256	165.8	331.5
Note: Partial mobility occurs when some particles of a given grain size are in a state of incipient motion. Full mobility occurs when all particles of a given grain size are in a state of incipient motion.			

4.0 Results

The presentation of the results of the geomorphological assessment that follows is organized from the scale of the Carpenter Creek watershed (Section 4.1) to the Carpenter Creek fan complex (Section 4.2) and ultimately to the active channel corridor and contemporary fan of Carpenter Creek (Section 4.3).

4.1 Watershed Characterization, Sediment Sources and Implications for Flooding

Carpenter Creek and its two major tributaries drain rugged, subalpine to alpine mountains in the headwaters of its 204.5 km^2 watershed. Both Seaton Creek and Kane Creek enter Carpenter Creek at the Three Forks, approximately 8 km upstream from the mouth of Carpenter Creek (**Figure 1**). Seaton Creek is approximately 8.2 km long and drops 845 m from its steep headwaters at 1640 m asl to 795 m asl at the Three Forks (**Figure 2**). After its headwater gully, Seaton Creek follows a U-shaped valley floor bordered by moderately steep, forested slopes below alpine ridges. Several snow avalanche paths reach colluvial fans that terminate on the valley floor. Beaver activity is widespread along Seton Creek, which is interrupted by multiple impoundments and treeless meadows.

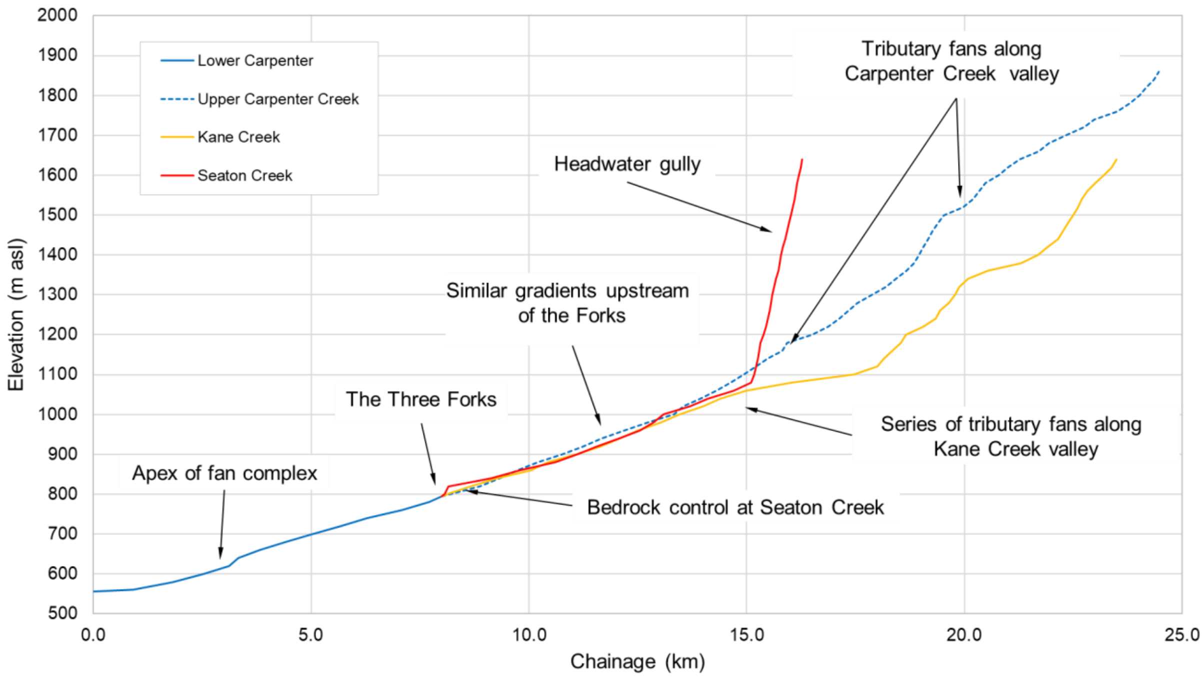


Figure 2: Longitudinal Profiles of Carpenter Creek and its two major tributaries, extracted from 20 m contours along the 1:20,000-scale BC freshwater Atlas stream linework. Note that gradients upstream and downstream of the Three Forks remain similar (approx. 3.4%).

Kane Creek is approximately 15.5 km long and drops 845 m from its headwaters at 795 m asl to 1640 m asl at the Three Forks (**Figure 2**). Steep, rugged, alpine basins rim the head of Kane Creek, preserving tiny glaciers and alpine tarns in north-facing hollows below the summits of Mt. Dryden and Whitewater Mountain. Evidence of rockfall, debris slides and debris flows is widespread in this headwater basin. The runouts from all these mass movements terminate in the subalpine valley bottom, well upstream from the Three Forks. Several snow avalanche paths reach and cross Kane Creek within its forested and mostly undisturbed valley.

Carpenter Creek itself has a total length of approximately 24.5 km, dropping 1,325 m from an elevation of 1,860 m asl at its head to 537 m asl at its mouth along the east shore of Slocan Lake (**Figure 2**). Its longitudinal profile is slightly concave-up, with a few minor slope-breaks associated with pinch-points at bedrock canyons and large tributary fans. Moderately steep, alpine cirques, one with a rock glacier, occupy north-facing basins in the headwaters of Carpenter Creek. Steep mountainsides punctuated by debris flow gullies and snow avalanche paths confine upper Carpenter Creek and its headwater tributaries to a relatively narrow valley bottom. Establishment of the historical silver mining town of Sandon along the valley floor upstream of the Three Forks (**Figure 1**) represents a persistent disturbance to channel morphology and sediment availability. In 1955, much of Sandon was destroyed by a flood that exceeded the capacity of a wood-frame culvert that had been built beneath the town to free up developable land (Turner et al., 2009). Downstream of the Three Forks, Carpenter Creek is confined by colluvium-mantled mountainsides and high, steep scarps at the edges of remnants of glaciofluvial terraces. The valley floor widens downstream of the apex of the fan complex at its mouth.

Table 3 summarizes watershed morphometrics for each of the three creeks. Based on a large dataset of steep creeks in British Columbia and Alberta, lowermost Carpenter Creek (Melton ratio: 0.09) is mainly subject to clearwater floods but may also be susceptible to debris floods (C_L; **Figure 3;** Church and Jakob., 2020). Even the subwatershed morphometrics of Kane, Seaton and upper Carpenter Creeks yield Melton ratios of 0.09 (K), 0.16 (S), and 0.13 (C_U), respectively, which are also associated with clearwater floods and debris floods. The propensity for floods and debris floods along each of these upper reaches indicates that sediment and woody debris that are ultimately transported along lower Carpenter Creek are unlikely to be sourced from debris flows upstream of the Three Forks. The fan at the mouth of Carpenter Creek does not appear to be susceptible to debris flows based on Church and Jakob (2020), review of historical and recent imagery, surface expressions in LiDAR data, and field observations of deposit sedimentology. Clast-supported rounded gravels to boulders in natural and anthropogenic exposures of alluvium comprising the fan corroborate this statistical characterization by reflecting a history of mostly clearwater floods (**Photo 2**).

Table 3: Watershed morphometrics for Carpenter Creek and its two major tributaries

Subwatershed	Stream Length (km)	Watershed Area (km^2)	Relief (km)	Melton Ratio
Kane Creek	15.5	81.7	0.845	0.09
Seaton Creek	8.5	27.0	0.845	0.16
Upper Carpenter Creek	16.5	70.0	1.060	0.13
Lower Carpenter Creek (at mouth)	24.5	204.5	1.325	0.09
Melton (1957) ratio is defined as watershed relief (km) divided by the square root of watershed area (km^2) Total stream length is calculated from Freshwater Atlas stream network				

