

# BC MINISTRY OF ENVIRONMENT



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## COMPREHENSIVE REVIEW OF FRASER RIVER AT HOPE FLOOD HYDROLOGY AND FLOWS – SCOPING STUDY FINAL REPORT

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OCTOBER 2008

**nhc** northwest  
hydraulic  
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*Leaders in water resource technology*

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FRASER RIVER AT HOPE, FLOOD HYDROLOGY  
AND FLOWS - SCOPING STUDY**

**FINAL REPORT**

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# 1 INTRODUCTION

## 1.1 BACKGROUND

There have been two catastrophic floods on the Lower Fraser River since European settlement in the Fraser Valley - in 1894 and 1948. The 1894 flood is considered to be the flood of record, although flood damages in 1948 were considerably higher due to more intensive development on the floodplain. Since the 1960's the 1894 flood was adopted for establishing flood protection standards in the region. The 1894 flood was also specified by Fraser Basin Council and the BC Ministry of Environment as the design flood event for recent hydraulic investigations to update the flood profile along the river. The magnitude and frequency of the 1894 flood is critical for assessing flood risk and flood protection requirements in the valley. The 1894 flood discharge at Hope was estimated from high water marks determined in 1934, not from actual discharge measurements at the time of the flood. Therefore, there is some uncertainty associated with the magnitude of the discharge. Furthermore, no comprehensive flood frequency analysis has been published since planning studies in the 1950's (Fraser River Board, 1958) and 1960's. As a result, the return period for a recurrence of an 1894 magnitude flood event needs assessment.

A comprehensive review of flood hydrology in the Fraser Basin is required, given the need for developing a long-term plan for managing flood risks along the Lower Fraser River. The problem is compounded by issues related to future climate change and land cover changes in the Fraser Basin. This scoping level report reviews the historic flood record, assesses the effect of different assumptions about the historic flood record on flood frequency estimates and defines additional work that could be carried out to reduce uncertainties in the analyses.

## 1.2 SCOPE OF WORK

This study was undertaken to:

- Confirm the 1894 and 1948 flood flow estimates for Hope and provide “uncertainty bounds” that approximate 95% confidence limits on the estimates.
- Establish an updated flood frequency analysis for the Fraser River at Hope incorporating the best available information on historic events and effects of flow regulation. Provide estimates of “uncertainty bounds” associated with the results.
- Recommend additional work to assess expected changes in flood hydrology due to climate change and land cover changes.

The following tasks were carried out:

- Compile and review historic information on past floods using published sources, archival information, and hydrometric data.
- Develop a hydraulic backwater model for the Laidlaw-Hope reach to provide an independent check on the 1894 flood discharge estimate.

- Evaluate the feasibility of estimating the 1894 flow at the Alexandra Bridge using archival accounts and photos of the flood and hydraulic information on the channel.
- Prepare an updated flood frequency analyses for Hope using appropriate methods for incorporating historic flood estimates and accounting for uncertainty in flow estimates.
- Review the feasibility of other non-standard methods for extending the flood record.
- Review recent publications concerning climate change and methods for assessing the expected impacts on snow-melt and precipitation.
- Prepare a summary report.

### 1.3 PREVIOUS STUDIES

Studies were undertaken by the Fraser Basin Board (1958) to estimate the probability of occurrence of floods at Hope and Mission. The studies were based on a standard period which included the 1894 flood. Accounts were taken of upstream diversion projects such as the Nechako diversion (which started in 1952) to account for natural flows. Curves of flow frequencies at Hope (in terms of annual peak discharges) and at Mission (in terms of peak water levels) were derived. The published curves indicated the 1948 flood had a return period of 60 years and the 1894 flood had a return period of 160 years. Based on the water level record at Mission the 1894 flood level was assigned a return period of only 100 years.

Inland Waters Branch (1970) published a detailed summary report on the hydrometric and sediment studies on the Lower Fraser River and included a section on flood frequency analysis. Frequency plots (in terms of annual maximum discharge) were presented for Fraser River at Hope, Fraser River at Mission and Fraser River at New Westminster. All flows were adjusted to compensate for the effect of upstream river regulation (the curves were in terms of natural flows). The period of record at Hope was 1912-1968 and 1894. The period of record at Mission was 1894 to 1968. The 1894 and 1948 floods both plotted as outliers on the graphs. Using the theoretical best fit curves (maximum likelihood method) the 1948 flood at Hope was assigned a return period of 70 years and the 1894 flood a return period of 200 years. The 1894 flood at Mission was assigned a return period of approximately 160 years.

