Attachment 1:

Trans Mountain Expansion Project, Hydrology – Notable Watercourse Crossings: NEB Condition 65, May 19, 2017.



TRANS MOUNTAIN EXPANSION PROJECT
Hydrology – Notable Watercourse Crossings

NEB Condition 65

May 19, 2017

TABLE OF CONCORDANCE

Condition 65 is applicable to the following legal instrument: OC-064 (CPCN). The table below describes how this report addresses the Condition requirements applicable to **Hydrology – Notable Watercourse Crossings**.

LEGAL INSTRUMENT CONCORDANCE WITH NEB CONDITION 65: HYDROLOGY – NOTABLE WATERCOURSE CROSSINGS

NEB Condition 65	OC-064 (CPCN)
Trans Mountain must file with the NEB, at least 3 months prior to commencing construction, revised flood frequency estimates for all notable watercourse crossings, as defined by Trans Mountain in its application. These estimates must incorporate the results of field investigations and bathymetric surveys completed since the Project application was filed, and be presented in a format similar to that presented in Application Volume 4A, Appendix I – Route Physiography and Hydrology Report, Appendix B – Notable Water Crossing Catchment Details (Filing A56000).	This Report Section 2.0

EXECUTIVE SUMMARY

In response to NEB Condition 65, Trans Mountain has revised the flood frequency estimates for all notable watercourse crossings, as defined by Trans Mountain in its application. The revised estimates are included in the BGC report "NEB Condition 65 – Hydrology – Notable Watercourse Crossings" (Appendix A). These estimates incorporate the results of field investigations and bathymetric surveys completed since the Project application was filed, and are presented in a format similar to that presented in Application Volume 4A, Appendix I – Route Physiography and Hydrology Report, Appendix B – Notable Water Crossing Catchment Details (Filing A56000).

Since the Application, a route revision has made the two crossings of the Fraser River near Rearguard obsolete. This report provides an update for the 60 watercourse crossings reported on by Trans Mountain (2013), to which 17 watercourse crossings were added after their importance was highlighted during the detailed engineering and design phase of the Project.

Table of Contents

1.0 INTRODUCTION

Trans Mountain Pipeline ULC (Trans Mountain) submitted a Facilities Application (the Application) to the National Energy Board (NEB) in December 2013 for the proposed Trans Mountain Expansion Project ("the Project" or "TMEP"). On November 29, 2016, the Governor in Council concluded that the Project was in the public interest of Canada. A Certificate of Public Convenience and Necessity (CPCN) allowing the Project to proceed, subject to 157 conditions, was issued on December 1, 2016

2.0 DISCUSSION

In response to NEB Condition 65, Trans Mountain has revised the flood frequency estimates for all notable watercourse crossings, as defined by Trans Mountain in its application. These estimates incorporate the results of field investigations and bathymetric surveys completed since the Project application was filed, and are presented in a format similar to that presented in Application Volume 4A, Appendix I – Route Physiography and Hydrology Report, Appendix B – Notable Water Crossing Catchment Details (Filing A56000).

2.1 Selection of Watercourse Crossings

Section 1.4 of the BGC report (Appendix A) discusses the criteria for selection of watercourse crossings and for their designation as Notable Watercourse Crossings. The list of Notable Watercourse Crossings is provided in Table 1-1 in Section 1.4 of the report, and includes a total of 77 crossings.

2.2 Field Investigations

Section 4.0 of the report (Appendix A) describes the field investigations completed in 2014 and 2015. Field observations were collected as part of the hydro-technical field investigations at each watercourse crossing visited and included, but were not limited to: stream process characterisation; measurement of channel dimensions along the RoW; surveying of the water level; estimation of the channel substrate particle size by Wolman sampling; and measurement of streamflow using a flowmeter.

Detailed surveys of watercourse crossings, completed in 2014 and 2015 by professional surveyors under the direction of the pipeline engineers, contributed to field investigations by providing site-specific topographic and bathymetric data.

2.3 Flood Frequency Estimates

Flood frequency estimates are included in Appendix D – Crossing Drawings of the report (Appendix A), and and are presented in a format similar to that presented in Application Volume 4A, Appendix I – Route Physiography and Hydrology Report, Appendix B – Notable Water Crossing Catchment Details (Filing A56000).

APPENDIX A: NEB CONDITION 65 – HYDROLOGY – NOTABLE WATERCOURSE CROSSINGS (BGC ENGINEERING INC.)

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

TRANS MOUNTAIN PIPELINE ULC

TRANS MOUNTAIN EXPANSION PROJECT

NEB CONDITION 65 – HYDROLOGY – NOTABLE WATERCOURSE CROSSINGS

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LIMITATIONS

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1.0 INTRODUCTION

1.1. Project Description

Trans Mountain Pipeline ULC (Trans Mountain) submitted a Facilities Application (the Application) to the National Energy Board (NEB) in December 2013 for the proposed Trans Mountain Expansion Project ("the Project" or "TMEP"). On November 29, 2016, the Governor in Council concluded that the Project was in the public interest of Canada. A Certificate of Public Convenience and Necessity (CPCN) allowing the Project to proceed, subject to 157 conditions, was issued on December 1, 2016.

In developing its Application, Trans Mountain commenced a program of extensive discussions with landowners, engagement with Aboriginal groups, and consultation with affected stakeholders. This program was intended to gather input from these groups into the Application and supporting Environmental and Socio-economic Assessment (ESA), and to continue to assist Trans Mountain in the design and execution of the Project. Trans Mountain is also working with Appropriate Government Authorities to carry out the necessary reviews, studies and assessments required for the Project.

The physical components of the Project include: the installation of new pipeline segments and reactivation of existing lines that are currently maintained in a deactivated state; construction of pump stations; expansion of existing terminals through the addition of new tanks and other infrastructure and construction of a new dock complex at Westridge Marine Terminal; and the addition of new power lines under the jurisdiction of the appropriate provincial authorities. Specific to this document, the proposed expansion will comprise the following:

- using existing active 610 mm (NPS 24) and 762 mm (NPS 30) O.D. buried pipeline segments;
- constructing three (3) new 914 mm (NPS 36) O.D. buried pipeline segments totaling approximately 863.5 km:
  - Edmonton to Hinton – approximately 338.6 km;
  - Blue River to Darfield – approximately 153.4 km; and
  - Black Pines to Burnaby – approximately 371.5 km;
- constructing one (1) new 1,067 mm (NPS 42) O.D. buried pipeline segment:
  - Hargreaves to Blue River – approximately 121.4 km;
- constructing two (2), 3.4km long 762 mm (NPS 30) O.D. buried delivery lines from the Burnaby storage Terminal to the Westridge Marine Terminal (the Westridge Delivery Lines).

Known reference points along the existing Trans Mountain pipeline system are commonly referred to as Kilometer Post or "KP". KP 0.0 is located at the Edmonton Terminal where the existing Trans Mountain system originates. KPs are approximately 1 km apart and are primarily used to describe features along the pipeline for operations and maintenance purposes. KPs referenced in this report are based on proposed alignment SSEID 005, dated December 19, 2016.

1.2. Background

The proposed SSEID005 route for the pipeline traverses a range of physiographic regions including the Southern Rocky Mountains, the Columbia Mountains, the Interior Plateau, the Cascade Mountains, and the Georgia Depression from Edmonton, AB to Burnaby, BC. A general description of the physiography, topography, bedrock lithology, geological history, surficial geology, climate and hydrology for each region that the proposed TMEP pipeline will pass through was presented as part of the Project Design and Execution Plan and filed with the NEB in 2013 under filing reference A56000, Application Volume 4A, Project Design and Execution – Engineering, Appendix I – Route Physiography and Hydrology Report (Trans Mountain 2013).

The crossing of such diverse landscape implies the existence of numerous geohazards along the proposed pipeline route, which were evaluated in a desktop-level Quantitative Geohazard Frequency Assessment presented as part of the Technical Update No. 1 Consultation Update No. 2 Part No. 2 and filed with the NEB in 2014 under filing reference A62087 (Trans Mountain 2014).

Since the issuance of Trans Mountain (2013) and Trans Mountain (2014), and as part of the Project's detailed engineering and design phase, field investigations and detailed analyses were conducted to assess these geohazards with respect to pipeline safety, and to provide mitigation design to protect the pipeline from exposure and loss of containment.

1.3. Scope of Work and Objectives

Trans Mountain (2013) presented detailed hydrological information such as average seasonal flows and estimated peak flows for various return periods for major rivers, and regional hydrological information for the multiple smaller watercourses crossed by the proposed pipeline. The conclusions presented by Trans Mountain (2013) were limited to the scope of the office study undertaken, as no field investigations or detailed analyses had been completed as part of the work. The scope of work for the present report is to satisfy the National Energy Board (NEB) condition No. 65, which reads:

> *"Trans Mountain must file with the NEB, at least 3 months prior to commencing construction, revised flood frequency estimates for all notable watercourse crossings, as defined by Trans Mountain in its application. These estimates must incorporate the results of field investigations and bathymetric surveys completed since the Project application was filed, and be presented in a format similar to that presented in Application Volume 4A, Appendix I – Route Physiography and Hydrology Report, Appendix B – Notable Water Crossing Catchment Details (Filing A56000)."*

This report provides an update on the regional climate and hydrology, and on the flood frequencies and design flow estimated at the proposed crossing of major watercourses presented by Trans Mountain (2013). These metrics were used as input for the characterisation of hydrotechnical hazards and the formulation of design criteria during the detailed engineering and design phase. The update on climate and streamflow monthly statistics, and flood frequencies and design flow was solely based on a revised selection of climate and hydrometric gauges that were deemed representative of the climatic and hydrologic conditions at the crossing. In this deliverable, the source of the data, the gauge selection, and the resulting flood quantiles and design flow are presented in order to provide further clarity.

1.4. Selection of Watercourse Crossings

The master list of watercourse crossings was first created by overlaying the proposed pipeline route with governmental and municipal networks of watercourses and water bodies. This list was complemented by mapping additional potential channels using satellite imagery, LiDAR topographic data, and field reconnaissance. A unique identifier (PXID) was assigned to every watercourse crossing, irrespective of subsequent changes in proposed pipeline alignment or chainage.

1.4.1. Site Selection Criteria

Objective criteria were applied to watercourses to identify major watercourses which will be presented in this report. In the report by Trans Mountain (2013), detailed hydrological information was provided for a total of 62 notable watercourse crossings. Since the issuance of this report in 2013, a route revision has made the two crossings of the Fraser River at RK 496.6 and 499.8 obsolete. This report provides an update for the 60 watercourse crossings reported on by Trans Mountain (2013), to which 17 watercourse crossings were added after their importance was highlighted during the detailed engineering and design phase of the Project. The complete list of 77 crossings is provided in Table 1-1.

The selection criteria for the list of major watercourse crossings generated for this report are:

- The watercourse crossing is included in the current master list of watercourse crossings
- The watercourse crossing was part of the list of notable watercourse crossings in the previous assessment (Trans Mountain 2013), or the design flow at the proposed crossing is greater than or equal to 25 m^3/s. Further details on design criteria and design flow can be found in Section 3.2 and Appendix A.

Table 1-1. List of notable crossings.

PXID[1]	Reference RK[2]	Crossing Name
W27.3	24.21	Blackmud Creek
W28.3	28.21	Whitemud Creek
W29.4	33.60	North Saskatchewan River
W32.5	36.97	Wedgewood Creek
W60.4	90.1	Unnamed Creek
W103.3	126.82	Sturgeon River
W110.3	135.04	Pembina River
W160.3	173.68	Little Brule Creek
W165.3	181.05	Brule Creek
W166.3	185.30	Lobstick River
W170.3	193.08	Carrot Creek
W180.3	220.58	Wolf Creek
W183.2	223.91	McLeod River
W184.4	227.54	Bench Creek
W190.3	245.15	Little Sundance Creek
W191.3	248.02	Sundance Creek
W197.1	269.57	Unnamed Creek
W255.2	327.50	Maskuta Creek
W1032.2	522.54	Swift Creek
W1036.3	531.24	Canoe River
W1038.3	534.42	Camp Creek
W1052.3	545.84	Camp Creek
W1056.2	547.59	Camp Creek
W1066.2	552.45	Albreda River
W1078.3	559.01	Clemina Creek
W1084.3	561.54	Albreda River

PXID[1]	Reference RK[2]	Crossing Name
W1087.3	563.69	Albreda River
W1096.1	567.62	Dominion Creek
W1097.2	571.91	Moonbeam Creek
W1118.2	580.31	Serpentine Creek
W1119.2	581.11	North Thompson River
W1120.2	582.02	Chappell Creek
W1158.3	592.94	Miledge Creek
W1175.3	600.24	Thunder River
W1185.2	613.79	Blue River
W1189.2	619.93	North Thompson River
W1196.2	626.56	Froth Creek
W1215.3	637.81	Finn Creek
W1252.2	651.55	North Thompson River
W1292.3	683.34	Mad River
W1326.2	717.69	Raft River
W1329.2	725.58	Clearwater River
W1334.2	735.13	Mann Creek
W1348.3	749.31	Lemieux Creek
W1349.3	750.93	Nehalliston Creek
W1350.2	752.34	Eakin Creek
W1361.2	768.20	Darlington Creek
W1362.2	768.50	Lindquist Creek
W1389.2	820.33	Jamieson Creek
W1431.1	846.82	Thompson River
W1478.3	892.87	Moore Creek
W1501.3	916.00	Clapperton Creek
W1524.3	928.00	Nicola River
W1532.2	931.40	Godey Creek
W1570.2	957.86	Coldwater River
W1582.2	970.26	Coldwater River
W1593.2	979.98	Coldwater River
W1594.3	980.83	Juliet Creek
W1607.3	990.02	Coldwater River

PXID[1]	Reference RK[2]	Crossing Name
W1627.2	1011.03	Boston Bar Creek
W1661.3	1020.29	Ladner Creek
W1663.2	1021.79	Coquihalla River
W1664.2	1022.88	Dewdney Creek
W1668.2	1026.48	Coquihalla River
W1671.3	1028.63	Coquihalla River
W1677.3	1032.59	Coquihalla River
W1686.2	1043.29	Coquihalla River
W1689.3	1047.25	Silverhope Creek
W1694.3	1055.49	Hunter Creek
W1698.3	1060.94	Lorenzetta Creek
W1700.3	1061.49	Wahleach Creek
W1756.1	1102.31	Vedder River
W1764.1	1110.68	Sumas Lake Canal
W1765.2	1114.60	Sumas River
W10460.0	1123.41	Clayburn Creek
W1793.1	1147.37	Salmon River
W1810.1	1169.30	Fraser River

Notes:

1. PXID's are unique watercourse crossing identifiers.
2. RK values were originally used as crossing identifiers and are provided for backward compatibility with Trans Mountain (2013).
3. Watercourse crossings added to the initial list of notable watercourse crossings presented by Trans Mountain (2013) are shaded grey.