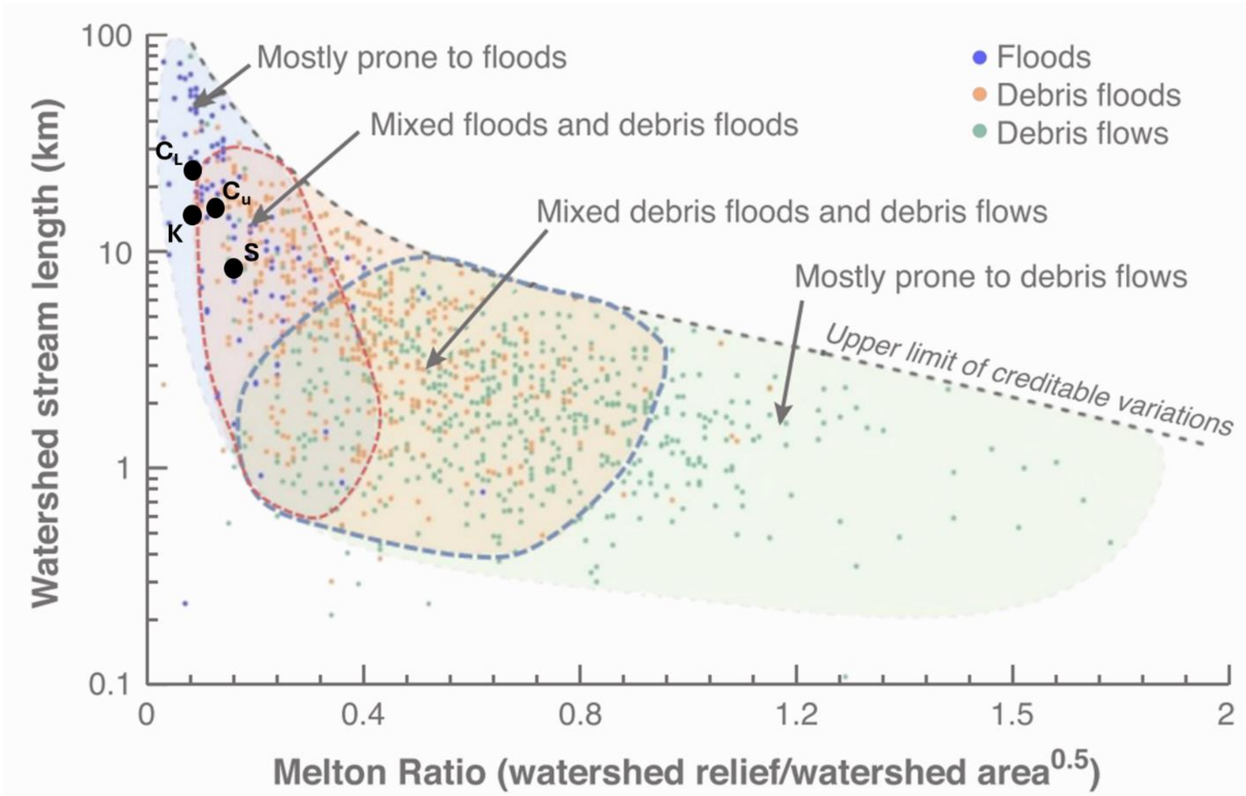


Figure 3: Distribution of dominant flood types based on watershed morphometrics (adapted from Church and Jakob, 2020). In this case, the term “floods” is specific to “clearwater floods.” The plotted positions of Carpenter Creek (CU: upper; CL: lower), Seaton Creek (S) and Kane Creek (K) indicate a propensity for clearwater floods and debris floods.

Photo 2: Typical exposure (~1.2 m high) of clast-supported, rounded gravels and cobbles comprising the contemporary fan of Carpenter Creek. Such materials indicate deposition primarily from clearwater floods.

A significant amount of sediment and woody debris are transported along lower Carpenter Creek, downstream of the Three Forks, even by clearwater floods. This sediment and debris load must be accounted for when considering flood hazard limits, as it can lead to bulking and commensurate increases in water levels (Section 5.1.1). Inputs from adjacent slopes also can, if conditions are right, at least partly obstruct flows prior to releasing suddenly (Section 4.1.1). Most of the sediment that is transported along lower Carpenter Creek is sourced from erosion of confining glaciofluvial and till scarps along the outer banks of meanders, locally and from upper Carpenter Creek (**Figure 4**). A few of the larger debris flow gullies that punctuate the mountainsides also deliver sediment to Carpenter Creek or its tributaries, but such inputs are episodic (multi-decadal timescales) and undoubtedly overwhelmed by the more frequent (yearly to decadal timescales) erosion of valley bottom scarps. Kane Creek additionally contributes some sediment to lower Carpenter Creek, also principally sourced from valley bottom scarps and episodic debris flow inputs along its lower reaches; abundant sediment inputs from moraines and rockfall talus in its headwaters are particularly coarse and unlikely significant contributions to lower Carpenter Creek. Seaton Creek appears to contribute little sediment to lower Carpenter Creek, probably because its beaver dams and associated meadows trap any sediment that it does recruit from hillside inputs.

Figure 4: Examples of the dominant types of sediment sources to lower Carpenter Creek. A) Incised colluvial fan with eroded toe, about 1.5 km upstream of Sandon. B) Partially revegetated road embankment failure, about 3 km upstream of the Three Forks. C) Ravelling glaciofluvial terrace scarp about 0.7 km upstream of the Union Street bridge. D) Sloughing cut-bank into till about 0.4 km upstream of the Three Forks.

The gradual down-cutting and incision of Carpenter Creek into the fan complex at its mouth (Section 4.2) indicates long-term reductions in sediment supply over the Holocene (last 11,700 years). Similar trends are apparent in historical aerial photography (since 1939) as some erosion scars are beginning to vegetate and stabilize, including along historical mining-related disturbances, and sections of valley floor along the alluvial fan are becoming abandoned by all but the most extreme flows as gradual incision continues. The fluvial geomorphological implications of reduced sediment availability are considered in Section 4.3.1.

Woody debris transported by lower Carpenter Creek originates from shrubs and trees that fall into the channel, and are rafted downstream, during flood conditions that undercut and collapse the banks. Such material is likely sourced locally, downstream of the Three Forks including on the fan, and from the lower reaches of the tributaries. A number of snow avalanche paths that reach or cross Carpenter Creek or its tributaries likely also deliver woody debris to the channel, following melt of runout debris.

4.1.1 Outburst Flood Potential

Assessment of flood and associated hazards on alluvial fans in mountainous landscapes, such as that at the mouth of Carpenter Creek, should consider the possibility of outburst flooding (Costa and Schuster, 1987; Engineers & Geoscientists British Columbia, 2018). An outburst flood occurs when some or all of the water in a temporary or permanent waterbody drains suddenly and augments any baseflow or meteoric flood downstream. Outburst floods from large impoundments (relative to flows upstream and downstream) can have discharges that are orders of magnitude larger than those associated with meteoric floods (Costa and Schuster, 1987). Relatively small outburst floods may be possible in association with the sudden breach of one of the following types of natural dams:

- **Landslide dam** – Landslide dams form when sediments and/or fractured rock from a mass movement enter and partly or fully obstruct a watercourse. Landslide debris may be readily eroded, such that augmentation of downstream flows is minimal, or may persist for decades to millennia. Narrow valley bottoms with inputs of large volumes of rock debris, or cohesive material, are predisposed to the formation of landslide dams, with the largest impoundments occurring where valley floor gradients are gentle. No evidence of existing or breached landslide dams, or associated outburst flooding, is available in historical or recent aerial photography, LiDAR data, or natural or anthropogenic exposures of sediment on the fan complex at the mouth of Carpenter Creek. Although long sections of Carpenter Creek and its tributaries flow within relatively narrow valley bottoms, locally confined by steep scarps, a sinuous planform indicates the availability of some floodplain to resist complete obstruction and aid attenuation of any flooding. Furthermore, most of the eroding scarps comprise coarse-grained, cohesionless sediments that fail through ravelling and shallow debris slides. Such processes are generally incapable of forming substantive landslide dams. Any debris flows that reach and enter Carpenter Creek or one of its tributaries are also unlikely to form complete obstructions for any length of time due to their slurry-like nature and propensity to entrain more water and attenuate. Evaluating the potential for larger, deep-seated landslide activity, and any associated outburst flood potential, was beyond the scope of this study.
- **Beaver dam** – As noted above (Section 4.1), a series of beaver dams exists along Seaton Creek. Many have persisted, at least in their current locations, for years or decades. These dams also indicate the possibility of beavers impounding channels elsewhere in the watershed. Case et al. (2003) document the occurrence and downstream morphological effects of the catastrophic failure of a beaver dam that raised water level in ~1 km^2 Chundnuslida Lake, in east-central British Columbia, by 1.5 to 2.5 m. The volume of water potentially impounded by beaver dams within the Carpenter Creek watershed is relatively small, due to the modest heights of beaver dams (typically no more than a few metres), relatively steep creek gradients (commonly >3%) and narrow valley floors (typically no more than a few tens of metres). As such, outburst floodwater from the sudden breach of a dam, or series of dams, could have localized impacts but would likely attenuate and contribute little to water levels by the time it reaches the Carpenter Creek fan.
- **Snow avalanche dam** – As noted above (Section 4.1), vegetative evidence indicates that numerous snow avalanche paths reach, if not cross, Carpenter Creek and its tributaries. Avalanches with the largest runouts, such as those that cross one of the channels on the valley floor, tend to initiate as dry slab avalanches in winter. The deposits from such avalanches generally do not form significant obstructions or impoundments of water due to their relatively low density and timing well before spring

melt. Wet snow avalanches that occur in the spring, commonly initiating down to ground, are more likely to obstruct flow, coincide with periods of increasing or high flow, and impound water. However, they tend not to run out as far as dry snow avalanches and may rarely fully obstruct a channel. Furthermore, similarly to beaver dams, the volume of water snow avalanche dams could impound within the Carpenter Creek watershed is relatively small, due to their modest heights on relatively steep creek gradients with narrow valley floors.

- **Glacier (ice) dam** – Water that is impounded by glacial ice can discharge suddenly if the ice dam collapses or locally floats, forming an outburst flood, also known as a jökulhlaup. The remnants of glaciers persist in the headwaters of Kane Creek (Section 4.1), but all are smaller than 0.15 km^2, thinning and receding on steep (well-drained) bedrock slopes, and exhibit no evidence of permanent or temporary ice-marginal or subglacial waterbodies. As such, there appears to be little to no potential for outburst flooding from a glacier dam.
- **Displacement wave** – Some outburst floods are the result of sudden mass movement (sediment, rock, ice or snow) into a waterbody generating a displacement wave and augmenting flows downstream. The only notable waterbodies in the Carpenter Lake watershed are tiny alpine tarns in the headwaters of Kane Creek. In the event that a landslide or ice/snow avalanche did enter one of them, its displacement wave would have only very localized effects and would attenuate even before reaching Carpenter Creek.