The Fraser River Joint Advisory Board (1976) prepared a comprehensive study to assess the need for upstream storage and regulation to achieve flood protection in the basin. A detailed review was made of the existing regulation in the basin at that time (Bridge River and Nechako) and its effect on the magnitude of the 1972 flood. The following is a brief extract from that report:

*“In response to requests made early in 1972 by the B.C. Water Resource Service both ALCAN and B.C. Hydro cooperated fully in making storage for flood control purposes available. ALCAN arranged for the discharge of 10,000 cfs more than normal spillage from the Nechako Reservoir during the period from April 13 to May 10, which lowered the reservoir by an extra two feet and so provided about 400,000 acre-feet of anticipatory flood control storage. This storage was utilized during the period from May 11 to June 22, when the outflow from the reservoir into the Fraser River was curtailed completely.*”

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*BC Hydro made the entire 1,370,000 acre-feet of storage capacity in Carpenter and Downton Lakes available as flexible flood control storage which was utilized from June 13 to June 17, the latter being the date when the peak of the freshet was recorded at Mission.”*

The use of the Nechako River and Bridge River storage for flood control purposes during the 1972 freshet reduced the peak flow of the Fraser River at Hope by approximately 1,100 m<sup>3</sup>/s (40,000 cfs). Without the relief provided in 1972 by the existing upstream storage, the peak flow at Hope would have reached 14,000 m<sup>3</sup>/s (compared to the recorded peak of 12,900 m<sup>3</sup>/s). In this particular case, the existing regulation was operated effectively to reduce the peak flow at Hope and Mission.

A daily flood routing analysis was developed for the Fraser River basin using the routing methods developed for the UBC Watershed Model. The effects of existing and planned upstream storage projects were evaluated for a 40 year standard period (1928 to 1968). Effects on flood frequency were summarized in terms of water levels at Mission. The 1894 flood was estimated to have a return period of 140 years under natural conditions and approximately 300 years under the present regulated regime.

This study also assessed for the first time the probable maximum flood that could occur on the Fraser River. The probable maximum flood (PMF) is considered to be the greatest flood that could conceivably occur and was computed on the assumption that all contributing factors would reach their critical magnitude simultaneously. The PMF at Mission was estimated to be 40,000 m<sup>3</sup>/s (1,400,000 cfs) or just over double the estimated 1894 flood discharge.

Since the 1980's a number of ad hoc unpublished flow frequency analyses have been carried out on the Fraser River and the results have varied considerably. Some analyses used only the published WSC records and completely ignored the 1894 flood estimate. Other analyses simply appended the 1894 flood to the WSC systematic record (which commenced in 1912), making it the largest flood in 98 years. Other analyses assumed the flood is the largest since 1894 (115 years). In fact, based on historical accounts (Section 2) the 1894 flood is probably the largest event since European exploration and settlement, which places the time interval at over 160 years. There has also been only limited accounting for upstream flow regulation in comparison to the detailed flow routing carried out by the Fraser River Joint Advisory Board. It has been common practice to either ignore the regulation or to assume its effect is too small to account for, given the other uncertainties in the flow record.

Starting in 1999 a series of hydraulic investigations was conducted to update the flood profile along the Lower Fraser River using the MIKE11 hydrodynamic model. The first investigations extended from Laidlaw (just downstream of Hope) to Mission (UMA, 1999). These were followed by hydraulic modelling in the tidally-affected reach between Mission and the sea (NHC, 2006). The two models were eventually combined into a single, fully hydrodynamic model of the entire Lower Fraser River (NHC, 2008a). The design flood for all of these investigations was specified by the Fraser Basin Council to be the adopted 1894 flood discharge of 17,000 m<sup>3</sup>/s at Hope.

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## 2 REVIEW OF HISTORIC INFORMATION

### 2.1 HYDROMETRIC RECORDS

#### 2.1.1 PUBLISHED DATA

Table 2.1 summarizes the operations of the Water Survey Canada (WSC) hydrometric gauges on the mainstem of the Lower Fraser River. The two key stations with long-term records are Fraser River at Hope (08MF005) and Fraser River at Mission (08MH024). Table 2.2 summarizes the ten highest published discharges and water levels at the two gauges. The following sections provide additional details on the flow data.

A review of historic floods and flow records was carried out to see if other stations in BC could provide cross-referencing for the Fraser River flood of 1894 and to explore the potential for extending the Hope flow records prior to 1912.