2.0 PHYSICAL SETTING

The physical geography of Alberta and British Columbia is complex. Vast prairies, multiple mountain ranges, high plateaus, and lowlands ranging from the water-rich Rockies and Pacific Coast to the drier prairies and interior of BC are all crossed by the proposed TMEP. These physical environments have been influenced by their geological history and are shaped by their surficial and bedrock geology, climate, water, and vegetation.

The proposed TMEP route passes through nine physiographic regions. Further details of the physiography, topography, bedrock lithology, relevant geological history, surficial geology and climate for each region can be found in Trans Mountain (2013). The report is arranged by physiographic regions as this provides a division of the different types of soil, rock, topographic, climatic, and hydrologic conditions the proposed pipeline passes through.

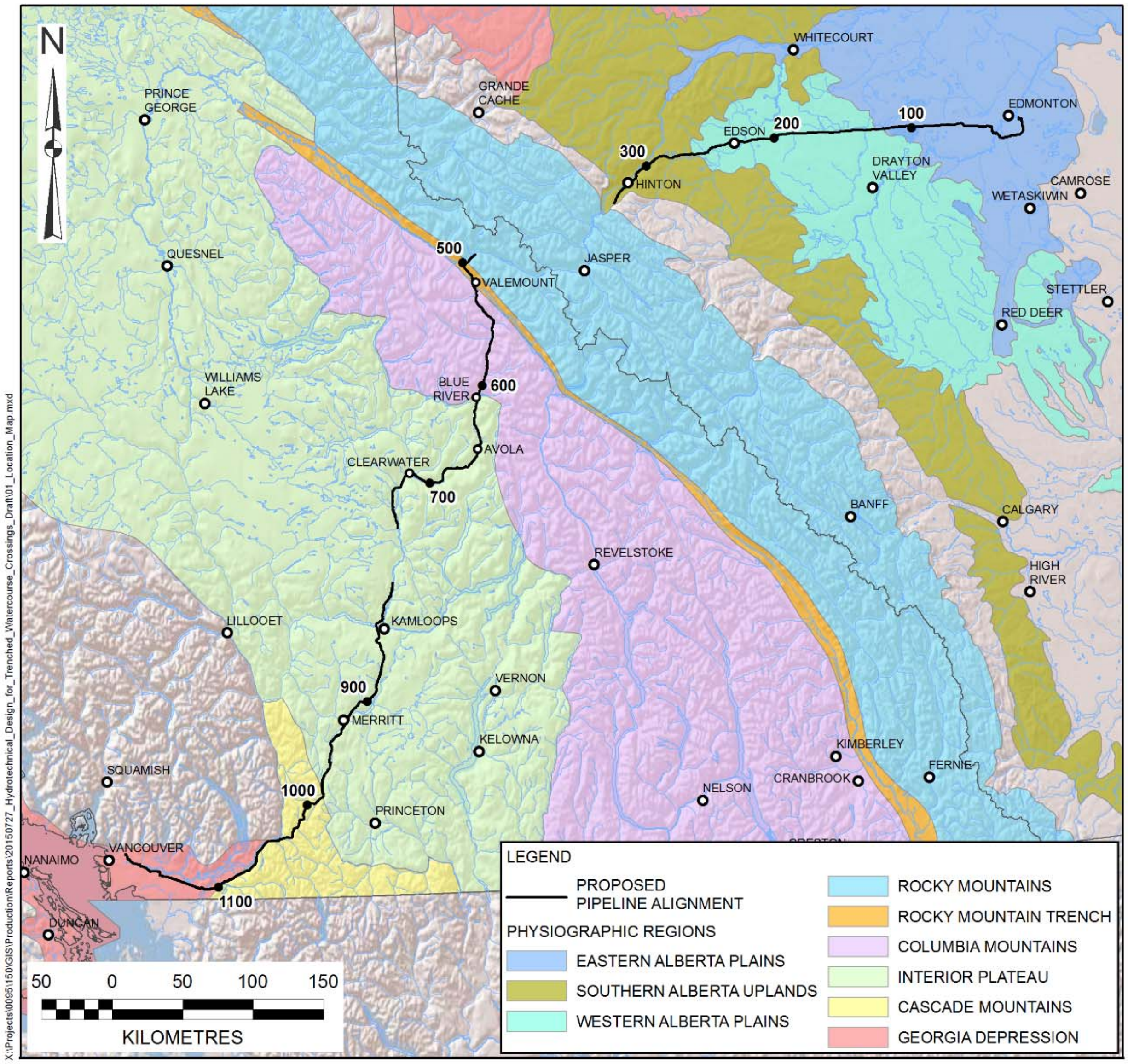

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Figure 2-1. Study area with physiographic zones.

3.0 METHODOLOGY

This section provides an overview of the various data sources used to describe climatic and hydrologic conditions, and to estimate a design flow for every major watercourse crossing along the proposed pipeline.

3.1. Climate Characterisation

3.1.1. Climate Normals

Site specific climate information is collected by climate stations and the data are available through the Canadian Database of Climate Normals and Averages operated by Environment Canada (2016a). Climate Normals and Averages are used to summarize and describe the average climatic conditions of a particular location and do not represent the spatial variability of climate variables. Climate normals are typically computed over 30 consecutive years. Those provided in this report are based on recorded climate data from 1981 through to 2010.

To account for this spatial variability, geostatistical methods were used to interpolate climate data between stations for Western North America. The CMIP3 dataset produced by the World Climate Research Programme Working Group on Coupled Modelling (http://cmip-pcmdi.llnl.gov/cmip3_overview.html?submenuheader=1) provides a reasonable interpolation of mean annual precipitation over the breadth of the Project and was used in watercourse crossing drawings (Appendix D).

3.1.2. Selection of Climate Stations

In Trans Mountain (2013), four to six climate stations were selected to represent the climate dynamics in each physiographic region. For this report, one climate station was selected for every major watercourse to represent the climate dynamics (precipitation input, temperature) within its catchment. It is important to note that climate stations are preferentially located at valley bottoms rather than ridge lines due to ease of access. Climate normals reflect this bias towards lower elevation, warmer temperature, and possibly lower precipitation.

It is acknowledged that a single climate station does not provide an exact representation of the spatial variability of climate dynamics encountered across a large catchment. However, climate normals provide an overview of the climate dynamics that could be expected on average across this catchment.

Climate stations were selected using the following criteria:

- The climate gauge was reported on in Trans Mountain (2013)
- The climate gauge is the closest to the centroid of the catchment.

3.2. Hydrological Characterisation

Streamflow data, along with the physical characteristics of the watercourse, are used to anticipate how watercourses might evolve over the lifespan of the Project. Streamflow data are recorded by hydrometric stations that have been established and are operated across Canada by the Water Survey Canada (WSC) and across the United States of America by the United States Geological Survey (USGS), to help understand and manage water resources. Streamflow records from hydrometric stations operated by the WSC were primarily used in the analysis; however, these data were complemented by streamflow records from hydrometric stations operated by the USGS for watercourse crossings located in the Lower Mainland.

Peak daily and monthly streamflow dynamics are captured in time series of daily streamflow records. Monthly averages are used for environmental and practical aspects of the crossings such as construction timing and techniques, while peak flow records are used for the characterization of hydrotechnical hazards and inform the design process requirements for the protection of watercourses, the environment, and infrastructures.

Two methods were applied to transfer the information from a gauged catchment (at the hydrometric station) to an ungauged catchment (at the proposed pipeline crossing). Proration is used when a single hydrometric station is deemed representative of the streamflow conditions at the proposed pipeline crossing. Proration is also occasionally used between a gauged catchment and an ungauged catchment providing they are in close proximity and they have similar hydrological characteristics. A regional approach is used when proration is not possible. The regional approach is based on streamflow statistics at a number of representative hydrometric stations located in the vicinity of the proposed pipeline crossing. Details of both methods, as they relate to the estimation of peak flows, are described in further detail in Appendix A.

3.2.1. Monthly Flows

Monthly flow statistics such as mean, median, and 25th and 75th percentiles were computed from daily streamflow records at a hydrometric station. While mean and median provide the general streamflow seasonal trend, the 25th and 75 percentiles provide an estimate of the variability of daily streamflow records within a month and across all selected years.

Hydrometric stations were screened for record completeness. Years with less than 90% of daily streamflow records were deemed incomplete and were discarded unless it could reasonably be assumed that the missing data coincided with a complete freeze-up of the watercourse during the winter months.

For the purpose of estimating monthly flow statistics at the proposed pipeline crossing, hydrometric stations were selected using the following criteria:

- A minimum of six complete years were available
- Both the catchment gauged by the hydrometric station and the catchment at the proposed pipeline crossing were located in the same physiographic zone and their area were of the same order of magnitude.

3.2.2. Peak Flows

Flood frequencies were computed from annual instantaneous or daily peak flows using Flood Frequency Analyses (FFA) techniques applied to Annual Maximum Series (AMS). FFA's were predominantly applied to records of annual instantaneous peak flows. In some instances, missing records were predicted from available annual daily peak flows using a standard linear regression model in order to increase the record length of annual instantaneous peak flows. The approach is covered in detail in Appendix A.

For the purpose of estimating flood frequencies at the proposed pipeline crossing, hydrometric stations were selected using the following criteria:

- A minimum of 20 recorded and predicted annual instantaneous peak flow values were available
- Both the catchment gauged by the hydrometric station and the catchment at the proposed pipeline crossing were located in the same physiographic zone
- Peak flows were not attenuated through manmade or natural features (e.g., lakes).

3.2.3. Design Criteria

The definition of a design flood event allows for the hydraulic characterisation of a watercourse crossing and for the subsequent characterisation of hydrotechnical hazards. Governmental and professional guidelines have been developed to support the management of flood protection work, or to regulate the design and construction of pipeline watercourse crossings.

The Government of British Columbia's *Guidelines for Managements of Flood Protection Works in British Columbia* (BC MoE 1999) state that the standard design flood is the flood having a 200- year recurrence period interval.

The Government of Alberta's *Code of Practice for Pipelines and Telecommunication Lines Crossing a Water Body* (AESRD 2013) under the *Alberta Water Act* states that new pipelines must be installed at an elevation that is below the 100-year bed scour depth of the water body. That is, a flood with magnitude up to the 100-year return period should not scour the bed down to the level of the pipeline.

The 200-year flood event was adopted as general design basis for the determination of the design flow used to quantify hydrotechnical hazards and design watercourse crossings along the proposed pipeline as it meets provincial guidelines in both Alberta and British Columbia.

3.2.4. Design Flow

Although the 200-year flood event was used a standard design basis, exceptions were made at three watercourse crossings to use site-specific information such as dam break and inundation studies indicating a peak flow magnitude exceeding that of the 200-year flood event. These three watercourses are the Nicola River, the Sumas River, and Clayburn Creek. Furthermore, flood magnitudes greater or equal to the 200-year event and up to the 500-year event were considered when computing the Frequencies of Loss of Containment (FLoC) as part of the Project's Quantitative Geohazard Frequency Assessment (NEB Condition No 16).

3.2.5. Accounting for Climate Change

Greenhouse gas emissions over the past century have led to significant climate change worldwide and in Canada. In terms of temperature and precipitation, clear temporal trends have emerged for Canada as illustrated in Figure 3-1 and Figure 3-2. Given the size of Canada and the variety of climatic regions, significant differences occur regionally.

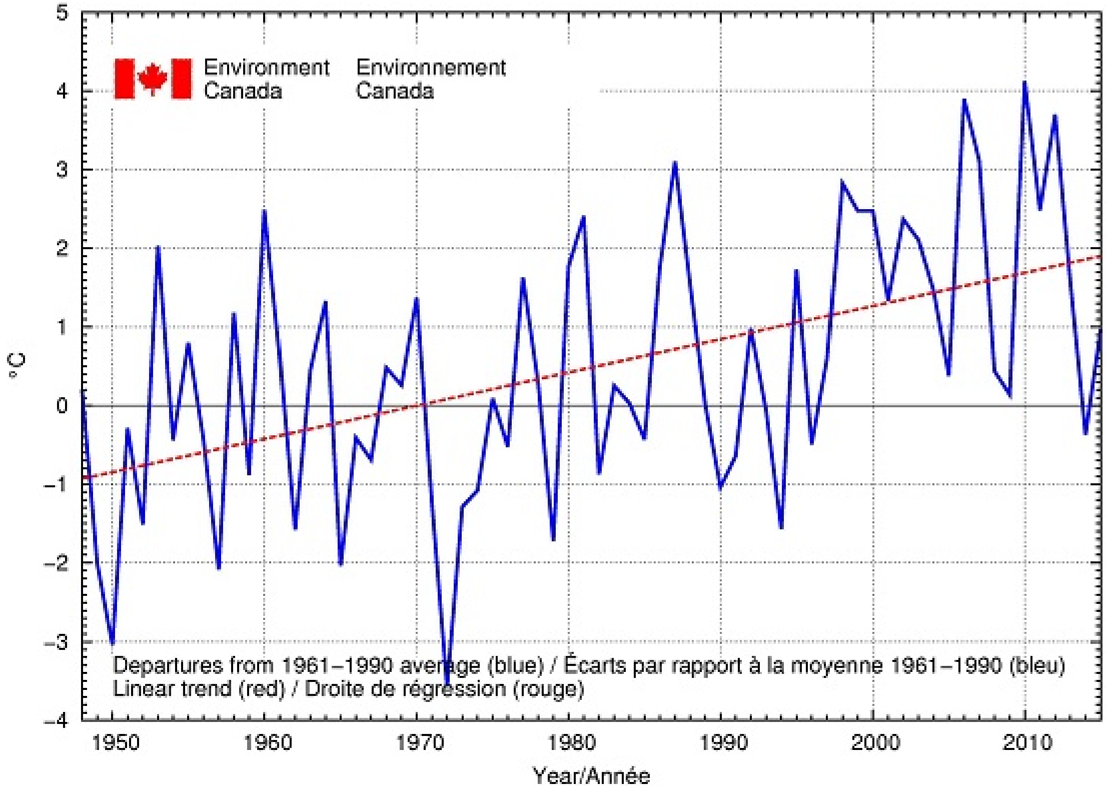

Figure 3-1. Winter mean temperature averaged across Canada (°C), 1948-2015. The linear trend (red line) indicates that winter temperatures averaged across the nation have warmed by 3.0°C over the past 68 years. Source: Environment Canada 2016b.