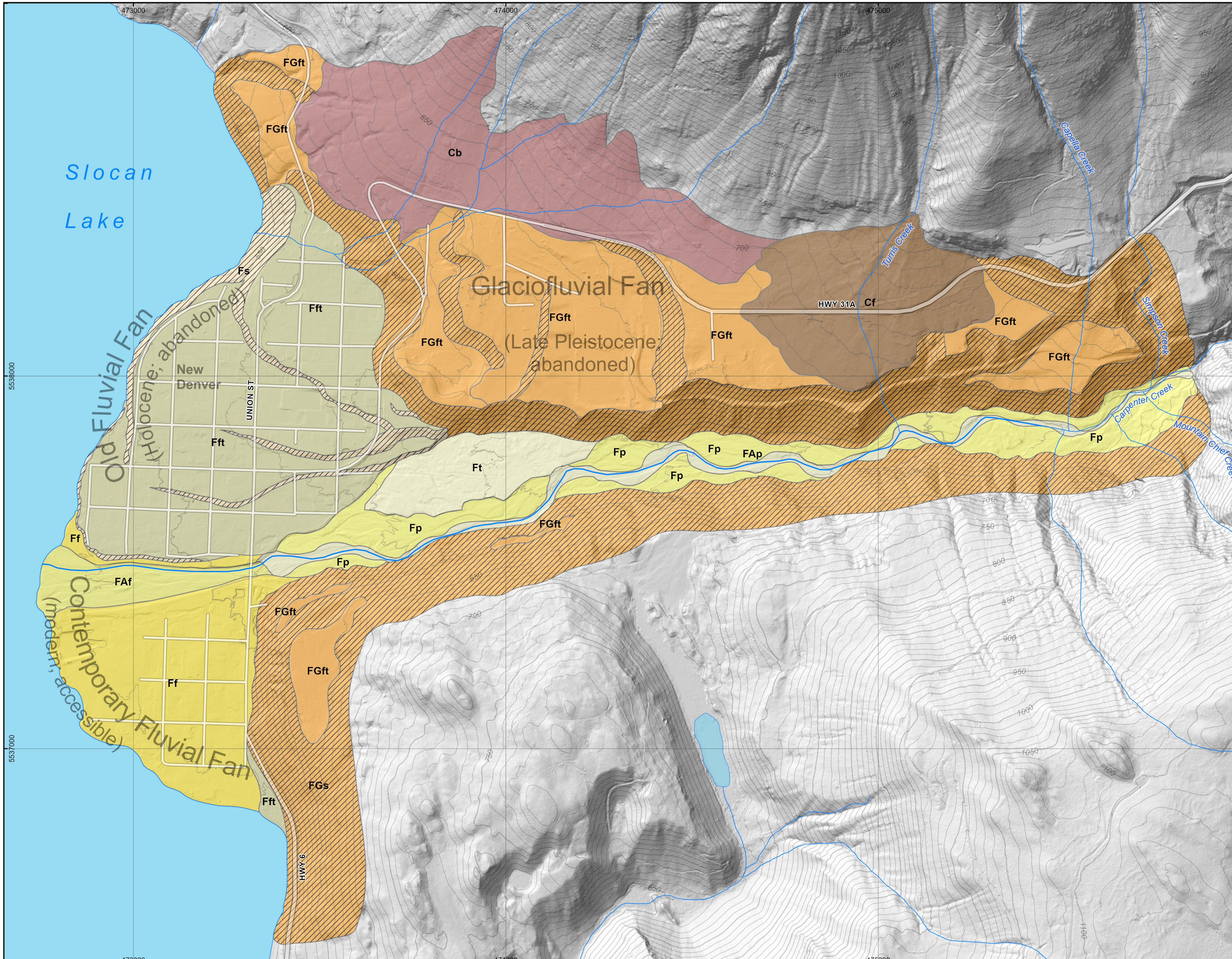
Notwithstanding these opportunities for generation of an outburst flood along Carpenter Creek, no evidence of significant outburst floods is available in historical or recent aerial photography, LiDAR data, or natural or anthropogenic exposures of sediment on the fan complex at the mouth of the creek.

4.2 Evolution of the Carpenter Creek Fan Complex

The fan complex at the mouth of Carpenter Creek begins immediately downstream of a short bedrock canyon, approximately 3.3 km upstream from Slocan Lake (**Figure 1**). The fan complex exhibits a complicated morphology and history, important to understanding the nature and extent of flood-related hazards to which portions of New Denver may be exposed. The geomorphology of the fan complex is mapped in **Figure 5** to identify key features and landforms and to help communicate their relevance to this study. Multiple former and existing fan surfaces are apparent.

Initial formation of the fan complex occurred during deglaciation of the region during the late Pleistocene. Following thinning of the Cordilleran Ice Sheet (Section 2.2), receding glaciers persisted in valleys and in some alpine cirques. It is interpreted that initial formation of the fan complex at the mouth of Carpenter Creek formed at this time, when meltwater discharging from alpine glaciers in the upper elevations in the watershed eroded and transported newly exposed, unvegetated sediments. A glaciofluvial fan (now fan-terrace: FGft) was deposited at the mouth of the creek, against the edge of a retreating or downwasting valley glacier or extending onto a former valley-spanning outwash plain (**Figure 5**). Incision of this glaciofluvial fan began as soon as sediment supplies began to diminish, in part due to colonization of exposed sediments by vegetation, within a few millennia of deglaciation. During and since this paraglacial period (Section 2.2), a series of fluvial fans formed within and at distinctly lower levels than the glaciofluvial fan; they have since been abandoned and preserved as fan-terraces (Fft). The staircase-like pattern of fan-terraces, with each lower surface representing a younger landform, record a history of incision and southward shifting of Carpenter Creek to the corridor of the current active channel (FAp) (**Figure 5**). Only the southernmost fringe of the lowest terrace north of the contemporary channel may be exposed to flooding and/or erosion during extreme events (Section 5.1.3). South of the channel, however, the fan surface is lower and inactive (Ff) but has not been fully abandoned to the point of constituting a terrace. Extreme flood events, especially if associated with widespread sediment transport and rapid aggradation or an avulsion, could potentially spill onto at least the adjacent portion of the inactive fan (Section 5.1.3).

The Carpenter Creek fan was first settled in the late 1800s in association with mineral exploration of the region. Aerial photography from 1939 reveals a fan surface with wider swaths of unvegetated areas, in association with braided distributary channels and overbank deposition. Since 1939, development of residential and commercial buildings, construction of roads, and reinforcement of creek banks with riprap has altered the fan’s surface expression and how the channel interacts with the fan (Section 4.3.2).



LEGEND

Surficial Material and Expression*

- **Cb** - Colluvial Blanket
- **Cf** - Colluvial Fan
- **Ff** - Fluvial Fan
- **Fp** - Fluvial Plain
- **FAf** - Active Fluvial Fan
- **FAp** - Active Fluvial Plain
- **Ft** - Fluvial Terrace
- **Fft** - Fluvial Fan-Terrace
- **Fs** - Fluvial Scarp
- **FGft** - Glaciofluvial Fan-Terrace
- **FGs** - Glaciofluvial Scarp

*Based on Howes and Kenk (1997)

Base Map

- Watercourse [1]
- Primary Road [2]
- Secondary Road [2]
- Waterbody [1]

1 - BC Freshwater Atlas (modified)
2 - BC Digital Road Atlas

0 100 200 300 400 500
METRE SCALE

North American Datum 1983
Universal Transverse Mercator Projection Zone 11

Scale: 1:10,000
Page Size: Tabloid (11 x 17 inches)

Drawn: RS/BE
Checked: JW
Date: Dec 10, 2024

NORTH

Source Notes:
Shaded relief and contours generated from Lidar (GeooBC, 2018). Contour interval is 10 metres (minor) and 50 metres (major). Contains information licensed under the Open Government License – British Columbia.

CLIENT
TRUE Consulting

PROJECT
Silverton and New Denver Fan Hazards

TITLE
Geomorphology of the Carpenter Creek Fan Complex

Palmer PART OF SLR

REF. NO. 2304301-5-3

Figure 5

Document Path: G:\Shared drives\Projects 2023\23085 - TRUE Consulting\2308501 - Silverton and New Denver Fan Hazards\GIS\1_Workspace\Task 6 - SG and Study Area Figure\2308501 SG Figure.aprx

4.3 Morphology and Dynamics of the Contemporary Channel Corridor of Lowermost Carpenter Creek

4.3.1 Channel Morphology

The contemporary channel corridor of lowermost Carpenter Creek extends approximately 3.3 km from the outlet of the bedrock canyon at the apex of the (glaciofluvial) fan complex to the creek mouth along the contemporary fan-front shoreline of Slocan Lake (**Figure 1**). Along the upstream three-quarters of this corridor, Carpenter Creek is confined by 55 to 103 m-high glaciofluvial terrace scarps on the north (**Photo 3**) and by discontinuous terrace scarps along a drift-mantled, bedrock-controlled slope on the south. The channel exhibits a sinuous planform with good connectivity to an alluvial floodplain (active and inactive) with a width that ranges from about 55 to 260 m, with the widest section immediately upstream of the apex of the contemporary alluvial fan. Carpenter Creek is predominantly a single-thread, wandering channel with discrete braided sections forming in response to high bedload transport events and subsequent scour of floodplain channels (**Photo 4**). Bankfull width ranges from about 20 to 25 m and bankfull depth ranges from about 1 to 1.5 m.

Fluvial terraces north of the contemporary channel corridor and the southern mountainside force the narrowing of the floodplain from its maximum of 135 m to just 18 m near the apex of the contemporary alluvial fan, which represents the downstream quarter of the contemporary channel corridor. The Union Street bridge crosses and further narrows this natural constriction along the channel corridor. Downstream of the Bridge, the channel gradually splays out and adopts a more braided morphology exhibiting frequent repositioning of the channel thalweg. Irregular vegetation growth along this lowermost section of channel reflects a cycle of channel adjustment, bar stabilization, and erosion and reworking of sediments.