The WSC flow measurement program started in 1894 in Alberta and Saskatchewan with some unpublished sporadic measurements. The earliest published record in British Columbia is for the Stave River and dates back to 1901. More extensive flow and water level records began in 1911 (Thompson River at Kamloops and Heffley/Shuswap/Fortune Lakes). A high water mark is available for Thompson River at Kamloops for 1894. However, uncertainty surrounds the reported value (NHC, 2005). Also, due to Thompson River channel changes the water level record is non-homogenous and a correlation with flows at Hope is not considered possible. As part of recent work for City of Prince George, an 1894 water level estimate at South Fort George derived in 1962 was found in the WSC archives. However, the source of this information is not clear and the water level may have been derived based on the Hope flow estimate.

#### 2.1.2 HOPE

*Station 08MF005, Fraser River at Hope*, is located on the right bank, 15 m downstream of the Highway/Old Kettle Valley Railroad Bridge as shown in Figure 2.1. To convert to geodetic datum, 27.926 m must be added to the gauge height. Flow measurements were previously obtained from the bridge using a Price Meter but are now taken by boat using an Acoustic Doppler Current Profiler (ADCP).

Water level and flow records begin in 1912 and are near continuous since then. Annual maximum daily peak flows for the period of record are plotted in Figure 2.2. The highest published discharge is 15,200 m<sup>3</sup>/s on May 31, 1948. This flow was derived from the recorded peak water level of 10.97 m using a stage-discharge rating curve. Assuming the rating curve extension was accurate, the flow may still have varied by  $\pm 5\%$  (WSC's standard curve accuracy) or between 14,400 m<sup>3</sup>/s and 15,960 m<sup>3</sup>/s. Other large published flood discharges were in 1972 and 1950. An estimate for the 1894 flood peak is not provided in WSC's published database.

The highest discharge ever measured was 12,290 m<sup>3</sup>/s at a gauge height of 9.99 m in 1948. A flow of 12,290 m<sup>3</sup>/s was also measured in 1972 at a gauge height of 10.02 m. Using their standard techniques, WSC extended the stage-discharge relationship to 16,200 m<sup>3</sup>/s.

A detailed review was made of the stability of the stage-discharge rating curve at the Hope gauge. Since 1912, 35 different stage-discharge curves have been used to estimate the peak discharges, indicating the cross section at the gauge is actively changing. Typically, a new rating curve is introduced if measurements consistently deviate from the curve in use by more than 5%. Historic rating curves in use for at least two months are plotted in Figure 2.3 along with flow measurements obtained over the entire period of record. Flow measurements fall in a band width of up to about 2,000 m<sup>3</sup>/s wide for a particular stage height, with the rating curve band being somewhat less or about 1,500 m<sup>3</sup>/s.

A specific gauge curve based on the stage-discharge curves was previously plotted (NHC, 2007) and is reproduced in Figure 2.4. The data shows aggradation from about 1920 to the 1940's, followed by degradation from the early 1950's to the 1980's and subsequent aggradation. These swings seem to roughly coincide with periods of higher and lower peak flows, with degradation occurring during periods of above normal peak flows and aggradation occurring during periods of below normal peak flows. This cyclical pattern of aggradation and degradation makes it more difficult to accurately extend rating curves to earlier ungauged floods.

### 2.1.3 AGASSIZ

Discharge measurements and daily flows were published for the period 1966 to 1986 as part of WSC's sediment transport measurement program. The main value of the Agassiz data is that it provides an independent check on the discharge measurements at Hope. This is because there are no significant tributary inflows between the two gauging stations. The agreement between the peak flows at Agassiz and Hope was generally very good. For example, during the 1972 flood the peak daily discharge on June 16<sup>th</sup> was reported to be 12,900 m<sup>3</sup>/s at Hope and 13,100 m<sup>3</sup>/s at Agassiz. In 1974, the peak daily discharge on June 21 was reported to be 10,800 m<sup>3</sup>/s at Hope and 11,300 m<sup>3</sup>/s at Agassiz. These checks increase the confidence of the published data at Hope and indicate the records are not biased (systematically over or under predicting actual values).

### 2.1.4 MISSION

The Mission gauge is located on the north bank of the Fraser River at the CPR rail bridge. The water levels are tidally affected at all flows. Annual maximum water levels have been reported for 1876, 1882 and then annually since 1894. To convert from gauge height to GSC datum, 0.073 m must be added before 1987 and 0.043 m thereafter. The data between 1876 and 1932 are not continuous and were collected by the Department of Public Works. Regular discharge measurements by WSC commenced in 1965 and have been complicated by the tidal nature of the flow and the unstable sand-bed channel. Discharge measurements in the 1960's and 1970's used the USGS "moving-boat" method in an attempt to compensate for the tidally-varying flows. In recent years the measurements have been made using an ADCP.