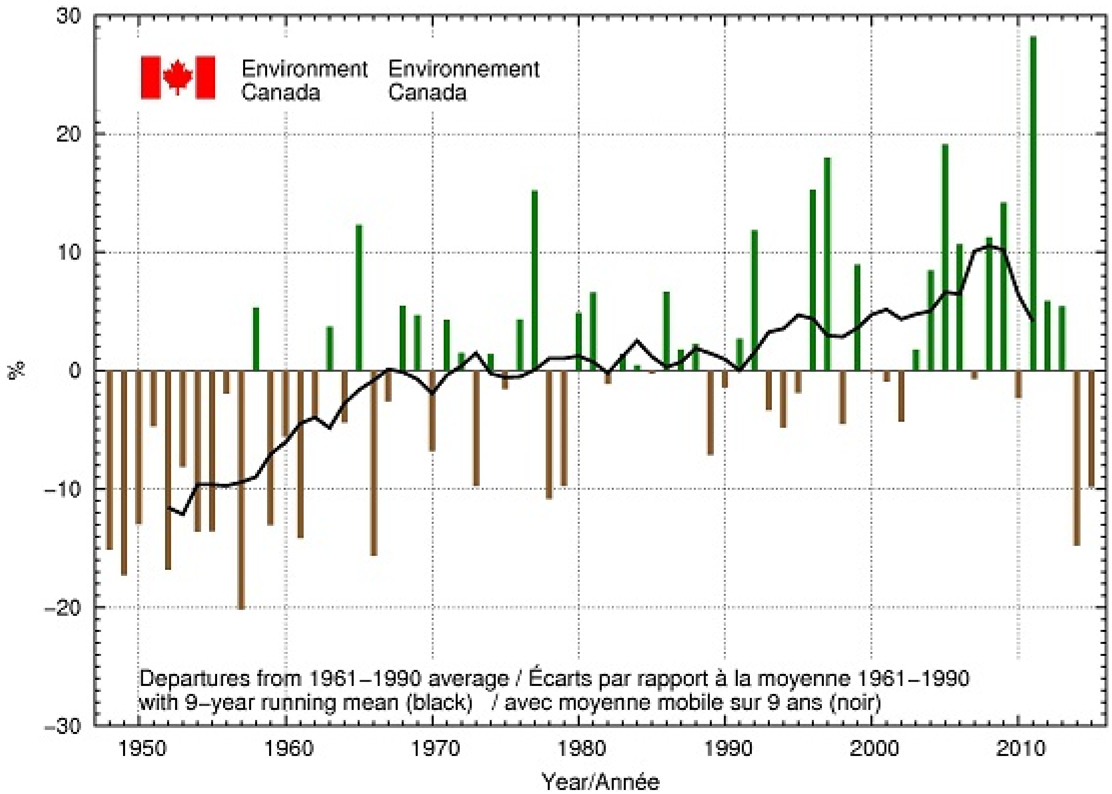

Figure 3-2. Winter total precipitation (expressed in % change from the 1961-1990 average) for Canada, 1948-2015. The trend indicates that winters have tended to be wetter than the 1961-1990 average since the mid-1970s, although the two most recent winters were drier than average. Source: Environment Canada, 2016b.

The effect chain for changes in the magnitude of peak flows and hydrotechnical hazards associated with climate change is interpreted as follows:

- Atmospheric warming will lead to changes in precipitation amounts and intensities (rates)
- Atmospheric warming will lead to the partition between precipitation falling as snow or as rain, the timing of snowmelt processes and ultimately runoff generation.

Therefore, climate change is expected to affect the magnitude - frequency relation of flood events which serves as basis for the determination of the design flow (see section 3.2.3).

The Association of Professional Engineers and Geoscientists of British Columbia (APEGBC 2012) recommends that a time series analysis of historical streamflow records be conducted and if a significant temporal trend is detected, account for it in the magnitude - frequency relation of flood events. In the absence of a significant temporal trend, APEGBC (2012) further recommends that a 10% upward adjustment be applied to the design flow to account for future changes in temperature and precipitation and their likely effect on peak flows.

While attempts have been made to detect trends in times series of extreme events (e.g., annual peak flows), the intrinsic variability of such events and relatively short record length (typically 20 to 50 years) makes trend detection difficult. Instead, trend analyses are usually conducted to detect a shift in mean conditions, rather than extreme conditions (APEGBC 2012).

As a result, a 10% upward adjustment was applied to the design flow at watercourse crossings where the 200-year flood event is used as design basis. No adjustment was applied to the design flow at watercourse crossings where a dam breach outflow was used as the design basis.

4.0 FIELD INVESTIGATIONS

Field reconnaissance plays a significant role in the assessment of hydrotechnical hazards and the formulation of the detailed engineering design of watercourse crossings. Site investigations and streamflow measurements were conducted in the summers of 2014 and 2015. Field observations were collected as part of the hydrotechnical field investigations at each watercourse crossing visited and included, but were not limited to: stream process characterisation; measurement of channel dimensions along the RoW; surveying of the water level; estimation of the channel substrate particle size by Wolman sampling (Wolman 1954); and measurement of streamflow using a flowmeter. All site investigations comprise numerous photographs, GPS waypoints and field notes.

Detailed surveys of watercourse crossings, completed in 2014 and 2015 by professional surveyors under the direction of the pipeline engineers, contributed to field investigations by providing site-specific topographic and bathymetric data. These surveys included a complete channel cross-section along the proposed pipeline route, as well as a thalweg profile extending upstream and downstream of the pipeline crossing. LiDAR data, collected between 2005 and 2014 along the proposed pipeline route for a band approximately 750 m in width, provided information on channel and floodplain characteristics above the water surface, including accurate estimates of channel gradients. Canadian Digital Elevation Data at a 1:50,000 scale was used to estimate drainage areas. Satellite imagery from Google Earth and historical aerial photographs provided additional information on the physical characteristics of the streams and their watersheds at a larger scale.

5.0 RESULTS

The climate and hydrometric stations selected for the determination of climate, streamflow and extreme flow statistics at each major watercourse crossing are presented in Table 5-1. Results of the analysis are presented in the form of a two-page drawing per crossing which illustrates the hydro-climatic context and the characteristics of the watercourse at each of the 77 watercourse crossings.

The first page of the drawing presents average climate and streamflow statistics, and the analysis of extreme flow statistics which resulted in the determination of the design flow at the watercourse crossing. Details of the climate stations and hydrometric stations used in the analysis are summarized in Appendix B and Appendix C, respectively. The second page of the drawing provides a characterization of the watercourse at the regional, reach, and crossing scales supported by field observations, survey data, and the analysis of remotely sensed data (LiDAR, aerial photographs). Crossing drawings are available in Appendix D.

Table 5-1. Summary of results for hydrologic analysis.

					Monthly Statistics		Peak Flow Statistics								
PXID[1]	Reference RK[2]	Reference KP[3]	Crossing Name	Design Flow (m^3/s)	Reference Climate Gauge	Reference Hydrometric Gauge	Nature of the Flood Frequency Analysis	Hydrometric Gauge 1	Hydrometric Gauge 2	Hydrometric Gauge 3	Hydrometric Gauge 4	Hydrometric Gauge 5	Hydrometric Gauge 6	Hydrometric Gauge 7	Hydrometric Gauge 8
W27.3	24.21	24.21	Blackmud Creek	101 (nhc 2014)[6]	3012205	05DF003	Pro-rated	05DF003_05DF006[5]							
W28.3	28.21	28.20	Whitemud Creek	170	3012205	05DF006	Pro-rated	05DF006							
W29.4	33.60	33.58	North Saskatchewan River	8070	3054845	05FD001	Pro-rated	05DF001							
W32.5	36.97	37.12	Wedgewood Creek	145	3062451	05EA012	Regional	05DF006	07BB005	07AH002	05CC009	07BA002			
W60.4	90.1	90.24	Unnamed Creek	9.6	3062451	07BB014	Regional	05EB902	07BB014	05FC002	07BB005	05CC009	05CE010		
W103.3	126.82	125.82	Sturgeon River	115	3062451	05DE009	Pro-rated	05EA010							
W110.3	135.04	134.00	Pembina River	2430	3054845	07BB002	Pro-rated	07BB002							
W160.3	173.68	172.66	Little Brule Creek	60	3065885	05CC010	Regional	07AF003	07BB005	07BA003	05EA010	07BA002	05CC010		
W165.3	181.05	180.00	Brule Creek	75	3065885	05DE009	Regional	07AF003	07BB005	07BA003	05EA010	07BA002	05CC010		
W166.3	185.30	184.24	Lobstick River	123	3065885	07BB011	Regional	07AF003	07BB005	07BA003	05EA010	07BA002	05CC010		
W170.3	193.08	192.02	Carrot Creek	130	3065885	07BB011	Regional	07AF003	07BB005	07BA003	05EA010	07BA002	05CC010		
W180.3	220.58	219.33	Wolf Creek	855	3065885	07AG003	Pro-rated	07AG003							
W183.2	223.91	222.73	McLeod River	3500	3063523	07AG001	Pro-rated	07AG001_07AG007[5]							
W184.4	227.54	226.40	Bench Creek	74	3065885	07BA003	Regional	07AF003	07BA003	07AF005	07BB005	07BA002	07AH002		
W190.3	245.15	243.98	Little Sundance Creek	21	3065885	07BA003	Regional	07AF010							
W191.3	248.02	246.69	Sundance Creek	32	3065885	07AF010	Pro-rated	07AF010							
W197.1	269.57	268.22	Sucker Creek	54	3065885	07AF010	Regional	07AF003	07BA003	07AF005	07AC008	07AF004			
W255.2	327.50	326.17	Maskuta Creek	160	3063523	07AC008	Regional	07AF015	07AF013	07AC008	07AF014	07BA003			
W1032.2	522.54	518.15	Swift Creek	72	1171393	08KA012	Pro-rated	08KA010_08KA012[5]							
W1036.3	531.24	526.82	Canoe River	205	1171393	08NC004	Pro-rated	08NC004							
W1038.3	534.42	529.96	Camp Creek	105	1171393	08KA012	Regional	08NC004	08KA008	08KA001	08LB038	07AA007			
W1052.3	545.84	541.38	Camp Creek	58	1171393	08KA012	Regional	08NC004	08KA008	08KA001	08LB038	07AA007			
W1056.2	547.59	543.14	Camp Creek	52	1171393	08KA012	Regional	08NC004	08KA008	08KA001	08LB038	07AA007			
W1066.2	552.45	548.02	Albreda River	32	1171393	08KA012	Regional	08NC004	08KA008	08KA001	08LB038	07AA007			
W1078.3	559.01	554.94	Clemina Creek	51	1171393	08KA012	Regional	08NC004	08KA008	08KA001	08LB038	07AA007			
W1084.3	561.54	557.47	Albreda River	114	1171393	08KA012	Regional	08NC004	08KA008	08KA001	08LB038	07AA007			
W1087.3	563.69	559.67	Albreda River	119	1171393	08KA012	Regional	08NC004	08KA008	08KA001	08LB038	07AA007			
W1096.1	567.62	563.68	Dominion Creek	55	1171393	08KA012	Regional	08NC004	07AA007	08KA008	08LB038	08KA001			
W1097.2	571.91	567.98	Moonbeam Creek	42	1171393	08KA012	Regional	08NC004	07AA007	08KA008	08LB038	08KA001			
W1118.2	580.31	576.36	Serpentine Creek	40	1171393	08KA012	Regional	08NC004	07AA007	08KA008	08LB038	08KA001			
W1119.2	581.11	577.12	North Thompson River	550	1171393	08LB047	Pro-rated	08LB047							
W1120.2	582.02	578.03	Chappell Creek	32	1171393	08KA012	Regional	08NC004	08KA009	08LB038	07AA007	08ND019	08KE024	08LB076	
W1158.3	592.94	588.99	Miledge Creek	46	1160899	08KA012	Regional	08NC004	07AA007	08KA008	08LB038	08KA001			
W1175.3	600.24	596.31	Thunder River	110	1160899	08LB038	Regional	08NC004	07AA007	08KA008	08LB038	08KA001			
W1185.2	613.79	609.90	Blue River	142	1160899	08LB038	Pro-rated	08LB038							
W1189.2	619.93	616.04	North Thompson River	955	1160899	08LB047	Pro-rated	08LB047							
W1196.2	626.56	622.68	Froth Creek	28	1160899	08LB038	Regional	08ND019	08LB076	08LB038	08NE008	08LE077			
W1215.3	637.81	633.92	Finn Creek	84	1160899	08LB038	Regional	08ND019	08LE077	08LB038	08NC004	08ND018	08LD009	08LB076	08NE008
W1252.2	651.55	646.81	North Thompson River	1050	1160899	08LB047	Pro-rated	08LB047							
W1292.3	683.34	678.81	Mad River	86	1168520	08LB076	Regional	08LE027	08LB076	08LB069	08LB038	08NE008			
W1326.2	717.69	713.38	Raft River	331	1168520	08LB017	Regional	08LB069	08LE027	08ND012	08LA004	08LB038			
W1329.2	725.58	721.36	Clearwater River	1730	1160899	08LA001	Pro-rated	08LA001							
W1334.2	735.13	730.52	Mann Creek	94	1165030	08LB050	Regional	08LB050							
W1348.3	749.31	744.80	Lemieux Creek	44	1165030	08LB042	Regional	08LB024	08LB076	08LB069	08LE027	08LE075			
W1349.3	750.93	746.44	Nehalliston Creek	14	1162265	08LB042	Regional	08LB024	08LB076	08LB069	08LE027	08LE075			
W1350.2	752.34	747.84	Eakin Creek	64	1162265	08LB042	Regional	08LB024	08LB076	08LB069	08LE027	08LE075			
W1361.2	768.20	763.76	Darlington Creek	16	1162265	08LB042	Regional	08LB024	08NM174	08LE075	08LE077	08LE108			
W1362.2	768.50	764.07	Lindquist Creek	18	1162265	08LB042	Regional	08LB024	08NM174	08LE075	08LE077	08LE108			