Photo 3: Upstream view of eroding scarp of remnant glaciofluvial (fan) terrace along the southern bank of lower Carpenter Creek, about 0.7 km upstream of the Bridge.

Photo 4: Upstream view from the Bridge at a sinuous, single-thread planform Carpenter Creek (left). Upstream view of a multi-thread planform of Carpenter Creek near its mouth (right).

A longitudinal profile of lowermost Carpenter Creek, derived from the blended LiDAR DEM and ground survey by TRUE, is provided in **Figure 6.** The contemporary channel corridor through this (glaciofluvial) fan complex has an average gradient of 2.2%, gentler than the channel upstream (3.4%). The gentler downstream gradient of the channel through the fan complex explains why some coarser sediment may deposit, especially in areas of wider floodplain. However, the absence of any notable slope-breaks as the active channel descends the contemporary fan indicates no major accumulations of sediment until its entry into Slocan Lake.

Grain size distributions for bed material upstream and downstream of the Bridge, estimated by Wolman (1954) pebble counts, are provided in **Figure 7**. Upstream of the Bridge, the D_{50} and D_{84} are 13 cm and 25 cm, respectively (PC-2; **Photo 5**). Near the creek mouth, D_{50} and D_{84} are 10 cm and 19 cm (PC-1; **Photo 5**). The apparent downstream fining is typical of channels on fans and is a reflection of the abrupt widening and slight reduction in gradient 125 m upstream of the creek mouth (**Photo 1**; **Figure 6**).

Riparian vegetation along lowermost Carpenter Creek mostly consists of cottonwood, spruce, fir and cedar trees. Density and age of trees generally increase away from the active channel, except where the channel is in contact with a terrace.

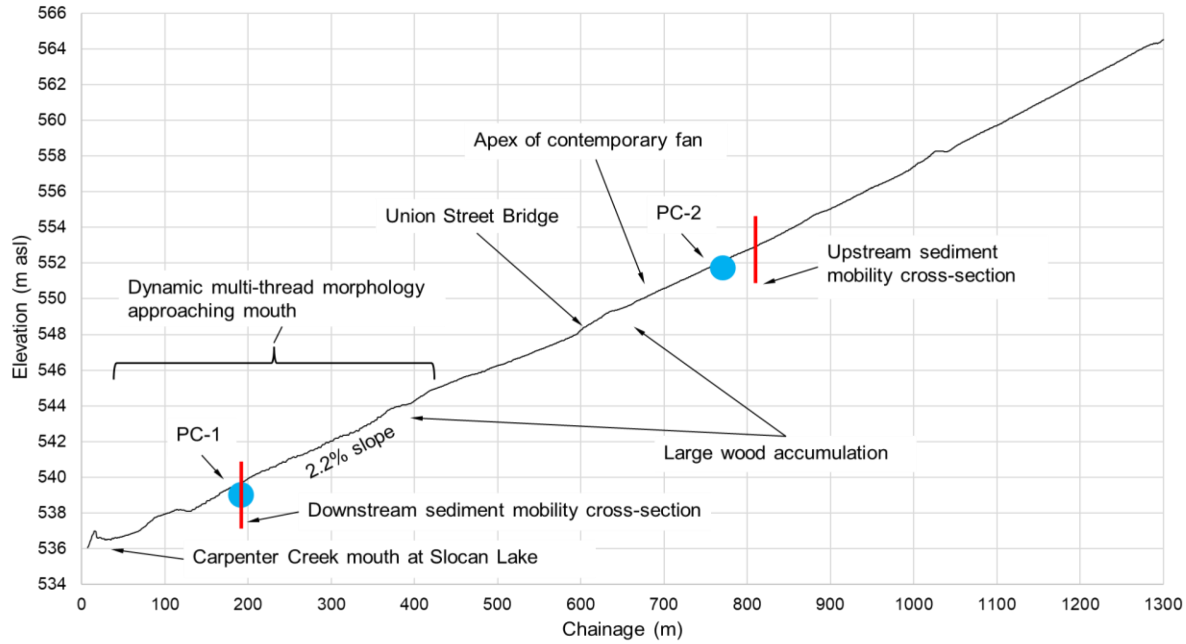
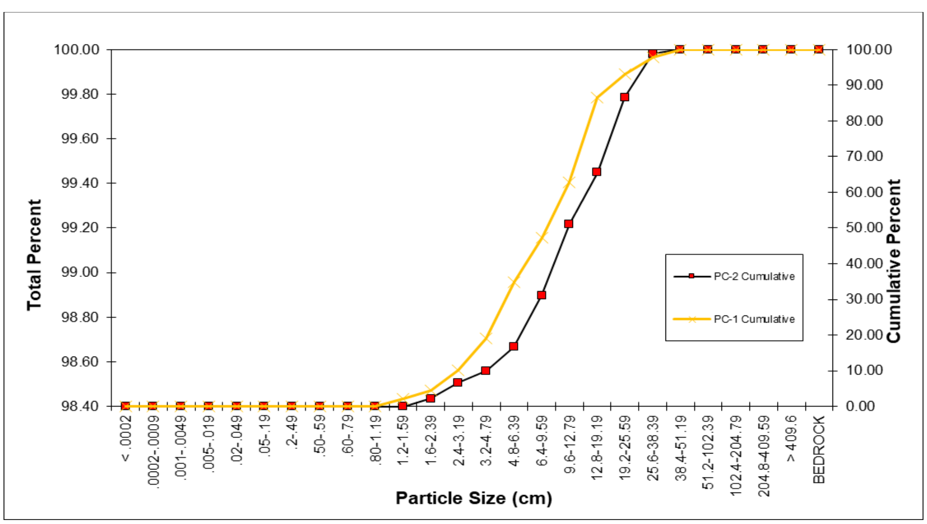


Figure 6: Longitudinal profile of lowermost Carpenter Creek (~water surface), derived from TRUE's ground-based survey data with blended LiDAR data (2018). Note the relative uniformity of the channel gradient, until the widening near the creek mouth. Sediment mobility analysis was completed based on two cross-sections (vertical red lines) and corresponding pebble counts (PC-1 and PC-2).



Note: Pebble count locations are shown on ***Figures 1*** *and* ***6****.*

Figure 7: Grain size distribution of bed material along lowermost Carpenter Creek. PC-1 is near the creek mouth; PC-2 is immediately upstream of the Bridge. Bed material slightly fines downstream.

Photo 5: Overview of bed material (gravels and cobbles) at the edge of an active bar upstream of the Bridge (left; PC-2; note 60 cm steel folding rule for scale) and near the mouth of Carpenter Creek (right; PC-1). Note the slightly greater proportion of sand and pebbles nearer the mouth.

Large wood debris is entrained from creek banks and rafted downstream during floods along lower Carpenter Creek. The 2020 flood event resulted in significant large wood input. Two notable wood debris jams were observed in the vicinity of the Bridge during field reconnaissance: one immediately upstream of the Bridge and adjacent to the newly repaired dike, and one 200 m downstream of the crossing (**Photo 6**). Other, smaller accumulations were observed nearer the creek mouth, as well. Based on these observations and no evidence or anecdotes to suggest otherwise, the Bridge appears to have sufficient span and freeboard to pass rafted wood debris, without formation of jams, at least during recent floods.

Photo 6: Upstream view of large wood jam opposite the recently repaired section of dike upstream of the Bridge (left) and downstream view of mid-channel jam downstream of the Bridge that is bifurcating flow (right).