The highest measured water level reached el. 7.92 m GSC on 5 June 1894. Other large floods occurred on 31 May 1948, 20 June 1950, 14 June 1882 and 17 June 1972. The relatively large floods in 1882 and 1876 do not show up in the hydrometric record at Hope since the gauge was not operating at the time. These water level measurements indicate the 1894 flood and 1948 floods were the two largest events since measurements commenced in 1876.

Published peak discharges are generally not available for the highest flood events on the river, with the exception of 1972 (14,400 m<sup>3</sup>/s). The highest discharge measurement made on the river at Mission was 13,900 m<sup>3</sup>/s on Jun 16, 1972.

## 2.2 ESTIMATED FLOWS FOR UNGAUGED FLOODS

### 2.2.1 HOPE

A number of high water marks were defined at important landmarks throughout the Lower Fraser Valley during or immediately after the 1894 flood. Unfortunately nothing was identified near the future site of the Hope gauge until 1934. The 1894 high water mark at the gauge was determined from anecdotal evidence forty years after the flood by Colonel G.H. Whyte (NHC, 2008a and Appendix A). The high water level was then applied to an approximate rating curve extension to estimate the design flow (Fraser River Board, 1958). The referenced high water marks are not exact and correspond to: 1) the water depth estimated from a canoe over some flat land located about 430 m upstream of the gauge; and, 2) the remembered door knob location of a demolished store about 790 m downstream of the gauge. Linear interpolation between the given high water marks gives a gauge height of 11.75 m (versus 10.973 m for the 1948 flood). An effort was made to check the estimate using a correlation of flows with the Columbia River. On this basis the Fraser River Board (1958) adopted a value of 17,000 m<sup>3</sup>/s for the 1894 flood. This value has been specified by regulatory agencies for all subsequent flood control work on the river.

Based on the historic rating curves, a gauge height variation of  $\pm 0.3$  m corresponds to a discharge range of about 16,000 m<sup>3</sup>/s to 18,000 m<sup>3</sup>/s. The cyclical shifts in the stage-discharge rating curves over time described in Section 2.1.2 add further uncertainty to the estimated discharge. For example, extrapolating the published rating curves indicates the actual 1894 discharge could range anywhere between approximately 15,000 m<sup>3</sup>/s and 19,000 m<sup>3</sup>/s.

### 2.2.2 MISSION

Estimating discharges for historic floods at Mission is complicated by the tidal nature of the river and the unstable sand-bed channel which has been subject to periodic degradation and aggradation in response to past dredging and river training activities. Fraser River Board estimated the peak discharges for the 1948 and 1950 floods at Mission using a variety of methods, including inflows from Hope and Harrison River and approximate flow routing techniques. McNaughton (1958) estimated the peak discharge of the 1948 flood at Mission to be 15,480 m<sup>3</sup>/s, virtually the same as the peak flow at Hope. The lack of increase in flow

between the stations is expected to reflect effects of upstream spills and overbank storage along the 80 km reach. The peak flow at Mission in 1950 was estimated to be 14,530 m<sup>3</sup>/s, while the published peak discharge at Hope was 12,600 m<sup>3</sup>/s.

The 1894 flood discharge at Mission can not be reliably estimated from the available high-water mark and cross-section information due to the following factors:

- The geometry of the 1894 channel is unknown. The river has undergone complex morphologic changes over the last century in response to both natural and anthropogenic activities.
- Widespread overbank flooding and flow attenuation occurred downstream of Hope.

However, based on the hydrometric measurements at Hope and Mission during their common period of record there is a reasonably good relation between the peak flows at Hope and Mission when the flows are confined within the channel zone. Figure 2.5 shows the relation between annual maximum discharges at Mission and Hope. The annual maximum daily discharge at Mission ( $Q_{\text{Mission}}$ ) can be expressed as:

$$Q_{\text{Mission}} = 1.142 Q_{\text{Hope}} - 135 \quad (R^2=0.92) \quad [1]$$

On average, annual maximum discharges at Mission are 12.5% higher than at Hope, although the variability from year to year can range from 2% to 29% depending on local inflows and snow-pack variations. The standard error of estimate was computed to be 530 m<sup>3</sup>/s. Based on this simple relation the expected peak discharge at Mission for a flood of 17,000 m<sup>3</sup>/s at Hope is around 19,000 m<sup>3</sup>/s, assuming flow is confined by dikes between Hope and Mission.