					Monthly Statistics		Peak Flow Statistics								
PXID[1]	Reference RK[2]	Reference KP[3]	Crossing Name	Design Flow (m^3/s)	Reference Climate Gauge	Reference Hydrometric Gauge	Nature of the Flood Frequency Analysis	Hydrometric Gauge 1	Hydrometric Gauge 2	Hydrometric Gauge 3	Hydrometric Gauge 4	Hydrometric Gauge 5	Hydrometric Gauge 6	Hydrometric Gauge 7	Hydrometric Gauge 8
W1389.2	820.33	816.29	Jamieson Creek	49	1165030	08LB024	Regional	08LB024	08NM174	08LE075	08LF094	08LB069			
W1431.1	846.82	842.92	Thompson River	4350	1162265	08LB064	Pro-rated	08LF051							
W1478.3	892.87	889.36	Moore Creek	59	1125079	08LE075	Regional	08LG016	08LG048	08LB024	08NM134	08LE108	08LG055		
W1501.3	916.00	912.62	Clapperton Creek	77	1125079	08LE075	Regional	08LG048	08LG016	08NM174	08NN015	08NN019	08NM171	08LB076	
W1524.3	928.00	924.66	Nicola River	122 (Golder 2009)[6]	1125079	08LG065	Pro-rated	08LG065							
W1532.2	931.40	927.73	Godey Creek	6	1125079	08NM134	Regional	05EB902	07BB014	05FC002	05CC009	05CE010			
W1570.2	957.86	954.45	Coldwater Riveru	390	1125079	08LG048	Pro-rated	08LG048							
W1582.2	970.26	966.95	Coldwater River	204	1125079	08LG048	Pro-rated	08LG048							
W1593.2	979.98	976.72	Coldwater River	175	1125079	08LG048	Pro-rated	08LG048							
W1594.3	980.83	977.66	Juliet Creek	95	1113581	08MF062	Pro-rated	08LG048							
W1607.3	990.02	986.90	Coldwater River	59	1113581	08LG048	Pro-rated	08LG048							
W1627.2	1011.03	1008.05	Boston Bar Creek	48	1113581	08MF062	Regional	12205000	12175500	08MF062	12178100	08MH056	12447390	12196000	
W1661.3	1020.29	1017.43	Ladner Creek	67	1113581	08MF062	Regional	12205000	12175500	08MF062	12178100	08MH056	12447390	12196000	
W1663.2	1021.79	1018.91	Coquihalla River	595	1113581	08MF068	Pro-rated	08MF003_08MF068[5]							
W1664.2	1022.88	1020.02	Dewdney Creek	125	1113581	08MF062	Regional	12205000	12175500	08MF062	12178100	08MH056	12447390	12196000	
W1668.2	1026.48	1023.67	Coquihalla River	755	1113581	08MF068	Pro-rated	08MF003_08MF068[5]							
W1671.3	1028.63	1025.85	Coquihalla River	985	1113581	08MF068	Pro-rated	08MF003_08MF068[5]							
W1677.3	1032.59	1029.84	Coquihalla River	1040	1113581	08MF068	Pro-rated	08MF003_08MF068[5]							
W1686.2	1043.29	1040.39	Coquihalla River	1280	1113581	08MF068	Pro-rated	08MF003_08MF068[5]							
W1689.3	1047.25	1044.36	Silverhope Creek	515	1113581	08MF009	Regional	12205000	08MF062	08MH056	12447390	12196000			
W1694.3	1055.49	1052.64	Hunter Creek	56	1104488	08MF002	Regional	12205000	12175500	08MF062	12178100	08MH056	12447390	12196000	
W1698.3	1060.94	1058.11	Lorenzetta Creek	33	1104488	08MF002	Regional	12192700	08MF062	12191800	08MG025	08MG026	12207750		
W1700.3	1061.49	1058.68	Wahleach Creek	245	1113581	08MF034	Regional	12205000	12175500	08MF062	12178100	08MH056	12447390	12196000	
W1756.1	1102.31	1100.40	Vedder River	1760	1101N65	08MH001	Pro-rated	08MH001							
W1764.1	1110.68	1108.80	Sumas Lake Canal	65	1100030	08MH091	Regional	08MH020_08MH018_08MH154[5]	08MH105_08MH155[5]	08MH129	12202300	12210900	12212050	08MH129	
W1765.2	1114.60	1112.80	Sumas River	605 (Klohn Leonoff 1989)[6]	1100030	08MH029	Pro-rated	08MH029							
W10460.0	1123.41	1121.90	Clayburn Creek	63 (KWL 2012)[6]	1100030	08MH090	Pro-rated	08MH090							
W1793.1	1147.37	1146.10	Salmon River	110	1100030	08MH126	Pro-rated	08MF005							
W1810.1	1169.30	1167.00	Fraser River	19640	1098940	08MH153	Pro-rated	08MH155	08MH098	08MH090	08MH026	08MH091	12210900		

Notes:

1. PXID's are unique watercourse crossing identifiers.
2. RK values were originally used as crossing identifiers and are provided for backward compatibility with Trans Mountain (2013).
3. KP values are based on route SSEID005 dated December 19, 2016.
4. Watercourse crossings added to the initial list of notable watercourse crossings presented by Trans Mountain (2013) are shaded grey.
5. Peak flow records from these stations were combined to create a time series of greater length.
6. A third-party peak flow estimate was adopted as design flow at this crossing (see Section 3.2.4).

6.0 CLOSURE

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Yours sincerely,

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APEGA Permit to Practice: 5366

REFERENCES

Alberta Environment and Sustainable Resource Development (AESRD). 2013. *Code of Practice for Pipelines and Telecommunication Lines Crossing a Water Body*. Alberta Government, June 24, 2013.

Association of Professional Engineers and Geoscientists of BC (APEGBC). 2012. Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC. June 2012.

British Columbia Ministry of Environment, Lands and Parks (BC MoE). 1999. *Guidelines for Managements of Flood Protection Works in British Columbia*. Public Safety Section, Water Management Branch, March 1999.

Environment Canada. 2016a. Climate Normals and Averages. Available from http://climate.weather.gc.ca/climate_normals/index_e.html. Accessed April 25, 2016.

Environment Canada. 2016b. Climate Trends and Variations Bulletin - Winter 2014-2015. Available from https://www.ec.gc.ca/sc-cs/default.asp?lang=En&n=D6271A08-1. Accessed April 25, 2016.

Golder Associates (Golder). 2009. Partial Dam Safety Review. Nicola Lake Dam British Columbia. Prepared for the Ministry of Environment. October 22, 2009.

Kerr Wood Leidal Consulting Engineers (KWL). 2012. Clayburn Creek Integrated Stormwater Management Plan Final Report. May 2012.

Klohn Leonoff Consulting Engineers (Klohn Leonoff).1989. Engineering Studies for Floodplain Management Plan Final Report. Prepared for the District of Abbotsford. July 1989.

Northwest Hydraulic Consultants (nhc). 2014. Nisku Flood Hazards Study Blackmud Creek. Prepared for Alberta Environment and Sustainable Resources Development.

Trans Mountain Pipeline ULC (Trans Mountain). 2013. Route Physiography and Hydrology. NEB Filing No A56000. https://docs.neb-one.gc.ca/ll-eng/llisapi.dll?func=ll&objId=2393365&objAction=browse. Accessed May 3, 2016.

Trans Mountain Pipeline ULC (Trans Mountain). 2014. Quantitative Geohazard Frequency Assessment NEB Filing No A62087. https://docs.neb-one.gc.ca/ll-eng/llisapi.dll/open/2490918. Accessed May 3, 2016.

APPENDIX A
DETERMINATION OF THE DESIGN FLOW

A.1. INTRODUCTION

A required input for hydrotechnical hazard assessment and design of pipeline crossings is flood discharge magnitude and quantiles (frequencies). For the TMEP, flood discharges have been estimated using a flood frequency analysis (FFA). The FFA are first carried out at gauged sites equipped with a hydrometric station and that have sufficiently long records for a statistically valid analysis. The information collected at gauged sites is then transferred to ungauged sites using regionalization methods. This appendix provides a brief description of the FFA (Section A.2), summarizes two regionalization methods (Section A.3), and outlines the selection process used to determine the most suitable regionalization method for a given crossing (Section A.4). This selection process is dependent on catchment characteristics and the amount of available regional information.

A.1.1. Historical Peak Flow Records

An FFA requires the input of streamflow data. The two federal agencies that monitor and manage hydrometric stations for Canada and the United Stated are the:

- Water Survey of Canada (WSC); and
- United States Geological Survey (USGS).

For the various watercourse crossings of the TMEP, the hydrometric stations retained for FFA were selected based on physiographic zone (Route Physiography and Hydrology, NEB Filing A56000), geographic location, availability of streamflow data (i.e., record length), drainage basin area, and regulation type. Hydrometric stations were selected which:

- demonstrate a similar monthly flow regime that is consistent with the physiographic region;
- have a reasonably long record length (minimum 20 years); and
- are not attenuated through manmade or natural features (such as lakes).

The preferred metric used for the FFA is the peak instantaneous streamflow (Q_{IMAX}) for each available year on record. However, peak streamflow records at hydrometric stations are often limited to maximum average daily streamflow (Q_{MAX}), which are lower in magnitude than peak instantaneous streamflow. The difference between peak instantaneous and average daily flows are typically greater for small basins than for very large drainage areas. In some cases, Q_{IMAX} values may be estimated from available Q_{MAX} records using regression analyses techniques.

A.2. FLOOD FREQUENCY ANALYSIS

A standard approach in hydrologic frequency modeling is the Annual Maximum Series (AMS) where the maximum value over a period of time is used for analysis. In this case, the AMS consists of the maximum peak instantaneous streamflow for each year on record. The AMS is assumed to be a random sample from the underlying population of hydrological events and can thus be predicted by the selection of an appropriate distribution.

In extreme value statistics, data follow one of three extremal types of distributions: Gumbel, Fréchet, or Weibull (Coles, 2001). These three distributions can be expressed as a single formula and are considered a family of distributions known as the Generalised Extreme Value (GEV) distribution. The GEV distribution is used for its theoretical basis in predicting extreme values. It is described by a location, scale, and shape parameter where the three extremal types are determined by the sign of the shape parameter (Gilleland and Katz, 2006). For example, when the shape parameter is negative, the distribution is described by the Weibull type. As the shape parameter approaches zero, the distribution is described by the Gumbel type. When the shape parameter is positive, the distribution is described by the Fréchet type.

For the TEMP, FFAs for gauged sites were carried out by BGC using the GEV distribution and applying the e*xtRemes* and *lmom* packages in R, a non-proprietary software environment for statistical computing and graphics (CRAN, 2015). These packages are specifically designed for extreme value statistics and implement two methods of inference (fit methods), namely *maximum likelihood estimate* and *linear moments*. The method of inference is selected on a case by case basis for each site investigation based on the availability of peak flow records. The maximum likelihood method of inference is generally preferred because it returns more precise flood quantiles estimates, but this method is unstable for small sample sizes. A record length of 60 was used as a cutoff value to select the inference method. At sites where the number of historical peak flow records exceeded this threshold, the *maximum likelihood estimate* method was implemented. Otherwise, the method of *linear moments* was implemented.

Figure A.2-1 illustrates the lack of fit of the GEV distribution inferred using the *maximum likelihood estimate* method for a record length of 42 years at WSC hydrometric station *07AF003 Wampus Creek near Hinton*. For this station, flood quantiles were derived using the method of inference based on *linear moments*. Figure A.2-2 illustrates comparable fits using either method of inference for a record length of 76 years at WSC hydrometric station *08MH016 Chilliwack River at Outlet of Chilliwack Lake*. For this station, although fits are comparable, flood quantiles were derived using the method of inference based on *maximum likelihood estimate*.