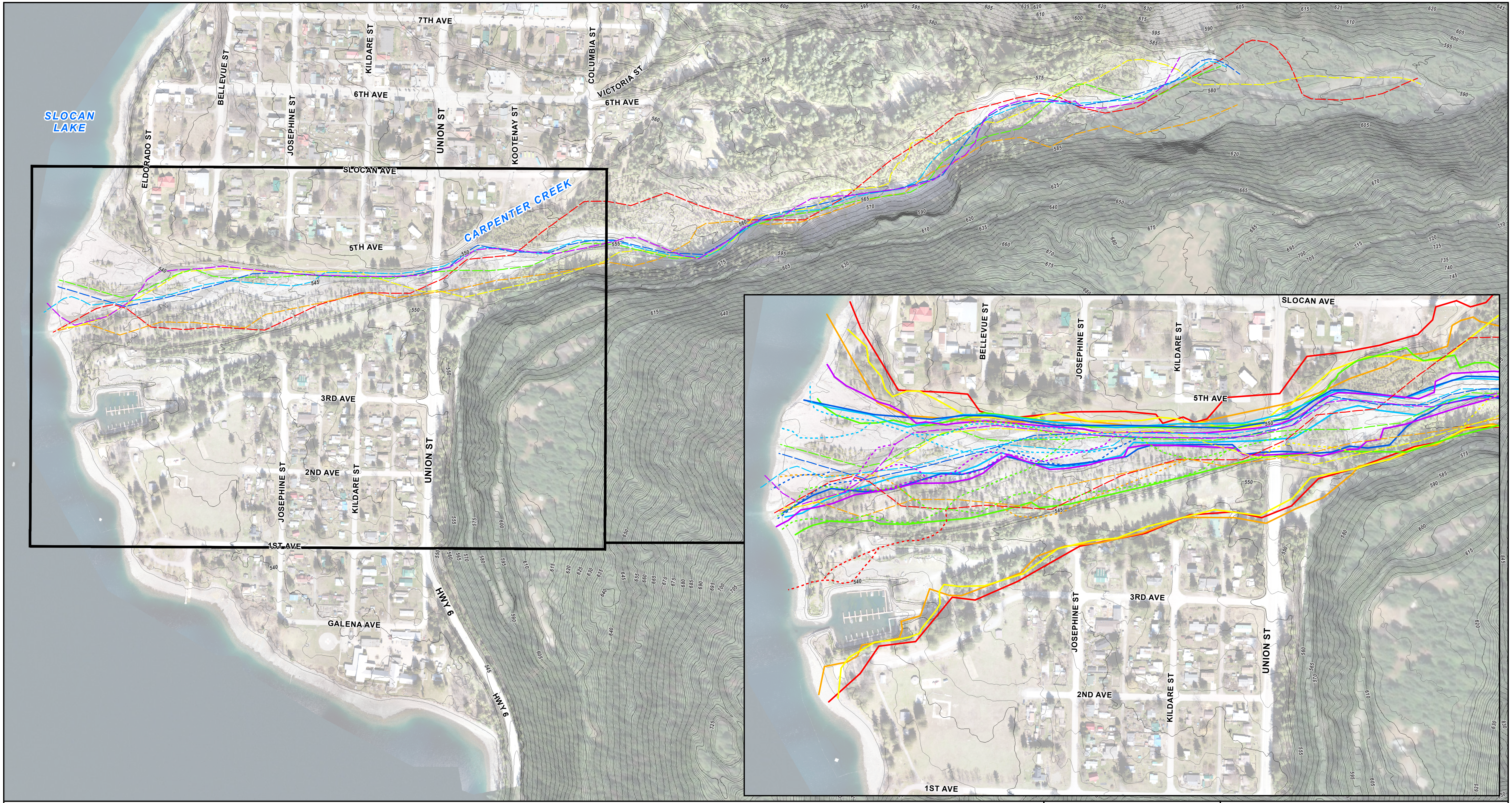
4.3.2 Historical Planform Changes

Comparative analysis of channel (**Figure 8**) and fan-front (**Figure 9**) positions since the earliest available aerial photography (1939), when combined with targeted field observations, revealed a variety of natural and anthropogenic changes in channel/fan morphology that warrant consideration as part of flood-related hazard assessment. Pertinent findings are described below for the Carpenter Creek channel (Section 4.3.2.1), flood/erosion mitigation dike that protects the north abutment of the Bridge (Section 4.3.2.2), and fan-front at the shoreline of Slocan Lake (Section 4.3.2.3).

4.3.2.1 Carpenter Creek Channel

The overall corridor along which lowermost Carpenter Creek flows has remained largely unchanged since 1939, given its confinement by steep slopes and old fluvial fan-terraces (**Figure 5**). The northern portion of valley floor, upstream of New Denver, has remained relatively unaffected by fluvial processes. In general, however, the proportion of this corridor occupied by the sinuous channel has decreased through a combination of ongoing incision and vegetative colonization and stabilization of peripheral floodplain areas. The channel has adopted a better defined thalweg, especially between 1939 and 1981, which is responsible for systematic lateral and down-valley migration of some meanders. Downstream of the Bridge, the thalweg has generally remained along the north side of the corridor, allowing bar stabilization and re-vegetation to the south. The unvegetated (flood-prone) channel width of lowermost Carpenter Creek has also decreased notably between 1981 and 1997, which may reflect reductions in the availability of sediment along re-vegetating banks and adjacent floodplain areas and/or a quiescent period between major floods. Channel narrowing continued until 2020, when a flood resulted in reworking of treed areas; however, channel width has remained consistent between 1997 and 2023.

Anthropogenic alteration of lowermost Carpenter Creek predates the earliest aerial photography (1939), based on observation of wood cribbing near where the channel is now crossed by Union Street. The Bridge, which was first constructed prior to 1939, has been replaced on several occasions, most recently between 1966 and 1981. This replacement likely coincided with construction of the flood/erosion mitigation dike in 1976 (SNT Geotechnical Limited, 2022a). Dike construction narrowed the natural unvegetated channel width from approximately 130 m to 40 m at the Bridge and by 50 m at the mouth of Carpenter Creek (**Figure 10**).



LEGEND

Carpenter Creek thawleg (approx.)	Carpenter Creek unvegetated (flood-prone) width	Side Channel
1939	1939	1939
1951	1951	1951
1966	1966	1966
1981	1981	1981
1997	1997	1990
2014	2014	2014
2023	2023	2023

Surface Elevation Contour (5m)
Surface Elevation Contour (1m)

Note:
Linework based on interpretation of historical aerial photography from UBC's Geographic Information Centre.

Key Map

Site Location (New Denver, BC)
Kimberley
Nelson
Cranbrook
Grand Forks
Trail

0 40 80 120 160 200
METRE SCALE

North American Datum 1983
Universal Transverse Mercator Projection Zone 11
Scale: 1:5,500
Page Size: Tabloid (11 x 17 inches)

NORTH

Drawn: CV/RS
Checked: MB
Date: Nov 22, 2024

Source Notes:
Base imagery (2021) provided by Hinterland Drone Services, with supplementary imagery (2022) outside the main area provided by Esri Basemap Services. Topographic data derived from LidarBC DEM, 2018. Contains information licensed under the Open Government Licence – British Columbia

CLIENT
TRUE Consulting

PROJECT
New Denver Fan Hazards

TITLE
Historical channel planforms of lowermost Carpenter Creek

Palmer. PART OF SLR

REF. NO. 2308501-ND-8-3

Figure 8

Document Path: G:\Shared drives\Projects 2023\23085 - TRUE Consulting\2308501 - Silverton and New Denver Fan Hazards\GIS\1_Workspace\Task 5 - Fluvial Figures\New Denver\2308501-8-2-Historical Channel Planforms of Lowermost Carpenter Creek.mxd

LEGEND

Carpenter Creek Fan Front

- 1939
- 1951
- 1966
- 1981
- 1997
- 2014
- 2017
- 2021
- 2023

Surface Elevation Contour (5m)

Surface Elevation Contour (1m)

Note: Shoreline position not mapped along active fan front. Represented as straightened line

0 40 80 120 160 200

METRE SCALE

North American Datum 1983
Universal Transverse Mercator Projection Zone 11

Scale: 1:5,000
Page Size: Letter (8.5 x 11 inches)

Drawn: CV/RS
Checked: MB
Date: Nov 22, 2024

NORTH

Source Notes:
Base imagery (2021) provided by Hinterland Drone Services, with supplementary imagery (2022) outside the main area provided by Esri Basemap Services. Topographic data derived from LidarBC DEM, 2018. Contains information licensed under the Open Government

CLIENT
TRUE Consulting

PROJECT
Silverton and New Denver Fan Hazards

TITLE
Historical positions of Carpenter Creek fan front

Palmer PART OF SLR

REF. NO. 2308501-ND-9-3

Figure 9

Document Path: G:\Shared drives\Projects 2023\23085 - TRUE Consulting\2308501 - Silverton and New Denver Fan Hazards\GIS\1_Workspace\Task 5 - Fluvial Figures\New Denver\2308501-9-2-Historical positions of Carpenter Creek fan front .mxd