There is also a fairly consistent relation between peak flows at Hope and maximum daily water levels at Mission if the analysis is restricted to a reasonably short time period when bed degradation effects are limited. Figure 2.6 shows the maximum daily water level at Mission ( $WL_{\text{Mission}}$ ) plotted against maximum daily discharge at Hope ( $Q_{\text{Hope}}$ ) for the period 1912 to 1950. The power law regression relation is as follows:

$$Q_{\text{Hope}} = 975 WL_{\text{Mission}}^{1.2577} \quad (R^2 = 0.87) \quad [2]$$

As shown, the flood of 1948 plots as an outlier. The 1894 Mission high-water mark (7.92 m GSC) and the estimated 1894 discharge at Hope (17,000 m<sup>3</sup>/s) were also plotted. The 1894 point also plots as an outlier, probably reflecting the significant overbank spilling and flow attenuation that occurred between Hope and Mission. Without this attenuation and if peak flows had increased significantly downstream, then the anticipated maximum water level at Mission would have been much higher (approximately 9.7 m GSC). According to the Fraser River MIKE11 hydraulic model (NHC, 2008a) the water level at Mission corresponding to a flow of 17,000 m<sup>3</sup>/s at Hope is 8.87 m GSC.

### 2.2.3 CORRELATION WITH THE COLUMBIA RIVER

Flow records for Columbia River at the Dalles in Oregon, USGS Station 14105700, date back to 1858. This flow record was reviewed to see if it could be used for extending the Fraser River at Hope record. The basin size is 613,800 km<sup>2</sup> compared to the Fraser basin at

Hope of 217,000 km<sup>2</sup>. The flow has been regulated since 1938 and peak flows show a distinct decrease over time since then.

A linear regression of flows at Hope and at the Dalles was carried out for the period 1911 to 1937 when both rivers were unaffected by regulation. The correlation was found to be poor ( $r^2=0.43$ ) as one would expect considering the differences between the basins. Based on the regression, the 1894 Hope flow would have been only 12,830 m<sup>3</sup>/s. Compared to the Mission correlation, the Columbia based flows consistently underestimated the high peaks and overestimated the lower peak flows. The Fraser River Board (1958) completed a similar correlation but surprisingly reported a correlation coefficient of 0.72 for partly regulated flows to 1956.

The unregulated Columbia/Fraser correlation is considered too weak for reliably extending the Fraser record. However, the Columbia flows show that the 1894 flood was by far the largest from 1858 to 1912 and that it possibly was the largest flood for the Fraser River over the same period.

## 2.3 EXTENDING THE HISTORIC RECORD

### 2.3.1 ANECDOTAL INFORMATION

Accounts of exceptionally large floods on the Fraser River have been provided by members of the Kwantlen First Nations on McMillan Island, near Fort Langley. However, it is difficult to rank these events in comparison to the 1894 flood or to assign a time period for them. The first Hudson's Bay farm settlement at Derby was established in 1827 (personal communication with Jane Watt). Flood information for the period from 1827 to 1847 has not been uncovered. A number of potential data sources for obtaining additional information regarding historic flooding are listed in Appendix B. According to Watt (2006), locals in the Fraser Valley considered the floods of 1876 and 1882 to be large, but small in comparison to the 1894 flood, implying that the 1894 flood was the largest flood since 1876. This is consistent with the water level measurements at Mission.

The Alexandra Bridge crosses the Fraser River 40 km north of Hope and was first completed in 1863, replacing a cable ferry at Spuzzum (Figure 2.1). The bridge was constructed in a narrow bedrock canyon (Figure 2.7), with the underside of the bridge deck situated approximately 23 m above normal low water. In 1894 most of the bridge decking washed away. The photograph in Figure 2.8 shows the bridge during the flood. The decking was repaired but with the Canadian Pacific Railway in place the bridge fell into disuse over time. In 1912 the cables were cut, to prevent accidents at the derelict structure. Given the particular history at this site it can be confirmed that the 1894 flood was the largest flood event since at least 1863. Further discussion on estimating the peak discharge during the 1894 flood at the Alexandra Bridge is contained in Section 3.3.