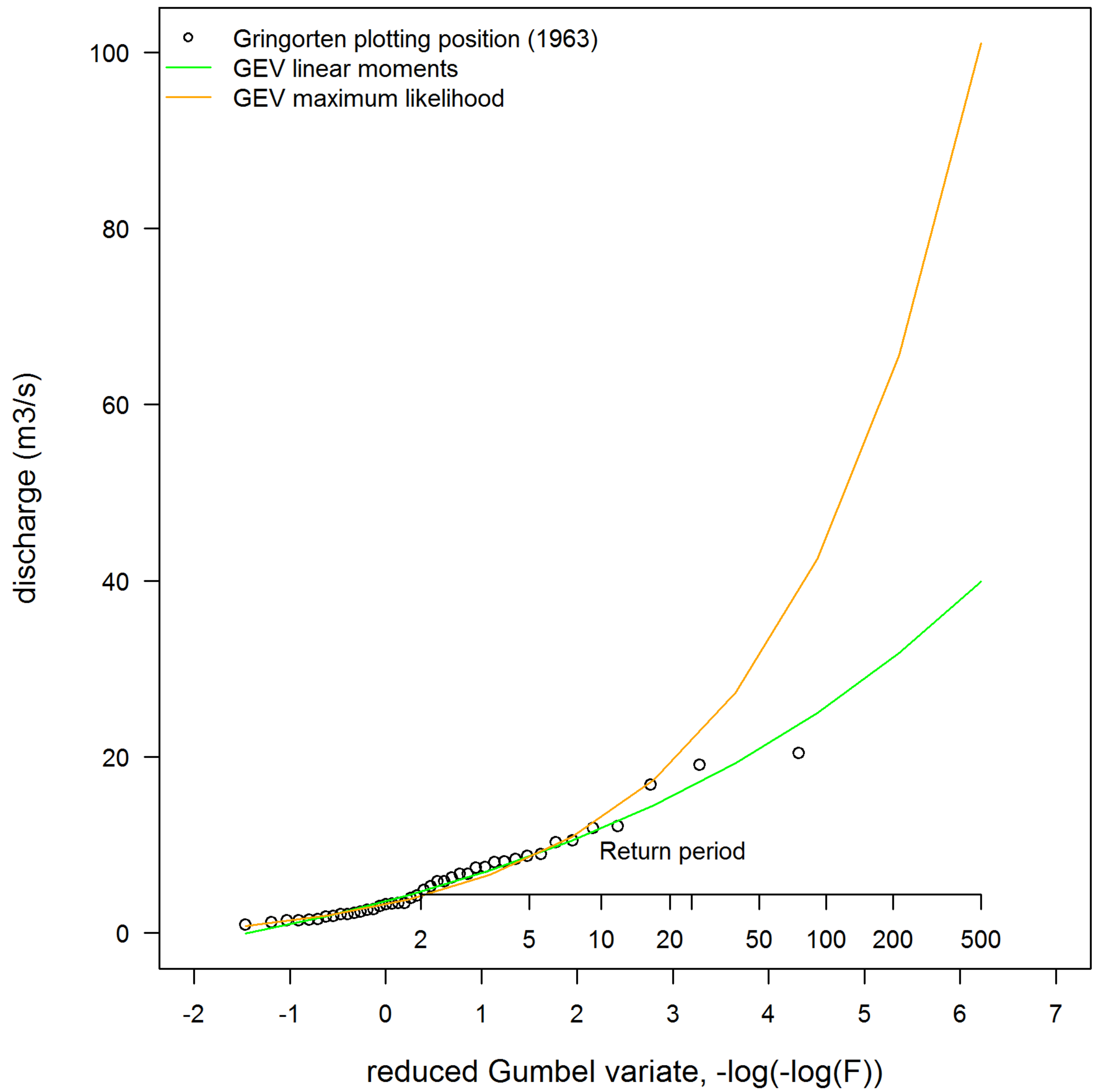

Figure A.2-1. Comparative fits at hydrometric station 07AF003 Wampus Creek near Hinton.

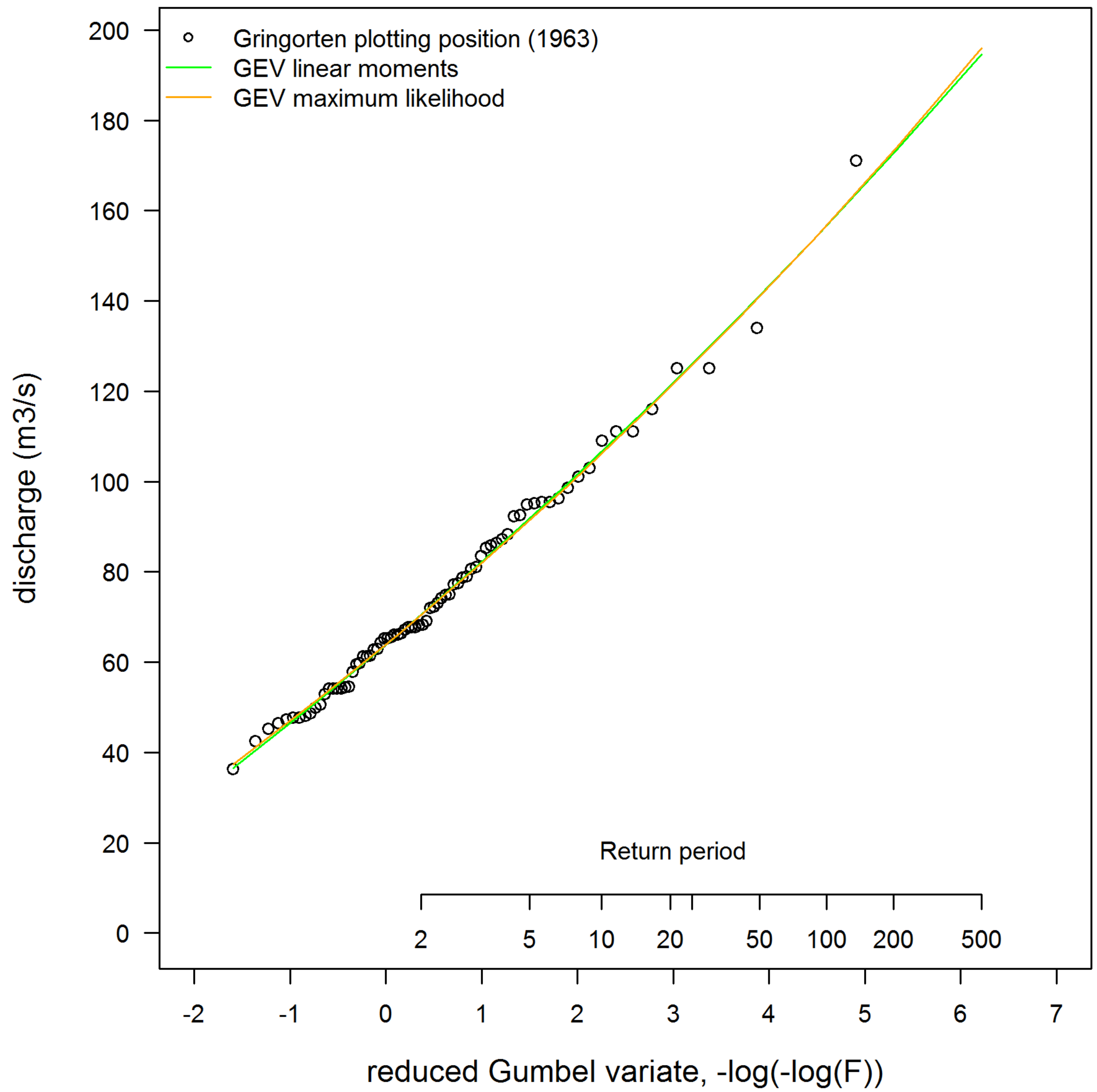

Figure A.2-2. Comparative fits at hydrometric station 08MH016 Chilliwack River at Outlet of Chilliwack Lake.

A.2.1. Prediction Limit of Dataset

The maximum return period for which a peak streamflow can be predicted reliably (i.e., the prediction limit) at a given hydrometric station is limited by the record length of the dataset defined by the number of years with a complete peak streamflow record. Where applicable, the dataset of the station of interest can be extended using a correlation analysis with a nearby hydrometric station in order to predict flood frequencies of higher return periods.

A.2.2. Statistical Validity of Dataset

The streamflow dataset needs to satisfy four statistical criteria in order to be valid for an FFA. The four statistical criteria include the following:

- Randomness
- Independence
- Stationarity
- Homogeneity

Randomness

In a hydrological context, randomness implies that the fluctuations in streamflow occur in response to natural causes. The term natural flow always means that the data series is not regulated and may be considered random. Alternatively, if the flood flows are altered by regulation (i.e., reservoir operations, water diversions, water extractions, major land-use changes etc.), the streamflow record cannot be considered random unless the regulation has been accounted for in some way. Note that some flow records may be published as regulated, although the level of regulation may not be significant. Even when statistical tests indicate that randomness has not been met, the flow data may result in an unbiased estimation of frequency if the other assumptions are valid (USGS, 1982). However, a non-random sample increases the degree of uncertainty in the relation.

Independence

Random events in a data series do not imply that they are independent. For example, large natural storage, such as provided by a lake, may cause high flows to follow high flows and low flows to follow low flows. The dependence between successive daily flows tends to be strong where the dependence between annual maxima tends to be weak.

Stationarity

The stationarity criterion implies that the data series does not change with respect to time. Examples that violate the stationarity criterion include trends, jumps and cycles. Trends may reflect a gradual change in land-use influencing the data series over time. Jumps in the data series resulting from an abrupt change in the basin or river due to the construction of a hydraulic structure is another example of non-stationarity. Another factor that can violate the stationarity criterion is the presence of cycles such as long-term climate fluctuations. However, no method is available for testing the influence of cycles adequately (Watt *et al*., 1989).

Homogeneity

Homogeneity indicates that the data series making up the sample originates from a single population. For example, a series containing a combination of snowmelt and rainfall floods may not be homogeneous and may result from different types of events (i.e., mixed populations of data). However, it may be acceptable to treat the sample as homogeneous if it is supported by a statistical test. Flow conditions can be changed due to urbanisation, diversions or a change in land cover conditions. These changes will affect record homogeneity. While such changes may not change the flow significantly from year to year, a cumulative effect can influence the flow after many years (USGS, 1982).

Statistical Tests

The statistical tests to assess the four criteria are listed in Table A.2-1. These statistical tests are non-parametric which avoid assumptions of the underlying distribution, which is generally not known for flood data. An element of judgment is inevitable in the process of assessing the statistical validity of a dataset. Statistical tests only provide a probability of satisfying particular criteria and will not yield a definitive answer. Furthermore, flood data may incorporate important measurements errors resulting from human error and the difficulty in the measurement of high flows.

Table A.2-1 Statistical criteria and corresponding statistical test.

Statistical Criteria	Statistical Test
Independence	Spearman Test for Independence
Trend	Spearman Test for Trend
Randomness	Runs Test for General Randomness
Homogeneity	Mann-Whitney Split Sample Test for Homogeneity

A.3. REGIONALISATION METHODS

The transfer of estimated design flood flows from hydrometric stations (gauged sites) to pipeline crossings (ungauged sites) requires further statistical analysis in the form of regression models. Two regionalisation methods (proration and regional FFA) were developed and are presented below. Both methods use catchment area to predict flood quantiles. The catchment area at the pipeline crossing is typically estimated using topographic data while catchment areas for the regional hydrometric stations are obtained from WSC or USGS records. The regionalisation method adopted for any given watercourse crossing is evaluated on a site-specific basis, depending on the amount of relevant regional information and the characteristics of the catchment. Details on the selection of the regional method for individual sites are provided in Section A.4.

A.3.1. Proration

Proration is conducted at sites where a single representative hydrometric station is located along the watercourse of interest. Proration is also occasionally used between a gauged catchment and an ungauged catchment providing they are in close proximity and they have similar hydrological characteristics. Flood quantiles are calculated using proration by relating the annual Q_{IMAX} values at the hydrometric station to the catchment area of the pipeline crossing. Equation A.3-1 defines this relation.

$$\frac{Q_U}{Q_G} = \left(\frac{A_U}{A_G}\right)^n \quad \text{[Eq. A.3-1]}$$

Q_U and Q_G are the peak instantaneous flow estimates (m^3/s) at the ungauged site (pipeline crossing) and gauged site (hydrometric station) respectively, A_U and A_G are the catchment areas (km^2) for the ungauged and gauged sites respectively, and n is a site-specific exponent related to peak streamflow data at both sites (Watt *et al.,* 1989). The exponent *n* has been found to vary with catchment area (TAoC, 2004). Figure A.3-1 and Table A.3-1 illustrate the proration of flood quantiles from hydrometric station *05DF001 North Saskatchewan River at Edmonton* (catchment area of 28,100 km^2) to the proposed pipeline crossing of the North Saskatchewan River (catchment area of 26,900 km^2).

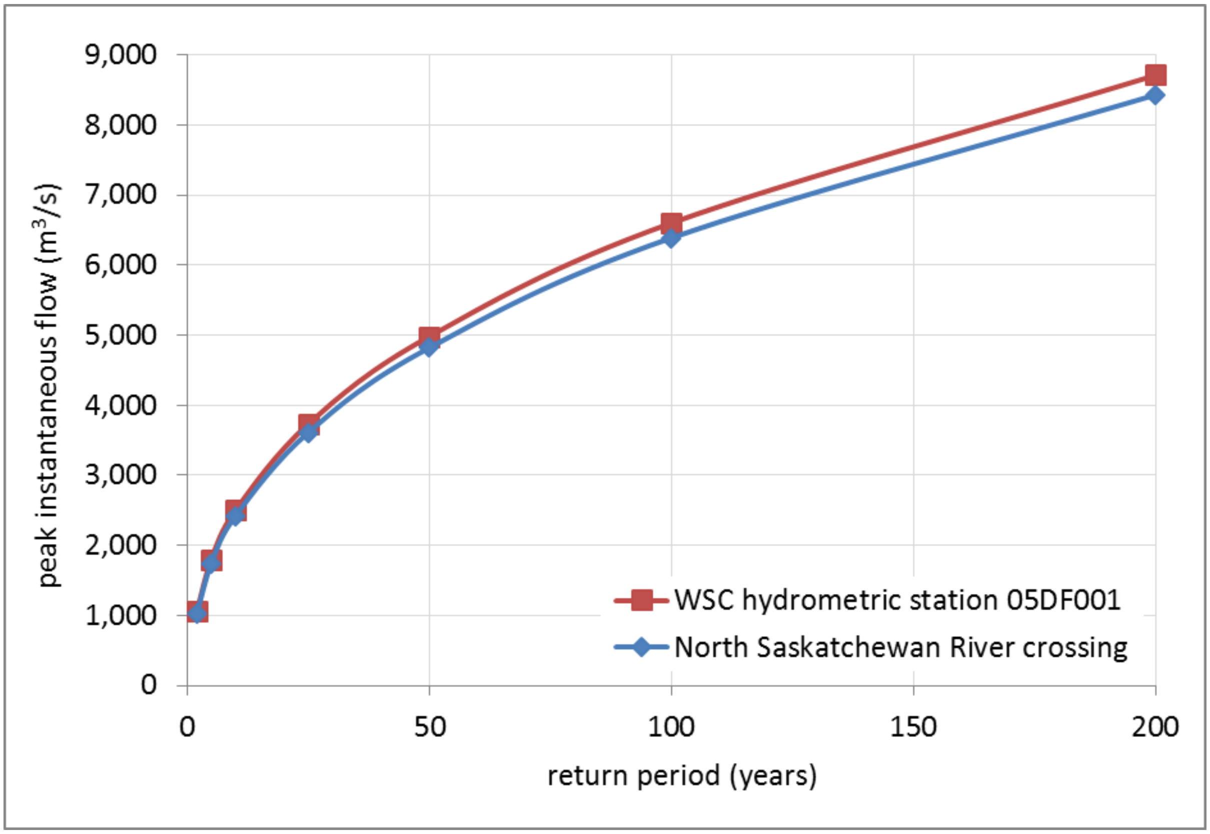

Figure A.3-1. Proration of flood quantiles at the proposed crossing of the North Saskatchewan River.