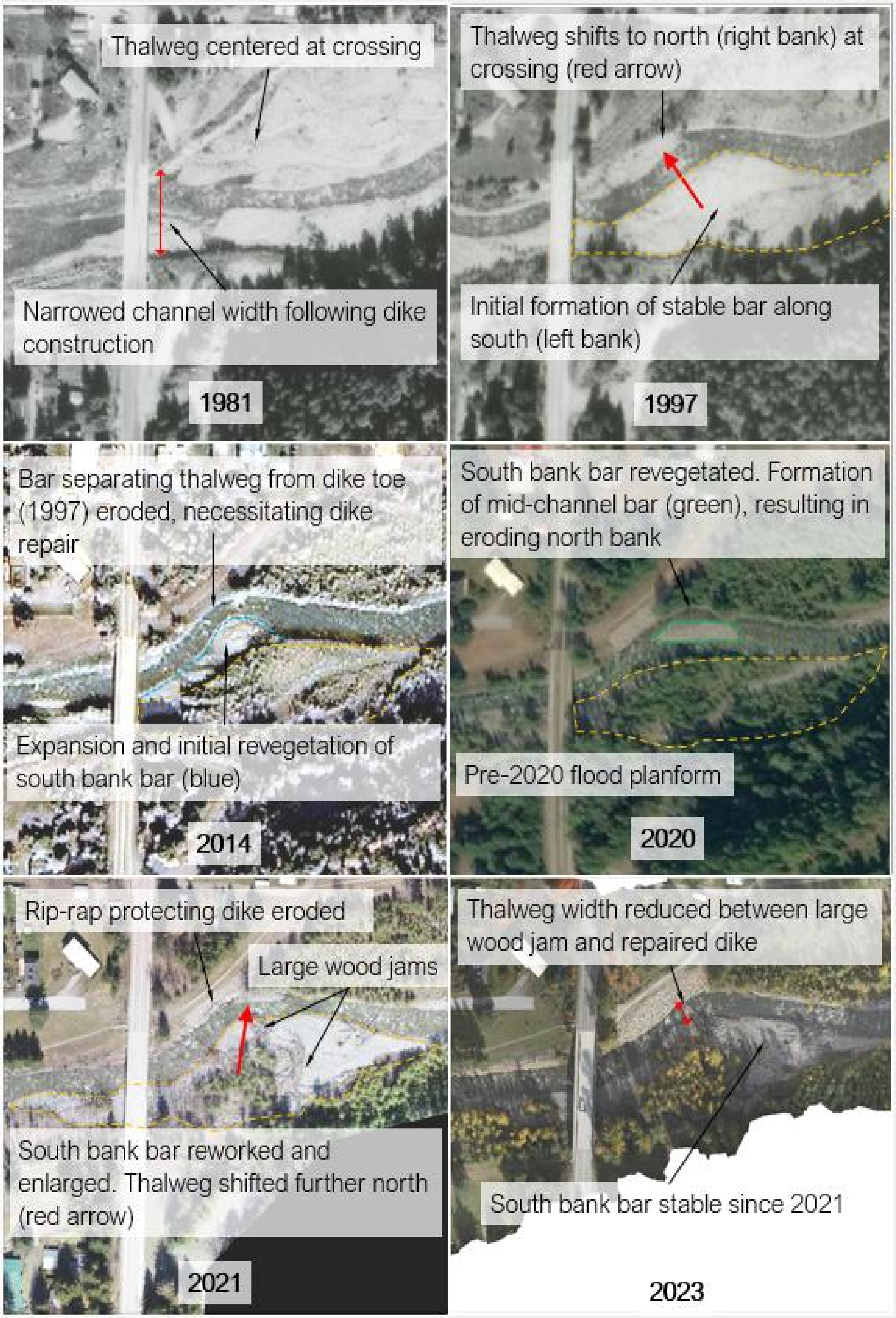


Figure 10: Comparison of historical imagery at the Bridge from 1981 (first available image following dike construction) to 2023. The channel thalweg has shifted northward to the dike, where it has remained in contact for approximately 40 years.

4.3.2.2 Flood/Erosion Mitigation Dike near the Union Street Bridge

Ongoing adjustments in channel morphology, sediment transport and riparian vegetation have compromised the stability of the flood/erosion mitigation dike upstream of the Bridge (**Figure 10**). Bar growth, wood debris accumulation and vegetative stabilization immediately upstream of the Bridge, between 1981 and 2023, have concentrated flood flows and better defined the thalweg along the outer bank of the bend protected by the dike. Recent floods (i.e., 2013, 2017 and 2020) resulted in partial failure of rip-rap along the north bank upstream and downstream of the Bridge where the channel thalweg maintains contact. Failure was presumably driven by undersizing and undermining of the rip-rap, due to erosion of underlying alluvium. Maintenance of the dike through the replacement of rip-rap into the thalweg, without any compensatory cut of the opposite bar (bank), has further narrowed and concentrated energy along the channel.

4.3.2.3 Carpenter Creek Fan Front

A comparison of the Carpenter Creek fan front since 1939 reveals a shoreline position that has remained largely unchanged, at least within the margin of uncertainty of georeferencing of older aerial photographs (**Figure 10**). Sediment discharges are largely balanced by erosion, over time, along the shoreline of Slocan Lake. A general narrowing of the unvegetated, or flood-prone, width is notable downstream of the Bridge. At the mouth of the creek, this width decreased from 366 m in 1939 to 150 m in 2023. This reduction in width appears to be explained by dike construction and natural vegetation colonization. Minor projection of the fan front in recent decades, at the mouth of the current distributary channel (thalweg), likely reflects the output of sediment during notable floods.

4.3.3 In-stream Sediment Mobility

Lower Carpenter Creek is a “transport-limited” channel system, in the context of sediment mobility, as opposed to a “supply-limited” system. Ample sediment is available for transport along the bed, banks and adjacent floodplain and scarps, but it can only be mobilized once certain threshold conditions are met. Understanding how readily sediment is entrained and transported by floods informs evaluation of the potential for major aggradation, with implications for flood levels. Peak flows for lowermost Carpenter Creek were provided by TRUE (2025) to estimate which grain sizes are likely mobile during the 2-year return flow (bankfull) and 200-year return flow at locations upstream and downstream of the Bridge (**Figure 1,Table 4**). Partial and critical mobility shear stresses for representative grain sizes ranging from very fine sand (0.062 mm) to boulders (256 mm) are presented in **Table 2**.

Upstream of the Bridge, Carpenter Creek has recently transitioned from a multi-thread, braided system to a single-thread channel in association with vegetation colonization and a reduction in the availability of sediment. Concentration of flows along a better defined thalweg has increased the capacity of the channel to entrain and transport cobbles during high frequency flood events (i.e., 2-year flow). Boulders are partially mobilized during less frequent flood events (**Table 2**).

Downstream of the Bridge, channel thalweg position has remained dynamic with a braided morphology still dominant in the largely unvegetated channel. The shallower and wider channel near the creek mouth has slightly lower capacity to transport sediment compared to upstream. A decrease in shear stress promotes deposition of fine cobbles and gravels, as observed in the field (**Photo 2** and **Photo 5**; T**able 4**). Localized progradation of the fan into Slocan Lake, at the current creek mouth, is apparent over the period of record of historical aerial photography (**Figure 10**; Section 4.3.2.3). Such progradation, albeit localized and minor, corroborates the analytical finding that most bed material is readily entrained and transported down lowermost Carpenter Creek during even frequent floods.

Table 4: Modelled shear stresses for lowermost Carpenter Creek for the estimated 2-year return flow (m^3/s) and 200-year return flow (m^3/s)

Grain Description	Upstream of the Bridge		Downstream of the Bridge	
	Shear Stress (N/m^2) @ 2 Year Flow	Shear Stress (N/m^2) @ 200 Year Flow	Shear Stress (N/m^2) @ 2 Year Flow	Shear Stress (N/m^2) @ 200 Year Flow
Very Fine Sand	168.7	231.0	50.3	105.3
Medium Sand	168.7	231.0	50.3	105.3
Coarse Sand	168.7	231.0	50.3	105.3
Very Fine Gravel	168.7	231.0	50.3	105.3
Fine Gravel	168.7	231.0	50.3	105.3
Medium Gravel	168.7	231.0	50.3	105.3
Coarse Gravel	168.7	231.0	50.3	105.3
Very Coarse Gravel	168.7	231.0	50.3	105.3
Fine Cobble	168.7	231.0	50.3	105.3
Coarse Cobble	168.7	231.0	50.3	105.3
Boulders	168.7	231.0	50.3	105.3

Note: Green cells represent 'full mobility', orange cells represent 'partial mobility', and red cells represent 'no mobility'.
Survey locations are presented on **Figures 1** and **6**

5.0 Discussion

The results of the multi-part geomorphological assessment outlined above have implications for flood hazard mapping and associated risk management in New Denver. Each implication is discussed below, with key points underlined (Section 5.1), prior to a brief list of recommendations (Section 5.2).

5.1 Implications for Flood-related Hazards in New Denver

5.1.1 Flood Process Considerations

Establishment of the types and limits of flood hazards to which portions of New Denver are exposed requires consideration of the contribution of steep creek processes to flooding. Based on Melton ratios (**Table 3**), interpretation of aerial/satellite imagery and LiDAR data, and geomorphological and sedimentological field observations, the contemporary fan of Carpenter Creek is not susceptible to debris flows. Any debris flows that enter Carpenter Creek from a steep gully on one of the confining mountainsides in the watershed are expected to rapidly attenuate, well before reaching the fan, due to the sudden addition of water and drop in gradient and confinement. Portions of the contemporary fan of Carpenter Creek may, however, be susceptible to debris floods. A debris flood could originate through transition from a debris flow that enters the creek from a steep, tributary gully, as described above, and, if close enough, could reach the fan. A debris flood could also originate from rapid and widespread erosion of the creek bed and banks, including confining scarps, during a major rainstorm, snowmelt, or rain-on-snow event. Water capable of initiating a debris flood could also originate from the outburst of a natural dam, mostly likely formed by a snow avalanche, landslide or beavers, although the relatively steep and narrow valley bottoms within the watershed limit the potential size of any outburst event.

Notwithstanding the possibility of debris floods reaching the contemporary fan of Carpenter Creek, clearwater floods appear responsible for most of the inundation and sedimentation events. Even during clearwater floods, there may be considerable transport of sediment and woody debris as banks get undermined and collapse and the bed is partly mobilized. Entrainment and incorporation of sediment and woody debris into floodwater has the effect of slightly increasing discharge. As such, we recommend TRUE include a "bulking factor" in its flood modelling and associated hazard mapping. Based on BGC Engineering Inc. (2020) and Church and Jokob (2020) consideration of watershed area and the proximity of primary sources of sediment and woody debris, a value of 0.1 should be conservative for this system.

An additional factor of safety, best quantified by TRUE, is warranted to account for the effects of climate change on flooding. Climate change is increasing the intensity of rainstorms and spatial and temporal patterns in snowfall, all of which can affect flooding along Carpenter Creek. Major storms can increase the magnitude of regular floods while also increasing the potential for debris floods, by triggering debris flows on adjacent slopes or breaching natural dams.

The flood process considerations summarized above underscore the importance of adopting a conservative approach to flood modelling and associated hazard mapping in New Denver.

5.1.2 Bed and/or Bank Erosion

Bed and/or bank erosion are common consequences of flooding, even when water levels remain at or below bankfull levels. Based on a sediment mobility analysis (Section 4.3.3), the results of which corroborate field observations, the alluvial gravels and cobbles comprising the active channel corridor and adjacent fan surface near the mouth of Carpenter Creek are readily entrained and transported by floodwater. This is expected as the alluvium comprising the contemporary fan of Carpenter Creek was, by definition, transported and deposited by the creek. Replacement of sediments eroded from the bed with sediments transported from upstream maintains a balance, over the long-term, and avoids severe down-cutting and incision. However, undermining of erosion control (e.g., rip-rap) or other structures (e.g., bridge abutments) along the banks is possible during individual floods.