Septer (2001) summarized floods in the southern and northern portions of British Columbia, for the period 1850-2000 based on newspaper descriptions, letters and old reports. The early records are sparse and the available Fraser River freshet data for the period 1862 to 1911 is summarized in Table 2.4. Relatively frequent flooding occurred in the valley during this time

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period. The extent and quality of diking was limited and crops and low-lying houses were regularly damaged. The flood history may not be complete but based on the information compiled by Septer, it appears the flood of 1894 was the largest since at least 1847.

### 2.3.2 GEOMORPHIC METHODS

It may be possible to document the occurrence and approximate date of very large floods from the past using paleohydrology methods. This approach has been suggested as a way of extending conventional hydrological techniques. Some applications on rivers with bedrock canyons in the US are contained in Patton, Baker and Kochel (1979). This approach involved dating sediments deposited in slack-water sections of stable canyons or bedrock controlled channels. Such sites include sudden expansions or tributary junctions. The flows were then estimated from the elevation of the deposits using hydraulic estimates. Sites in the Fraser Canyon could prove analogous.

Another approach could involve coring in the floodplain to assess annual variations in sedimentation rates. For example, Hatzic Slough is a former meander bend of the Fraser that cutoff as a result of past channel shifting. Until diking it was still actively receiving sediment from the Fraser River during the freshet and was gradually silting-in. It is expected the sedimentation process will produce a series of annual varves (similar to lacustrine deposition), and the thickness of the varves will vary with the magnitude of the freshet. Recent coring techniques could provide a deposition record of several centuries, and could provide a means for identifying periods of unusually high sedimentation (and by inference freshet flows).

It is expected that these or other paleohydrology techniques could supplement or at least help to interpret the existing hydrological record. The work is best carried out by researchers in university departments such as Earth Science or Physical Geography or by the Geological Survey of Canada. A substantial effort would be involved, yet positive identification of historic floods could prove difficult.

## 3 1894 FLOOD EVENT

### 3.1 OBJECTIVE

The purpose of this section is to verify the estimates of the 1894 flood and attempt to provide realistic confidence limits and error bounds on the magnitude of the flow. The first step was to review the meteorological conditions in 1894 and compare these to the conditions in 1948. The next step involved carrying out additional hydraulic computations to try to verify the peak discharge that has been attributed to the 1894 flood. Two different methods were used:

- Hydraulic modelling to reproduce high-water marks near the Hope gauge.
- Review of high-water conditions documented at the Alexandra Bridge.

### 3.2 METEOROLOGICAL CONDITIONS IN 1894

Long term climate stations within the Fraser basin are Station No. 1090660, Barkerville which began operation in 1888 and Station No. 1100120, Agassiz CDA that started in 1889. These are the two oldest stations within British Columbia. Other early climate stations are Vernon/ Coldstream (1890), Big Creek (1893 – missing data for 1894), Fort St James, Bella Coola, Chilliwack and Quatsino (1895). Nearly complete precipitation and temperature daily records are available at Barkerville and Agassiz for the years 1893-94 and 1947-1948. The station elevation at Barkerville is 1,265 m and at Agassiz CDA 15 m. The Fraser River Board (1958) also analyzed the Fort St James record. However, digital data is available starting only in 1895 and this station was not included in this analysis. A review of these records were undertaken to see if meteorological conditions were highly unusual leading up to the 1894 and 1948 floods.

Mean monthly total rainfall and snowfall values along with mean monthly temperatures are plotted against long term averages (Canadian Climate Program, 1951-1980) for the years 1893-1894 in Figure 3.1 and for the years 1947-1948 in Figure 3.2. The analyses were limited to monthly averages. Some general observations can be made:

#### ***1893-94 Barkerville:***

- 1893 was a particularly wet year. The months of May and June were very rainy. The October rain- and snowfall exceeded average values considerably. In November all the precipitation fell as snow and was well above normal. The December snowfall records are unfortunately missing – perhaps a key component for explaining the 1894 flood.
- Surprisingly, the 1894 snowfall from January to April was reported to be less than average. This seems unlikely and a detailed review of the gauge history would be required to try and resolve this issue. (According to Fraser River Board (1958) the Barkerville station represents the entire basin quite well).
- Mean temperatures in 1893 were close to normal, which contradicts the anecdotal evidence provided by Fraser River Board (1958) that the summer had been unusually

cold resulting in snow from the winter of 1892-93 forming a base for the following winter's snow-pack. The mean springtime temperature in 1894 was above normal.

***1893-94 Agassiz CDA:***

- The period from March to June, 1893 was wetter than normal, similarly the late fall. The January to March snowfall in 1894 was well above average.
- The 1894 mean spring-time temperatures were below average.