Table A.3-1. Hydrometric station selected for the proration of flood quantiles at the proposed crossing of the North Saskatchewan River.

Station Name	Station ID	Latitude	Longitude	Basin Area (km^2)	Record Period	Record Length (years)
North Saskatchewan River at Edmonton	05DF001	53º 32' 13"	113º 29' 7"	28,100	1915-2011	68

A.3.2. Regional FFA

Regional FFA are conducted when there are several representative hydrometric stations along a watercourse of interest or along adjacent watercourses in the area. Regional flood quantiles for various return periods at the pipeline crossing are calculated using a power law combining the Q_{IMAX} data from the selected regional hydrometric stations. The power law form is described by the following equation:

$$Q_p = aA^b \quad \text{[Eq. A.3-2]}$$

where Q_p is the peak flood estimate at the pipeline crossing, A is the catchment area for the crossing, and a and b are regression coefficients developed from the Q_{IMAX} and catchment area of several regional hydrometric stations (Watt *et al.,* 1989). Figure A.3-2 and Table A.3-2 illustrate the regional FFA based on a set of five representative hydrometric stations.

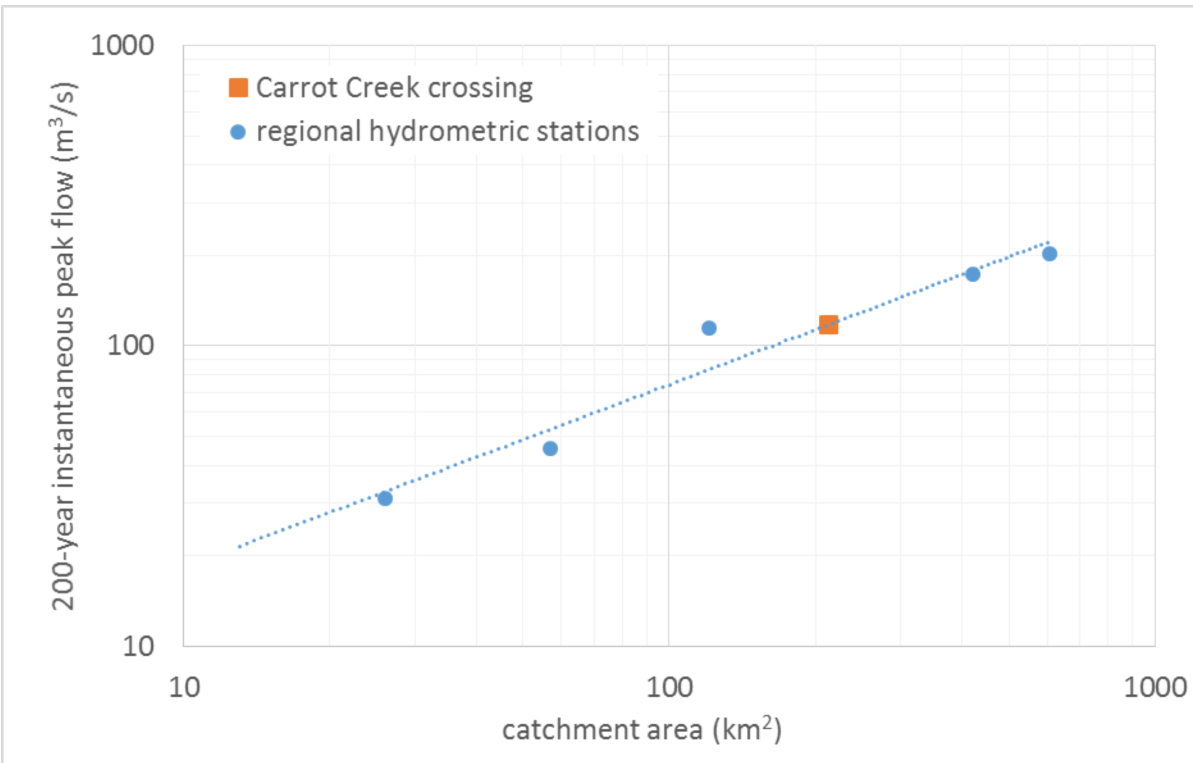

Figure A.3-2. Regional FFA at the proposed crossing of Carrot Creek.

Table A.3-2. Hydrometric stations selected for the regional FFA at the proposed crossing of Carrot Creek.

Station Name	Station ID	Latitude	Longitude	Basin Area (km^2)	Record Period	Record Length (years)	Distance to Pipeline Crossing (km)
Little Paddle River Near Mayerthorpe	07BB005	53° 56' 52"	115° 1' 24"	423	1963-2011	35	67
Rat Creek Near Cynthia	07BA002	53° 8' 17"	115° 29' 20"	606	1972-2011	33	59
Wampus Creek Near Hinton	07AF003	53° 9' 26"	117° 15' 39"	26	1968-2011	42	106
Sturgeon River Near Magnolia Bridge	05EA010	53° 35' 28"	114° 51' 34"	121	1982-2011	21	67
Block Creek Near Leedale	05CC010	52° 34' 25"	114° 34' 39"	57	1977-2010	26	145

A.4. SELECTION OF THE REGIONALISATION METHOD

The most suitable regionalisation method is evaluated on a site-specific basis, depending on the size of the catchment and the amount of available regional information. Proration is the preferred method as it draws a relation between two nested catchments, which provides overlap resulting in a high level of confidence in flood quantile estimates. Proration is used when catchment areas of the gauged and ungauged sites differ by at most one order of magnitude. It is typically applicable to large (>1000 km^2) watercourses where flows are recorded by one or multiple WSC-operated hydrometric stations. A regional FFA approach is used when the watercourse of interest is not gauged, or when catchment areas of the gauged and ungauged sites differ by more than one order of magnitude. A regional FFA approach is typically used for small to medium watersheds (< 1000 km^2). Because the regional FFA approach relies on an adequate selection of hydrometric stations, and on either interpolation, or extrapolation to the ungauged catchment of interest (pipeline crossing), the resulting flood quantiles are regarded as more uncertain than those derived from proration.

REFERENCES

Coles, S. 2001. An Introduction to Statistical Modeling of Extreme Values. Springer Verlag London Limited. pp.208.

The Comprehensive R Archive Network (CRAN). http://cran.r-project.org/. Accessed May 3, 2016.

Gilleland, E. and Katz, R.W. 2006. Analyzing Seasonal to Interannual Extreme Weather and Climate Variability with the Extremes Toolkit. Research Applications Laboratory, National Center for Atmospheric Research.

Trans Mountain Pipeline ULC. 2013. Route Physiography and Hydrology. NEB Filing No A56000. https://docs.neb-one.gc.ca/ll-eng/llisapi.dll?func=ll&objId=2393365&objAction=browse. Accessed May 3, 2016.

Transportation Association of Canada (TAoC). 2004. Guide to Bridge Hydraulics. Second Edition.

USGS. 1982. Flood Flow Frequency. Bulletin 17B of the Hydrology Subcommittee. Interagency Advisory Committee on Water Data. Office of Water Data Coordination. Reston, Virginia. 194 pp.

Watt, W. E. (Editor-in Chief), 1989. Hydrology of Floods in Canada: a Guide to Planning and Design. N.R.C., Ottawa, Canada. 245 pp.

APPENDIX B
TABULATED CLIMATE DATA

B.1. INTRODUCTION

The data provided in this appendix were taken from the Canadian Climate Normals and Averages online database for 1981 – 2010 (http://climate.weather.gc.ca/climate_normals/). These data were accessed on April 13th, 2016 for the creation of this appendix.

The table below provides a list of all climate stations used in this report. Specific station data and details can be found on the respective pages.

Station ID	Station Name	Page Number
3012205	Edmonton Int'l A	B-2
3054845	Nordegg RS	B-3
3062451	Entwistle	B-3
3065885	Shining Bank	B-4
3063523	Jasper East Gate	B-4
1171393	Cariboo Lodge	B-5
1160899	Blue River A	B-5
1168520	Valvenby	B-6
1165030	McLure	B-6
1162265	Darfield	B-7
1125079	Merritt STP	B-7
1113581	Hope Slide	B-8
1104488	Laidlaw	B-8
1101N65	Chilliwack R Hatchery	B-9
1100030	Abbotsford A	B-9
1098940	Williams Lake A	B-10

B.2. STATION DATA

Station Data Code Legend	
A	WMO “3 and 5 rule” (i.e. no more than 3 consecutive and no more than 5 total missing for either temperature or precipitation)
B	At least 25 years
C	At least 20 years
D	At least 15 years

B.2.1. 3012205 – EDMONTON INT’L A, Alberta

Latitude	Longitude	Elevation
53°19'00.000" N	113°35'00.000" W	723.30 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-12.1	-9.9	-4.4	4.2	10.2	14.1	16.2	15.2	10.2	3.8	-5.4	-11	2.6	A
Rainfall (mm)	1.4	0.5	0.9	14.9	42.9	72.7	95.6	54.9	40.3	12.6	1.6	0.8	338.8	A
Snowfall (cm)	21.7	13.4	17.5	14.4	6.5	0	0	0.1	1.1	10.4	17.3	15.9	118.1	A
Total Precipitation (mm)	23.1	13.9	18.4	29.3	49.4	72.7	95.6	55	41.4	23	18.9	16.7	446.1	A

B.2.2. 3054845 – NORDEGG RS, Alberta

Latitude	Longitude	Elevation
52°30'00.000" N	116°03'00.000" W	1,320.10 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-9.7	-7.6	-4.0	1.6	6.4	10.3	12.8	12.1	7.4	2.2	-5.6	-9.7	1.4	C
Rainfall (mm)	0.0	0.5	1.3	9.7	47.0	105.3	106.7	86.8	57.3	11.2	0.9	0.1	426.8	C
Snowfall (cm)	23.4	18.4	27.6	25.8	20.2	0.1	0.0	0.0	5.7	21.6	22.8	18.5	184.1	C
Precipitation (mm)	22.1	18.0	26.2	34.2	68.2	105.4	106.7	86.8	63.0	32.6	21.8	18.3	603.3	C

B.2.3. 3062451 – ENTWISTLE, Alberta

Latitude	Longitude	Elevation
53°36'00.000" N	114°59'00.000" W	780.30 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-11.3	-7.5	-2.8	5.0	10.3	14.3	16.5	15.4	10.8	4.4	-4.1	-9.1	3.5	D
Rainfall (mm)	1.0	0.3	0.4	20.0	55.1	101.9	103.4	76.3	43.8	17.9	2.8	1.7	424.5	D
Snowfall (cm)	27.1	15.5	16.0	9.3	5.9	0.0	0.0	0.0	1.0	14.1	22.1	15.1	126.1	D
Precipitation (mm)	28.1	15.8	16.4	29.2	61.0	101.9	103.4	76.3	44.8	32.0	24.9	16.8	550.6	D

B.2.4. 3065885 – SHINING BANK, Alberta

Latitude	Longitude	Elevation
53°51'00.000" N	115°58'00.000" W	829.10 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-11.9	-8.7	-3.5	3.8	9.2	13.1	15.5	14.2	9.2	3.1	-5.8	-10.5	2.3	A
Rainfall (mm)	1.2	0.3	2.3	15.6	49.6	86.0	98.6	69.6	46.0	15.9	1.9	1.0	387.8	A
Snowfall (cm)	28.5	17.7	20.5	10.5	3.0	0.0	0.0	0.0	1.4	9.4	21.0	16.7	128.6	A
Precipitation (mm)	29.3	17.8	21.4	26.0	52.4	86.0	98.6	69.6	47.4	25.2	22.8	17.3	513.9	A

B.2.5. 3063523 – JASPER EAST GATE, Alberta

Latitude	Longitude	Elevation
53°14'00.000" N	117°49'00.000" W	1,002.80 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-6.9	-4.6	-1.0	4.2	9.0	12.9	15.3	14.2	9.8	4.9	-2.4	-6.4	4.1	C
Rainfall (mm)	2.0	0.8	2.5	17.6	59.7	89.9	88.9	91.5	63.5	25.7	4.0	1.6	447.7	C
Snowfall (cm)	20.6	16.0	27.2	16.3	6.0	0.0	0.0	0.0	5.1	15.1	26.5	18.3	151.0	C
Precipitation (mm)	22.6	16.8	29.7	33.9	65.6	90.0	88.9	91.5	68.6	40.8	30.5	19.8	598.7	C