Erosion of banks is perhaps a greater concern than bed scour along lowermost Carpenter Creek, because it can result in loss of important land and any balancing deposition of bed material on the opposite (e.g., inner) bank may only concentrate flows and further exacerbate erosion. Shear stresses are higher along the outer banks of a channel bend, or meander, than along the inner banks. If the bed is also erodible, bank erosion can occur through a combination of particle-by-particle entrainment and undercutting and collapse. Indeed, rip-rap upstream and downstream of the Bridge was locally displaced and eroded by floods in 2013 and 2020 (**Figure 10**). The rip-rapped dike was repaired in 2014 (WSA Engineering Ltd., 2017) and again repaired in 2022 (SNT Geotechnical Ltd., 2022a, 2022b; **Photo 7**). Much of the material still comprising the dike along the north bank of the active channel has a similar grain size distribution – and, thus, erodibility – to mobile material within the channel. Angularity of the rip-rap somewhat helps offset its smaller size. If the thalweg maintains and strengthens its position along the north bank, upstream of the bridge, the repaired section of rip-rap may be susceptible to outflanking at its upstream end (**Photo 8**).

Photo 7: Recently placed rip-rap following scour during the 2020 flood (orangey tan colour). Rip-rap repaired upstream of the bridge (left, upstream view) has larger material (up to 1,200 mm), whereas the downstream portion (right, downstream view) has smaller material (up to 400 mm). The smaller material has a higher chance to be displaced based on the sediment mobility analysis.

Photo 8: Northeast view along the upstream portion of the dike protecting the Bridge, looking toward the intersection of Slocan Avenue and Columbia Street. Note this section of dike, although locally set back from the active channel, is constructed of erodible, cobbly fan deposits.

5.1.3 Rapid Sedimentation and Avulsion

The results of flood modelling and associated mapping of hazard limits by TRUE (2025) indicate regular floods up to the 200-year return flow, plus a 0.1 times bulking factor and climate change factor, are contained within the active channel corridor between the rip-rapped flood/erosion control dikes. These results are based on current channel bed elevations and cross-sectional geometry. A more conservative assessment of flood hazard limits would consider the possibility of sudden accumulation of bed material and/or woody debris impeding flow along the active channel corridor, to a point that floodwater spills overbank and inundates adjacent areas of the contemporary fan of Carpenter Creek. If such an accumulation formed downstream of the Bridge, the portions of fan closest to the active channel corridor would most likely be affected soonest and to the greatest depth (**Figure 11**). This inundation zone would terminate at the marina and generally be within the limits of the flood-prone width of Carpenter Creek as recently as 1966 (**Figure 8**). Prior to dike construction, the marina was damaged following a spring flood in 1974 (WSA Engineering Ltd., 2012). A more extreme accumulation could lead to backwatered floodwater spilling overbank around the intersection of Josephine Street and 3rd Avenue and flowing southwestward to the fan front at Slocan Lake.

An overspill event or more substantive avulsion could theoretically initiate at, or near, the apex of the contemporary fan of Carpenter Creek (where the Bridge is located) in response to one, or both, of two processes:

- **Rapid aggradation at, or immediately upstream of, the Bridge** – In the event that sediment deposits and rapidly accumulates in the channel beneath or immediately upstream of the Bridge, such as in the waning stages of a clearwater flood or debris flood, the corresponding rise in bed elevation would reduce hydraulic capacity and freeboard beneath the Bridge. Floodwater could eventually become backwatered and rise upstream of the bridge.
- **Obstruction of the Bridge crossing by woody debris** – Floodwaters are forced to narrow as they pass beneath the Bridge to a width slightly narrower than the natural pinch-point along the active channel corridor. Any woody debris, including large trees, rafted by the floodwater must also pass beneath the Bridge. If enough woody debris reaches the constriction beneath the bridge at the same time, it could form a logjam and at least partially obstruct flows. In addition to risking damaging the bridge structure or its approaches, a sufficiently large logjam could initiate upstream backwatering and a corresponding rise in water level.

Based on the surface morphology of the Carpenter Creek fan complex, water that spills overbank at or near the apex of the contemporary fan would gradually begin inundating areas south of the creek and east of Union Street. An avulsion could occur if floodwater overtops and/or breaches a section of the Union Street embankment, likely in the vicinity of its intersection with 3rd Avenue. Despite the potential for an overspill or avulsion event to occur, the likelihood remains low for several reasons: (1) most bed material that reaches the Bridge will continue, unimpeded, to the creek mouth at Slocan Lake (Section 4.3.3); (2) woody debris accumulations have been too small to obstruct flow beneath the Bridge during recent floods; and (3) the raised approaches to the Bridge are well above the natural fan surface. Furthermore, the likelihood of the surface of the contemporary fan being affected by an overspill or avulsion event decreases away from the active channel corridor, largely based on existing fan surface topography (**Figure 11**).

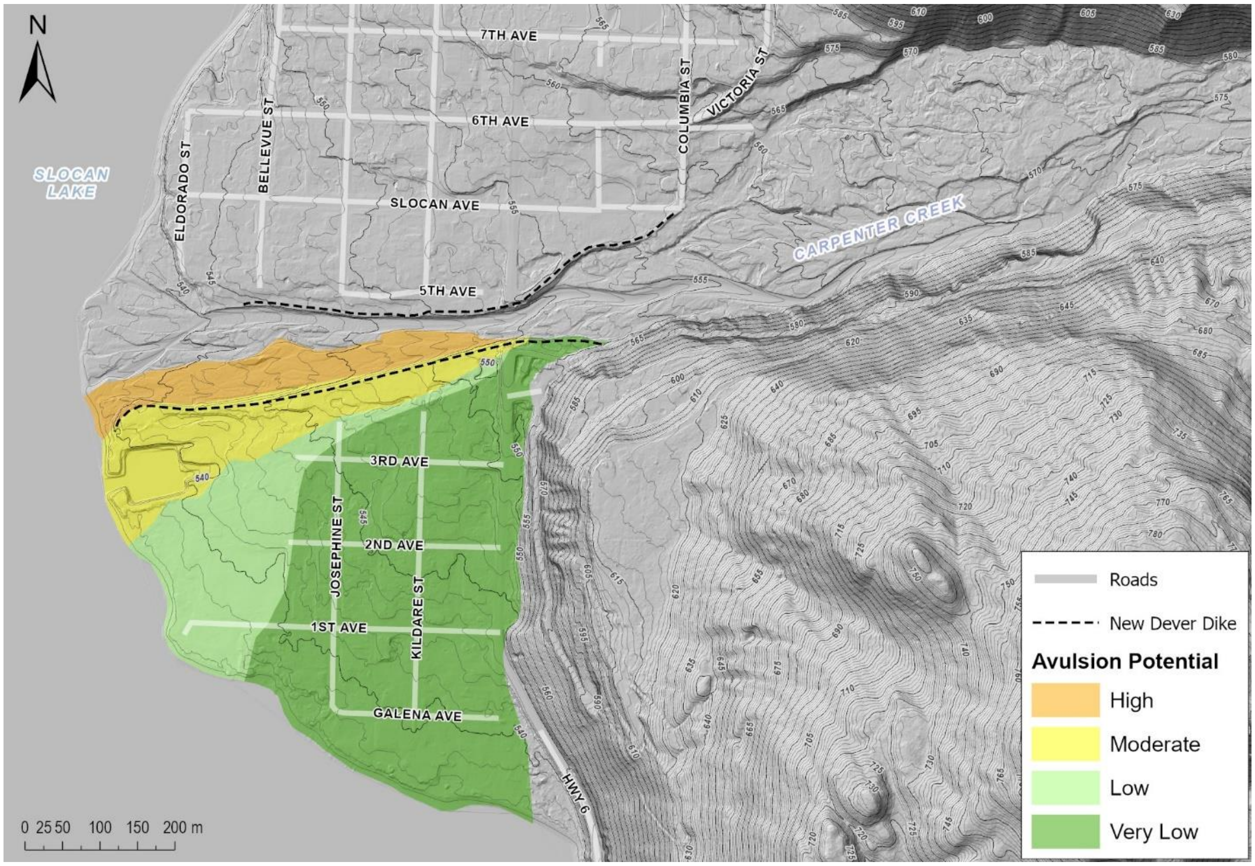


Figure 11: Generalized zones of relative avulsion potential on the contemporary fan of Carpenter Creek (south of the active channel corridor), based on consideration of potential initiation mechanisms, effects of existing dikes, and surface topography. Dashed black lines depict extent of flood/erosion mitigation dikes. Base image: Hillshaded 2018 LiDAR (GeoBC) with 1 m contours.

5.2 Recommendations

Three recommendations for TRUE's consideration follow from this geomorphological assessment:

1. **Floodplain survey updates** – Lowermost Carpenter Creek is inherently a dynamic system, with a wandering to braided pattern that is sensitive to flood events and variations in sediment supply. Bed elevations, bar patterns and thalweg configurations can vary over short periods, sometimes undergoing adjustment over the course of a single flood. Channel conditions are a key input to flood modelling and associated hazard limit mapping. As such, updates to topographic and bathymetric surveying of the active channel corridor may be worthwhile every 5-10 years and/or after any major floods. Flood hazard mapping could then be updated, accordingly.
2. **Watershed review** – A variety of mountain slope and valley bottom processes occurs within the Carpenter Creek watershed, some of which have the potential to affect flooding in New Denver. A desktop review, potentially supported by an overview flight by helicopter or fixed-wing aircraft, could be periodically completed to inspect the valleys for any features with the potential to increase flood-related hazards and risks (e.g., landslide dams).