***1947-48 Barkerville:***

- The 1947 June, July and October rainfall and November-December snowfall were well above normal. The February to April snowfall in 1948 was extremely high.
- Temperatures in the early spring of 1948 were less than average, switching to much higher than average in May-June.

***1947-48 Agassiz CDA:***

- The fall of 1947 was wet and snowfall in February-March was high.
- Temperatures in the early spring of 1948 were less than average, switching to much higher than average in June.

The findings are similar to those of the Fraser River Board (1958). Precipitation records do not explain the magnitude of the 1894 flood. It appears the snow pack during the winter of 1893-94 was not as extreme as expected and although temperatures in the early spring of 1894 were below normal at Agassiz, they were not unusual. The 1948 snow pack was exceptionally high and it is not surprising that it resulted in a very large flood.

### **3.3 HYDRAULIC MODEL OF 1894 FLOOD AT HOPE**

The Lower Fraser River MIKE11 hydraulic model ends at Laidlaw, 15 km downstream of Hope. As a way to verify the upper end of the Hope rating curve and verify if the estimated 1894 water level at Hope corresponds to a flow of 17,000 m<sup>3</sup>/s, a separate hydraulic model was developed for the Laidlaw-Hope reach.

#### **3.3.1 MODEL DEVELOPMENT**

Bathymetric surveys by the Dominion-Provincial Board in 1952 were used to establish the cross sections for the model. These historic surveys are appropriate for this analysis since we are concerned with reproducing conditions for the 1948 and 1894 flood, not present-day conditions. The model extended upstream of the Hope Bridge, covering a total main channel length of 15.5 km and incorporating 23 cross-sections. The extent of the model is shown in Figure 2.1. Side branches were introduced for the Greenwood and Bristol back channels.

The MIKE11 rating curve for the last cross-section of the Lower Fraser River model was used as the starting condition for the Laidlaw-Hope model. The rating curve is based on 1999 bathymetry and is not representative of the 1950's channel conditions. However, subsequent

additional runs showed that the starting condition would not affect the accuracy of predictions at the Hope gauge.

### 3.3.2 CALIBRATION

Limited historic high water marks are available for the Fraser River near Hope as listed in Table 3.1. The 1967 and 1972 information for Ruby Creek was obtained from rating curves prepared in conjunction with the profile study by Department of Energy, Mines and Resources, Inland Waters Branch (1969). The source of the 1894 water level at Ruby Creek is CP Rail archives. The data for Hope gauge corresponds to published WSC water levels.

The 1972 flood, with a discharge of 12,900 m<sup>3</sup>/s at Hope, was used for model calibration. Using a universal n-value of 0.032, the computed water level at Hope was within 0.05 m of the observed level. The 1967 flood, with a discharge of 10,800 m<sup>3</sup>/s, was used for model validation and the corresponding computed water level at Hope was within 0.02 m of the observed level. For both floods, the model under-predicted the observed levels.

Figure 3.3 compares the computed MIKE11 rating curve with the historic WSC curves at the Hope gauge. The computed curve closely matches the curve in use in 1948-52. This analysis confirms the reasonableness of the extended rating curve.

### 3.3.3 MODEL RESULTS

Following calibration, the model was used to compute water levels at Hope with the 1948 and 1894 flow estimates. The computed flood profiles are shown in Figure 3.4. Profiles are shown for two different assumed downstream boundary conditions:

- Based on output from the Lower Fraser River Hydraulic Model (1999 bathymetry).
- Based on reported high-water marks at Ruby Creek.

The profiles converge after approximately 10 km, indicating the predictions at the Hope gauge are not affected by the downstream boundary.

Using the model and a flow of 15,200 m<sup>3</sup>/s, the 1948 peak water level was only 0.07 m less than observed at the Hope gauge. The good agreement confirms the 1948 rating curve extension that was carried out previously by WSC to estimate the 1948 discharge.

Figure 3.5 shows the computed flood profile for a discharge of 17,000 m<sup>3</sup>/s along with the reported 1894 high-water marks upstream and downstream of the Hope gauge. If a linear interpolation is made between the two high-water marks to the Hope gauge then this interpolated value is 0.26 m higher than the computed level at the gauge site, which implies the 1894 flood was substantially higher than 17,000 m<sup>3</sup>/s. However, given the varying slope through this reach it does not appear reasonable to linearly interpolate between the gauges. Therefore, the profile was compared directly with the high-water marks (HWM). The agreement was as follows:

Downstream HWM: computed water level – reported high-water mark = -0.17 m

Upstream HWM: computed water level – reported high-water mark = +0.10 m

A sensitivity analysis was made by varying the assumed 1894 discharge to determine the range of flows that could fit the high-water marks. If the flow was reduced to 16,800 m<sup>3</sup>/s the model fit the upstream high-water mark but underestimated the downstream high-water mark by 0.3 m. If the assumed discharge was increased to 17,700 m<sup>3</sup>/s the model fit the downstream high-water mark but overestimated the upstream high-water mark by 0.4 m.