B.2.6. 1171393 – CARIBOO LODGE, British Columbia

Latitude	Longitude	Elevation
52°43'10.091" N	119°28'18.297" W	1,095.80 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-8.1	-5.7	-1.7	2.9	7.8	12.0	14.1	13.7	9.0	2.5	-4.2	-8.4	2.8	C
Rainfall (mm)	6.4	6.1	17.9	25.4	51.5	71.4	72.4	75.2	74.1	96.4	30.5	1.9	529.2	C
Snowfall (cm)	117.5	79.1	69.3	18.0	2.4	0.0	0.0	0.0	0.7	23.4	114.3	107.2	531.7	C
Precipitation (mm)	123.9	85.1	87.1	43.4	53.9	71.5	72.4	75.2	74.7	119.7	144.8	109.1	1061	C

B.2.7. 1160899 – BLUE RIVER A, British Columbia

Latitude	Longitude	Elevation
52°07'44.500" N	119°17'22.300" W	690.40 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-7.3	-4.4	0.5	5.2	10.2	14.0	16.4	16.0	11.0	4.5	-1.9	-7.1	4.8	A
Rainfall (mm)	21.3	17.6	35.8	52.7	75.6	98.8	107.3	82.4	71.3	94.0	49.5	13.5	719.7	A
Snowfall (cm)	113.5	49.5	38.3	7.0	0.4	0.0	0.0	0.0	0.0	10.0	82.4	103.4	404.4	A
Precipitation (mm)	105.4	53.8	64.7	58.7	75.8	98.8	107.3	82.4	71.3	102.5	115.2	88.4	1024	A

B.2.8. 1168520 – VALVENBY, British Columbia

Latitude	Longitude	Elevation
51°34'34.000" N	119°46'41.000" W	445.00 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-5.2	-2.7	2.7	8.0	12.3	15.7	18.2	17.6	12.1	5.7	-0.2	-4.7	6.6	C
Rainfall (mm)	12.3	10.7	20.0	29.0	43.6	56.5	58.2	43.1	37.2	41.0	26.8	10.9	389.3	A
Snowfall (cm)	27.2	11.7	5.0	0.9	0.1	0.0	0.0	0.0	0.0	2.2	17.3	30.4	94.8	A
Precipitation (mm)	39.5	22.4	25.0	29.8	43.8	56.5	58.2	43.1	37.2	43.2	44.1	41.4	484.1	A

B.2.9. 1165030 – MCLURE, British Columbia

Latitude	Longitude	Elevation
51°02'48.000" N	120°13'18.000" W	381.00 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-4.5	-1.7	3.8	9.0	13.1	16.9	19.7	19.6	14.2	6.9	0.5	-4.5	7.7	D
Rainfall (mm)	11.7	14.0	23.8	30.9	43.3	55.0	46.7	39.7	40.5	39.6	35.1	10.1	390.3	C
Snowfall (cm)	26.2	9.4	4.6	0.4	0.2	0.0	0.0	0.0	0.0	0.9	17.9	36.8	96.2	C
Precipitation (mm)	37.9	23.4	28.4	31.2	43.5	55.0	46.7	39.7	40.5	40.4	53.0	46.8	486.5	C

B.2.10.1162265 – DARFIELD, British Columbia

Latitude	Longitude	Elevation
51°17'50.400" N	120°10'57.600" W	412.00 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-4.5	-1.8	3.5	8.4	12.9	16.5	19.1	18.4	13.0	6.4	0.4	-4.0	7.4	A
Rainfall (mm)	10.3	9.7	19.7	28.0	45.5	54.1	52.1	41.8	35.2	38.7	29.1	8.4	372.5	A
Snowfall (cm)	32.4	13.1	5.3	0.6	0.0	0.0	0.0	0.0	0.0	1.3	22.4	37.5	112.6	A
Precipitation (mm)	42.8	22.8	25.0	28.6	45.6	54.1	52.1	41.8	35.2	40.0	51.4	45.9	485.1	A

B.2.11.1125079 – MERRITT STP, British Columbia

Latitude	Longitude	Elevation
50°06'51.004" N	120°48'03.005" W	609.00 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-6.9	-4.6	-1.0	4.2	9.0	12.9	15.3	14.2	9.8	4.9	-2.4	-6.4	4.1	C
Rainfall (mm)	2.0	0.8	2.5	17.6	59.7	89.9	88.9	91.5	63.5	25.7	4.0	1.6	447.7	C
Snowfall (cm)	20.6	16.0	27.2	16.3	6.0	0.0	0.0	0.0	5.1	15.1	26.5	18.3	151.0	C
Precipitation (mm)	22.6	16.8	29.7	33.9	65.6	90.0	88.9	91.5	68.6	40.8	30.5	19.8	598.7	C

B.2.12.1113581 – HOPE SLIDE, British Columbia

Latitude	Longitude	Elevation
49°16'00.000" N	121°14'00.000" W	685.00 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-1.8	-0.3	2.5	5.8	9.4	12.5	15.1	15.3	11.8	6.5	1.2	-1.8	6.3	C
Rainfall (mm)	106.5	60.1	58.2	61.6	66.7	64.4	48.5	41.3	61.7	130.2	160.5	73.0	932.7	C
Snowfall (cm)	68.9	44.7	40.0	15.7	1.9	0.0	0.0	0.0	0.0	3.9	42.0	70.6	287.8	C
Precipitation (mm)	175.4	104.8	98.2	77.3	68.6	64.4	48.5	41.3	61.7	134.1	202.5	143.6	1220	C

B.2.13.1104488 – LAIDLAW, British Columbia

Latitude	Longitude	Elevation
49°21'23.000" N	121°34'46.070" W	37.00 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	2.2	4.2	7.1	10.2	13.6	16.3	18.8	19.3	16.2	10.7	5.4	2.0	10.5	D
Rainfall (mm)	262.6	177.7	193.5	165.8	131.8	113.8	84.7	64.2	104.7	228.9	344.8	236.2	2109	C
Snowfall (cm)	24.9	16.6	7.7	0.8	0.0	0.0	0.0	0.0	0.0	0.6	7.9	19.6	78.2	C
Precipitation (mm)	287.6	194.3	201.2	166.6	131.8	113.8	84.7	64.2	104.7	229.6	352.7	255.8	2187	C

B.2.14.1101N65 – CHILLIWACK R HATCHERY, British Columbia

Latitude	Longitude	Elevation
49°04'48.008" N	121°42'15.002" W	225.00 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	1.8	3.5	6.0	9.0	12.0	14.7	17.5	17.7	14.6	9.6	4.5	1.6	9.4	D
Rainfall (mm)	159.0	113.2	123.5	112.2	92.9	88.9	54.0	52.8	70.3	162.1	235.4	164.3	1428	C
Snowfall (cm)	21.8	14.8	9.0	0.8	0.0	0.0	0.0	0.0	0.0	0.3	9.4	18.3	74.5	C
Precipitation (mm)	180.8	127.9	132.5	113.0	92.9	89.0	54.0	52.8	70.3	162.4	244.9	182.5	1503	C

B.2.15.1100030 – ABBOTSFORD A, British Columbia

Latitude	Longitude	Elevation
49°01'31.000" N	122°21'36.000" W	59.10 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	3.6	5.0	7.2	9.8	13.0	15.7	18.1	18.2	15.3	10.5	6.0	2.9	10.4	A
Rainfall (mm)	193.6	123.4	144.9	117.1	99.8	74.8	43.2	45.9	75.5	152.7	241.5	170.9	1483	A
Snowfall (cm)	18.5	8.6	4.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	6.7	16.5	55.2	A
Precipitation (mm)	211.7	132.3	149.3	117.8	99.8	74.8	43.2	45.9	75.5	152.7	248.2	186.6	1538	A

B.2.16.1098940 – Williams Lake

Latitude	Longitude	Elevation
52°10'59.000" N	122°03'15.000" W	939.70 m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-6.7	-4.1	0.3	4.9	9.6	13.3	16.0	15.3	10.6	4.6	-2.3	-7.3	4.5	A
Rainfall (mm)	4.6	2.0	3.9	13.2	36.0	58.3	52.7	46.1	41.2	32.6	14.2	2.9	307.6	A
Snowfall (cm)	36.9	21.1	17.5	10.2	3.3	0.3	0.0	0.0	0.6	9.4	33.0	44.5	176.8	A
Precipitation (mm)	33.1	18.6	17.9	22.2	39.1	58.6	52.7	46.1	41.8	41.0	42.2	37.6	450.7	A

APPENDIX C
TABULATED HYDROMETRIC DATA

C.1. GAUGE DATA

Station No.	Station Name	Latitude (º)	Longitude (º)	Catchment Area (km^2)	Record Length	Record Period	Q2 (m^3/s)	Q5 (m^3/s)	Q10 (m^3/s)	Q25 (m^3/s)	Q50 (m^3/s)	Q100 (m^3/s)	Q200 (m^3/s)
12175500	THUNDER CREEK NEAR NEWHALEM, WA	48.672778	121.071667	271.8	84	1931 - 2014	116	181	236	324	407	507	628
12178100	NEWHALEM CREEK NEAR NEWHALEM, WA	48.660278	121.246389	69.6	53	1961 - 2012	56	88	114	151	183	218	258
12191800	SULPHUR CREEK NEAR CONCRETE, WA	48.677778	121.75	21.64	14	1963 - 1981	12	18	22	28	33	37	43
12192700	THUNDER CREEK NEAR CONCRETE, WA	48.602222	121.704722	58	7	1983 - 1994	24	33	40	48	55	62	70
12196000	ALDER CREEK NEAR HAMILTON, WA	48.5281669	-121.95070	27.7	36	1943 - 1979	9.1	13	16	20	22	25	28
12202300	OLSEN CREEK NEAR BELLINGHAM, WA	48.7512221	-122.35349	9.8	17	1968 - 2015	6.4	10.1	13	17	21	25	30
12205000	NOOKSACK RIVER BL CASCADE CREEK NR GLACIER, WA	48.906111	121.843056	271.8	78	1938 - 2015	173	233	272	323	357	394	425
12207750	WARM CREEK NEAR WELCOME, WA	48.7673399	-121.96459	10.6	11	1998 - 2008	10	13	14	14	15	15	15
12210900	ANDERSON CREEK AT SMITH ROAD NEAR GOSHEN, WA	48.8326141	-122.33905	23.3	14	1999 - 2014	13	19	24	29	33	38	42
12212000	FISHTRAP CREEK AT LYNDEN, WA	48.9642832	-122.43155	57.7	26	2000 - 2014	14	23	30	41	50	62	75
12212050[1]	FISHTRAP CREEK AT FRONT STREET AT LYNDEN, WA	48.9387257	-122.47905	97.9	13	2001 - 2014	-	-	-	-	-	-	-
12447390	ANDREWS CREEK NEAR MAZAMA, WA	48.823056	120.144722	57.2	46	1969 - 2015	10	15	18	24	29	35	43
05CC009	LLOYD CREEK NEAR BLUFFTON	52.74037933	-114.146843	238.8	25	1973 - 2011	14	27	39	56	72	91	113
05CC010	BLOCK CREEK NEAR LEEDALE	52.5737381	-114.57767	56.8	26	1977 - 2010	3.3	7.3	11	18	25	34	46
05CE010	RAY CREEK NEAR INNISFAIL	52.00117111	-113.59971	44.4	26	1968 - 2011	2.1	4.3	6.1	9.0	12	15	18
05DD004	BROWN CREEK AT FORESTRY ROAD	52.76396179	-116.36081	218.7	37	1974 - 2011	26	54	80	126	172	232	309
05DF001[2]	NORTH SASKATCHEWAN RIVER AT EDMONTON	53.53720856	-113.48550	28096	61	1911 - 1971	1240	1900	2510	3550	4590	5900	7580
05DF003[3]	BLACKMUD CREEK NEAR ELLERSLIE	53.41455078	-113.51651	643	32	1978 - 2011	8.6	14	17	21	24	26	29
05DF006	WHITEMUD CREEK NEAR ELLERSLIE	53.41262817	-113.590889	330.4	36	1970 - 2011	15	30	45	71	99	136	184
05EA010	STURGEON RIVER NEAR MAGNOLIA BRIDGE	53.5913887	-114.8597183	121.2	21	1982 - 2011	15	30	42	60	76	94	115
05EB902	POINTE-AUX-PINS CREEK NEAR ARDROSSAN	53.59944153	-113.1636124	105.7	31	1979 - 2011	3.1	5.5	7.3	9.9	12	14	17.
05FC002	BIGKNIFE CREEK NEAR GADSBY	52.51737976	-112.355957	281.3	31	1970 - 2010	6.4	13	18	26	32	40	48
07AA001	MIETTE RIVER NEAR JASPER	52.86412048	-118.1071701	628.5	38	1973 - 2011	75	93	105	122	134	147	161
07AA007	SUNWAPTA RIVER AT ATHABASCA GLACIER	52.21627045	-117.2320938	29.3	52	1949 - 2011	11	13	15	17	19	20	22
07AC008	LITTLE BERLAND RIVER AT HIGHWAY NO. 40	53.67866135	-118.2411575	93	24	1986 - 2011	12	20	26	33	39	45	51
07AF003	WAMPUS CREEK NEAR HINTON	53.15745926	-117.2608871	25.9	42	1968 - 2011	4.7	8.6	12	17	21	26	31
07AF004	DEERLICK CREEK NEAR HINTON	53.15555954	-117.2433319	14	21	1967 - 1990	2.5	4.8	7.0	11	15	20	27
07AF005	EUNICE CREEK NEAR HINTON	53.15277863	-117.2319412	17.1	24	1968 - 1991	2.1	3.9	5.5	8.0	10	13	17
07AF010	SUNDANCE CREEK NEAR BICKERDIKE	53.56652069	-116.7033081	178	39	1973 - 2011	5.8	9.1	12	16	19	23	27
07AF013	MCLEOD RIVER NEAR CADOMIN	53.07942963	-117.1980591	329.6	26	1984 - 2010	42	65	83	108	129	152	178
07AF014	EMBARRAS RIVER NEAR WEALD	53.37591934	-116.8061981	639.7	25	1984 - 2012	46	82	110	152	188	229	276
07AF015	GREGG RIVER NEAR THE MOUTH	53.25188828	-117.3565903	384	26	1985 - 2011	37	63	82	110	133	157	184
07AG001[4]	MCLEOD RIVER NEAR WOLF CREEK	53.65417099	-116.2805634	6310	25	1958 - 1983	-	-	-	-	-	-	-
07AG007[4]	MCLEOD RIVER NEAR ROSEVEAR	53.69704819	-116.1620178	7143.3	27	1984 - 2012	416	753	1060	1590	2110	2780	3620
07AG003	WOLF CREEK AT HIGHWAY NO. 16A	53.59835052	-116.271843	826	57	1955 - 2011	46	92	137	220	307	425	584
07AH002	CHRISTMAS CREEK NEAR BLUE RIDGE	54.22766876	-115.332489	423.1	38	1973 - 2012	18	34	47	68	87	109	136
07BA002	RAT CREEK NEAR CYNTHIA	53.13830185	-115.4889069	606.1	33	1972 - 2011	22	39	56	85	115	153	202
07BA003	LOVETT RIVER NEAR THE MOUTH	52.99988174	-116.6560135	102.7	32	1975 - 2011	14	27	38	55	70	87	107
07BB002	PEMBINA RIVER NEAR ENTWISTLE	53.60419083	-115.0047379	4401.6	66	1914 - 2010	179	337	497	799	1130	1580	2200
07BB005	LITTLE PADDLE RIVER NEAR MAYERTHORPE	53.94799042	-115.0235901	422.78	35	1963 - 2011	30	54	73	100	122	147	174
07BB011	PADDLE RIVER NEAR ANSELMO	53.8593483	-115.3638763	253.4	26	1980 - 2011	24	55	85	140	199	279	387
07BB014	COYOTE CREEK NEAR CHERHILL	53.87371063	-114.6711884	48.9	23	1982 - 2011	2.7	5.0	6.4	8.1	9.3	10	11
08KA001	DORE RIVER NEAR MCBRIDE	53.31055832	-120.2458267	409	43	1969 - 2013	91	111	124	141	154	166	179
08KA008	MOOSE RIVER NEAR RED PASS	52.91999817	-118.8000031	458	26	1961 - 1995	101	135	158	186	207	227	248
08KA009	MCKALE RIVER NEAR 940 M CONTOUR	53.44406128	-120.2201385	253	40	1972 - 2012	68	85	99	119	135	154	175
08KA010[5]	SWIFT CREEK ABOVE BARRETT CREEK	52.87694168	-119.1963882	111	9	1972 - 1980	-	-	-	-	-	-	-