3. **Sensitivity analysis of avulsion potential and pathways** – The discussion of avulsion potential (Section 5.1.3) focused on explanations of how and roughly where an avulsion might occur. To better explore the likelihood of an avulsion occurring, and potential flow paths, a sensitivity analysis could be completed as part of a future study. Cross-sectional geometry along the current channel could be manipulated to simulate bed aggradation and/or logjam formation, as a basis for assessing flows at which overspill may occur and the potential pathways of initial floodwater. Such information may assist in risk management and in emergency preparedness initiatives.

6.0 Summary

SLR completed a geomorphological assessment of flood-related hazards to which New Denver may be exposed based on its situation on a fan complex at the mouth of Carpenter Creek. Carpenter Creek drains a mountainous watershed with rugged, alpine peaks in its headwaters and V- to U-shaped valleys along which it and its two major tributaries, Kane Creek and Seaton Creek, flow. Although debris flows are widespread on gullied mountainsides within the watershed, they do not appear to affect the fan at the mouth of Carpenter Creek. Clearwater floods and debris floods represent the main hazards, based on a Melton ratio of 0.09, interpretation of aerial/satellite imagery and LiDAR data, and field observations. Recent floods, such as those in 2013 and 2020, forced the repair of sections of rip-rapped dikes designed to control flooding and erosion in the vicinity of the Bridge. The channelization (e.g., dikes) of Carpenter Creek and its history of degradation have created a terraced fan surface that helps confine flood flows to the contemporary channel corridor. The potential for overspill or avulsion outside the active channel corridor has been preliminarily mapped. Potential hazard areas are concentrated along the northern portion of the fan where elevations are lower. Risk management initiatives in the community would benefit from updates to flood hazard mapping (TRUE, 2025) and key elements of this geomorphological study at regular intervals (e.g., 5-10 years) and/or after major floods.

7.0 Closure

SLR appreciates the opportunity to support TRUE in its assessment of flood-related geomorphological hazards to which New Denver may be exposed. Should you have any questions, please do not hesitate to contact the undersigned.

Regards,

SLR Consulting (Canada) Ltd.

Michael Brierley, M.Sc.
Fluvial Processes Specialist
michael.brierley@slrconsulting.com

Robin McKillop, M.Sc., P.Geo.
Principal Geomorphologist
robin.mckillop@slrconsulting.com

Roberta Adams, M.Sc., P.Geo., PMP
Operations Lead – Geology
roberta.adams@slrconsulting.com

EGBC Permit to Practice #1001562

8.0 References

BGC Engineering Inc., 2019. Flood and Steep Creek Geohazard Risk Prioritization. Report prepared for the Regional District of Central Kootenay.

BGC Engineering Inc., 2020. Steep Creek Assessment Methodology, RDCK Floodplain and Steep Creek Study. Report prepared for the Regional District of Central Kootenay.

Case, B., Egyir, P., and Geertsema, M., 2003. Catastrophic failure of a beaver dam at Chudnuslida Lake, east central British Columbia. In Proceedings of the 3rd Canadian Conference on Geotechnique and Natural Hazards, Edmonton, AB.

Church, M. and Jakob, M., 2020. What is a debris flood? Water Resources Research, 56(8), e2020WR027144.

Church, M. and Ryder, J.M., 1972. Paraglacial Sedimentation: A Consideration of Fluvial Processes Conditioned by Glaciation. Geological Society of America. Bull. 83(10), 3059.

Clague, J.J. and Evans, S.G., 2000. A review of catastrophic drainage of moraine-dammed lakes in British Columbia. Quaternary Science Reviews, 19(17-18), pp.1763-1783.

Climate Change Adaptation Program, 2024. Regional Adaptation for the Kootenay and Boundary. Accessed via https://www.bcclimatechangeadaptation.ca/regional-adaptation/kootenay-boundary/

Clover Point Cartographics, 1980. Terrain inventory mapping. FRBC 36, BAP ID 4409, scale 1:50,000.

Costa, J.E., and Schuster, R.L., 1987. The formation and failure of natural dams. U.S. Geological Survey, Open File Report 87-392, 39 p.

Engineers & Geoscientists British Columbia, 2018. Legislated flood assessments in a changing climate in BC, Version 2.1. Natural Hazards, Professional Practice Guidelines, August 28, 2018, 175 pp. incl. appendices.

Fulton, R.J., Rutter, N.W. and Shetsen, I., 1984. Surficial geology, Kootenay Lake, British Columbia-Alberta. Geological Survey of Canada, Open File, 1084.

Howes, D.E. and Kenk, E., 1997. Terrain Classification System for British Columbia (Version 2). Province of British Columbia, Resource Inventory Branch, Ministry of Environment, Lands and Parks; Recreational Fisheries Branch, Ministry of Environment; and Surveys and Resources Mapping Branch, Ministry of Crown Lands, 102 pHungr, O., Evans, S.G., Bovis, M. and Hutchinson, J., 2001. Review of the Classification of landslides of the flow type: Environmental and Engineering Geoscience. Geological Society of America and the Association of Engineering Geologists, 7(3), pp.231-228.

Hungr, O., Evans, S.G., Bovis, M.J., and Hutchinson, J.N., 2001. A review of the classification of landslides of flow type. Environmental and Engineering Geoscience, 7, pp. 221-238.

Hungr, O., Leroueil, S., and Picarelli, L. 2013. Varnes Classification of landslide types, an update. Landslides, 11, 167-194.

Melton, M.A., 1957. An analysis of the relations among elements of climate, surface properties, and geomorphology (Vol. 11). New York: Department of Geology, Columbia University.

Ryder, J.M., Fulton, R.J., and Clague, J.J., 1991. The Cordilleran ice sheet and the glacial geomorphology of southern and central British Colombia. Géographie physique et Quaternaire, 45(3), pp.365-377.Clague, J.J. and Ward, B., 2011. Pleistocene glaciation of british Columbia. In Developments in quaternary sciences (Vol. 15, pp. 563-573). Elsevier.

Shields, A., 1936. Anwendung der Ähnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung. Mitteilung der preussischen Versuchsanstalt fur Wasserbau und Schiffbau, 26, Berlin.

SNT Geotechnical Ltd., 2020. New Denver Dike Erosion 2020 Disaster Financial Assistant Application

SNT Geotechnical Ltd., 2022a. Carpenter Creek Flood Mitigation, New Denver, BC for the Village of New Denver

SNT Geotechnical Ltd., 2022b. Design Brief – Carpenter Creek Dike Repair 2022

Surewood Forest Consultants Ltd., 2000. Carpenter Arrow KL. Terrain stability mapping. FRBC KB97202-0RE1, scale 1:20,000.

TRUE Consulting, 2025. Flood Frequency Analysis of Carpenter Creek, Village of New Denver.

Turner, R.J.W., Anderson, R.G., Franklin, R., Anderton, L., and Fowler, F., 2009. GeoTour Guide for the West Kootenay, British Columbia Geology, landscapes, mines, ghost towns, caves, and hot springs. GeoFile GF2009-06.

Wilcock, P. R., and McArdell, B. W., 1993. Surface-based fractional transport rates: Mobilization thresholds and partial transport of a sand-gravel sediment. Water Resources Research, 29(4), 1297-1312.

Wilcock, P.R., and Crowe, J.C., 2003. *Surface-based Transport Model for Mixed-Size Sediment*. Journal of Hydraulic Engineering, 129(2), p. 120-128.

Wilford, D.J., M.E. Sakals, J.L. Innes, R.C. Sidle, and Bergerud, W.A., 2004. Recognition of debris flow, debris flood and flood hazard through watershed morphometrics. Landslides 1(1):61–66.

Wilford, D.J., Sakals, M.E., Grainger, W.W., Millard, T.H., and Giles, T.R., 2009. Managing forested watersheds for hydrogeomorphic risks on fans. B. C. Ministry of Forest and Range, Victoria. Land Management Handbook 61: 1–62

Wolman, M.G., 1954. A method of sampling coarse river-bed material. *EOS, Transactions American Geophysical Union*, *35*(6), pp.951-956.

WSA Engineering Ltd., 2012. Carpenter Creek Restoration Plan.

WSA Engineering Ltd., 2017. New Denver Preliminary Flood Hazard Assessment Report.

Palmer™

PART OF SLR

APPENDIX D

Flood Hazard Map

200-Year End of Century with Climate Change Flood Hazard Map

- Flow Direction
- Creek
- Flood Construction Level (FCL) Creek Isoline
- Major Ground Contours at 5m Intervals
- Lakeshore Flood Hazard Limit
- Flood Hazard Zone with Freeboard
- Municipal Boundary (Village of New Denver)

Scale:	1:5,000		
Coordinate System:	NAD83 CSRS UTM 11N		
Vertical Datum:	CGVD2013		
Drawn by:	ET	Review:	PP
Rev:	01	Issued for:	Review
Project No.:	1479-111	Date:	3/14/2025

1479-111-01

TRUE

\\tcgbckamdc1\Data\Clients\1400-1499\1479\1479-111\03 Drawings\GIS\1479-111.aprx