Station No.	Station Name	Latitude (º)	Longitude (º)	Catchment Area (km^2)	Record Length	Record Period	Q2 (m^3/s)	Q5 (m^3/s)	Q10 (m^3/s)	Q25 (m^3/s)	Q50 (m^3/s)	Q100 (m^3/s)	Q200 (m^3/s)
08KA012[5]	SWIFT CREEK NEAR THE MOUTH	52.83832932	-119.2666702	132	14	1985 - 1998	27	35	40	47	52	58	64
08KE024	LITTLE SWIFT RIVER AT THE MOUTH	52.91490173	-121.7674713	127	36	1972 - 2011	26	35	41	50	57	64	72
08KH010	HORSEFLY RIVER ABOVE MCKINLEY CREEK	52.28971863	-121.0602798	790	46	1965 - 2013	115	141	157	177	192	206	220
08LA001	CLEARWATER RIVER NEAR CLEARWATER STATION	51.64944077	-120.066391	10300	73	1914 - 2011	957	1130	1240	1370	1460	1540	1620
08LA004	MURTLE RIVER ABOVE DAWSON FALLS	51.97943878	-120.1036072	1380	30	1927 - 1983	195	233	259	293	318	344	370
08LB024	FISHTRAP CREEK NEAR MCLURE	51.12332916	-120.2094421	135	37	1972 - 2011	7.4	11	12	14	16	17	18
08LB038	BLUE RIVER NEAR BLUE RIVER	52.1166687	-119.3013916	272	26	1985 - 2012	76	90	100	112	121	130	139
08LB047	NORTH THOMPSON RIVER AT BIRCH ISLAND	51.60277939	-119.9152832	4490	52	1960 - 2011	683	799	872	963	1030	1090	1150
08LB069	BARRIERE RIVER BELOW SPRAGUE CREEK	51.24721909	-119.9305573	624	32	1974 - 2011	80	103	117	135	147	159	171
08LB076	HARPER CREEK NEAR THE MOUTH	51.35417175	-119.8805618	166	36	1974 - 2010	38	46	51	56	59	62	65
08LE027	SEYMOUR RIVER NEAR SEYMOUR ARM	51.26250076	-118.9466705	805	41	1970 - 2011	215	259	291	333	367	402	439
08LE075	SALMON RIVER ABOVE SALMON LAKE	50.28889084	-119.9555588	143	36	1966 - 2002	8.3	11	13	15	16	18	19
08LE077	CORNING CREEK NEAR SQUILAX	50.91833115	-119.5333328	26.2	27	1981 - 2010	5.4	7.5	8.8	10	12	13	14
08LE108	EAST CANOE CREEK ABOVE DAM	50.69721985	-119.1966705	20.8	27	1983 - 2011	1.0	1.5	1.9	2.5	2.9	3.4	3.8
08LF051	THOMPSON RIVER NEAR SPENCES BRIDGE	50.35694122	-121.3938904	55400	60	1952 - 2011	2720	3200	3480	3790	4000	4180	4350
08LF084	ANDERSON CREEK ABOVE DIVERSIONS	50.72639084	-121.6352768	31.9	20	1979 - 1998	1.1	1.9	2.7	4.0	5.4	7.3	9.7
08LF094	JOE ROSS CREEK NEAR THE MOUTH	51.15277863	-120.8558273	98.9	23	1984 - 2010	2.2	3.7	5.0	7.1	9.2	12	15
08LG008	SPIUS CREEK NEAR CANFORD	50.13528061	-121.0297165	775	37	1970 - 2011	108	150	177	208	229	249	268
08LG016	PENNASK CREEK NEAR QUILCHENA	49.97417068	-120.1347198	87.6	39	1970 - 2011	9.1	13	15	18	20	22	23
08LG048	COLDWATER RIVER NEAR BROOKMERE	49.8555603	-120.9075012	316	44	1967 - 2010	67	90	109	138	163	191	224
08LG055	BETHSAIDA CREEK ABOVE HIGHLAND VALLEY ROAD	50.47999954	-121.0333328	15.5	13	1973 - 1985	0.4	0.7	0.9	1.2	1.5	1.7	1.9
08LG056	GUICHON CREEK ABOVE TUNKWA LAKE DIVERSION	50.60832977	-120.9108276	78.2	41	1968 - 2010	1.2	1.9	2.4	3.1	3.7	4.2	4.8
08LG064	BEAK CREEK AT THE MOUTH	50.11111069	-119.9824982	85	17	1983 - 2001	5.1	8.4	11	15	19	23	27
08LG065	NICOLA RIVER AT OUTLET OF NICOLA LAKE	50.16444016	-120.6641693	2960	28	1983 - 2011	30	43	50	57	61	64	67
08MF003	COQUIHALLA RIVER NEAR HOPE	49.37527847	-121.4194412	741	12	1971 - 1983	282	417	524	680	820	980	1160
08MF068[6]	COQUIHALLA RIVER ABOVE ALEXANDER CREEK	49.36943817	-121.3888931	720	18	1987 - 2011	-	-	-	-	-	-	-
08MF005	FRASER RIVER AT HOPE	49.38056183	-121.4513931	217000	62	1950 - 2012	8600	10100	11000	12200	13000	13800	14600
08MF062	COQUIHALLA RIVER BELOW NEEDLE CREEK	49.54188919	-121.1199722	85.5	38	1966 - 2011	26	36	45	59	72	88	107
08MG025	PEMBERTON CREEK NEAR PEMBERTON	50.31721878	-122.8013916	32.4	18	1987 - 2012	18	24	27	32	35	38	40
08MG026	FITZSIMMONS CREEK BELOW BLACKCOMB CREEK	50.12028122	-122.9472198	89.7	14	1994 - 2012	19	25	29	37	43	52	62
08MH001	CHILLIWACK RIVER AT VEDDER CROSSING	49.09722137	-121.9625015	1230	36	1969 - 2011	420	620	772	990	1170	1370	1600
08MH016	CHILLIWACK RIVER AT OUTLET OF CHILLIWACK LAKE	49.08388901	-121.4566727	335	76	1924 - 2011	70	91	106	126	141	157	173
08MH018[7]	MAHOOD CREEK NEAR NEWTON	49.15610886	-122.8419418	18.4	12	1970 - 1985	-	-	-	-	-	-	-
08MH020	MAHOOD CREEK NEAR SULLIVAN	49.14527893	-122.7994385	34.4	6	1953 - 1958	31	44	55	74	91	111	136
08MH154[7]	MAHOOD CREEK AT 144 STREET, SURREY	49.14611053	-122.8219376	27.3	10	1987 - 1998	-	-	-	-	-	-	-
08MH029[8]	SUMAS RIVER NEAR HUNTINGDON	49.00249863	-122.2322769	144	59	1953 - 2012	27	37	43	50	55	59	62
08MH056	SLESSE CREEK NEAR VEDDER CROSSING	49.07110977	-121.69944	160	40	1958 - 2011	87	116	134	154	168	180	192
08MH090	SALMON RIVER AT 72 AVENUE, LANGLEY	49.13360977	-122.5963898	48.9	41	1969 - 2012	28	40	48	59	69	78	89
08MH105[9]	NICOMEKL RIVER BELOW MURRAY CREEK	49.10055923	-122.6455612	64.5	13	1971 - 1983	-	-	-	-	-	-	-
08MH155[9]	NICOMEKL RIVER AT 203 STREET, LANGLEY	49.09566879	-122.6600037	70	24	1985 - 2011	45	66	80	98	112	126	141
08MH129	MURRAY CREEK AT 216 STREET, LANGLEY	49.07249832	-122.6241684	26.2	13	1969 - 1983	20	28	34	44	51	60	70
08NB014	GOLD RIVER ABOVE PALMER CREEK	51.67694092	-117.7166672	429	37	1973 - 2013	115	133	144	156	164	172	180
08NC004	CANOE RIVER BELOW KIMMEL CREEK	52.73157883	-119.3846436	305	37	1972 - 2012	84	96	105	120	134	150	170
08ND012	GOLDSTREAM RIVER BELOW OLD CAMP CREEK	51.66833115	-118.5969391	934	48	1964 - 2012	207	249	279	320	353	388	424
08ND019	KIRBYVILLE CREEK NEAR THE MOUTH	51.63943863	-118.6705627	112	32	1973 - 2005	35	48	60	79	97	119	146
08NE008	BEATON CREEK NEAR BEATON	50.7358284	-117.7288895	96.7	35	1973 - 2011	11	14	16	19	21	24	26
08NM133	BULL CREEK NEAR CRUMP	49.62083054	-119.9027786	46.9	20	1965 - 1986	1	2	3	4	5	6	7
08NM134	CAMP CREEK AT MOUTH NEAR THIRSK	49.71110916	-120.0083313	34.6	47	1966 - 2013	2	2	3	3	3	3	4

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08NM138	TERRACE CREEK NEAR KELOWNA	50.0708313	-119.6666718	31.3	27	1966 - 1994	4	5	5	6	6	7	7
08NM165	LAMBLY CREEK ABOVE TERRACE CREEK	49.99417114	-119.6144409	76.1	25	1971 - 1996	7	10	11	13	14	15	15
08NM171	VASEUX CREEK ABOVE SOLCO CREEK	49.24943924	-119.3211136	117	40	1971 - 2011	14	21	24	28	30	33	34
08NM174	WHITEMAN CREEK ABOVE BOULEAU CREEK	50.21221924	-119.5386124	114	38	1971 - 2010	8	12	14	18	20	22	25
08NM241	TWO FORTY-ONE CREEK NEAR PENTICTON	49.65139008	-119.3916702	4.5	28	1984 - 2012	1	2	2	3	3	4	5
08NM242	DENNIS CREEK NEAR 1780 METRE CONTOUR	49.62443924	-119.3808289	3.73	23	1985 - 2011	1	1	1	2	2	2	2
08NN015	WEST KETTLE RIVER NEAR MCCULLOCH	49.70417023	-119.0919418	233	49	1965 - 2013	45	57	63	70	75	79	83
08NN019	TRAPPING CREEK NEAR THE MOUTH	49.56444168	-119.0522232	145	48	1966 - 2013	17	22	25	29	32	35	38

Note: 1 Hydrometric station 12212050 was used to extend the record length of hydrometric station 12212000.
2 Only pre-regulation instantaneous peak flows were used to compute flood frequencies.
3 Hydrometric station 05DF006 was used to extend the record length of hydrometric station 05DF003 (nhc 2014).
4 Hydrometric station 07AG001 was used to extend the record length of hydrometric station 07AG007.
5 Hydrometric station 08KA010 was used to extend the record length of hydrometric station 08KA012.
6 Hydrometric station 08MF068 was used to extend the record length of hydrometric station 08MF003.
7 Hydrometric stations 08MH018 and 08MH154 were used to extend the record length of hydrometric station 08MH020.
8 Flood frequencies account for overbank flow of the Nooksack River into the Sumas River (Klohn Leonoff 1989).
9 Hydrometric station 08MH105 was used to extend the record length of hydrometric station 08MH155.

REFERENCES

Klohn Leonoff Consulting Engineers (Klohn Leonoff).1989. Engineering Studies for Floodplain Management Plan Final Report. Prepared for the District of Abbotsford. July 1989.

Northwest Hydraulic Consultants (nhc). 2014. Nisku Flood Hazards Study Blackmud Creek. Prepared for the Alberta Environment and Sustainable Resources Development.