### 3.3.4 ASSESSMENT OF RESULTS

Based on the reported high-water marks near the Hope gauge, the hydraulic modelling indicates the 1894 peak discharge could have ranged between 16,000 m<sup>3</sup>/s and 18,000 m<sup>3</sup>/s. Given the uncertainty associated with the high-water marks and the rapidly varying nature of the flood profile in this region it is unlikely this value could be refined much further. The main uncertainties in this analysis include:

- Uncertainties in the accuracy of the original high-water mark determinations in 1934.
- Uncertainty of the location of the high-water marks in relation to the gauge and cross sections.
- Potential cross section changes between the 1952 surveys and conditions that existed in 1894, effects of channel curvature and secondary currents on water levels determined in a one dimensional model.
- Changes in hydraulic roughness between 1948 flood and 1894 flood conditions.

## 3.4 HYDRAULIC ASSESSMENT OF ALEXANDRA BRIDGE

### 3.4.1 BACKGROUND INFORMATION

Background information on the history of the Alexandra Bridge was described briefly in Section 2.3.2. Documentation of the 1894 flood level at the Alexandra Bridge is more complete than at Hope. Furthermore, the channel at Alexandra Bridge is incised in bedrock and appears to have changed little over time. A preliminary assessment was undertaken to determine whether it is feasible to use the historical information at the bridge to provide an independent estimate of the 1894 flood flow.

### 3.4.2 AVAILABLE INFORMATION

Figure 3.6 shows the general arrangement of the 1926 bridge. Design drawings of the original 1863 bridge was also obtained from the provincial archives and compared. The 1926 bridge used the same foundations as the 1863 bridge, but concrete extensions were built on top of the foundations, raising the bridge by about 4.8 m. The overall span length for both bridges (tower to tower) was 84 m. The 1926 bridge plans showed an 1894 flood level of 272 ft or 82.9 m. This water level appears to be over 1 m higher than the water level in the photograph of the 1894 flood (Figure 2.8). It is not known if the photograph was taken at the peak of the flood and the water level shown on the bridge drawing may be more representative.

The 1926 bridge drawing also shows the low water level for November 1924 at 197 feet (60.0 m), indicating the river was nearly 23 m higher during the 1894 flood at this site. The mean discharge in November 1924 was reported to be 1,310 m<sup>3</sup>/s at the Hope gauge. The cross section geometry below the 1924 water surface is not known.

A site visit was made to Alexandra Bridge on May 25, 2008, roughly at the peak of the freshet. The water level at the site was estimated to be 75.0 m or 7.9 m lower than the 1894 peak level. On the same day, WSC measured a flow of 9,659 m<sup>3</sup>/s at Hope. Final freshet flows have not yet been approved by WSC. The water level and pier dimensions at the bridge site were recorded as shown in Figure 3.7. The surface velocity was estimated to be roughly 6 m/s and flow was seen to be highly turbulent. A secondary channel, to the left of the left bank pier was actively conveying flow and large surges resulting in water level fluctuations of up to 1 m were observed at the pier. The water level by the right bank showed less fluctuation, varying by about 0.5 m. The water level shown in the diagram refers to an average level.

A second informal inspection was made on August 4, 2008 when the flow had reduced to approximately 3,400 m<sup>3</sup>/s at Hope. The inspection was made during a rafting trip between Hell's Gate and Yale, which provided an opportunity to observe the general hydraulic conditions through the canyon.

### 3.4.3 PRELIMINARY HYDRAULIC ANALYSIS

The 1926 bridge plans were used to estimate channel properties at the bridge. No information was available below the low water (el. 60.0 m) survey of November 1924 (1,310 m<sup>3</sup>/s at Hope). Cross sectional areas relative to this reference low water level are as follows:

- El. 75.0 m to El. 60.0 m (2008 HWM – November 1924) Area = 883 m<sup>2</sup>
- El. 82.9 m to El. 60.0 m (1894 HWM – November 1924) Area = 1,625 m<sup>2</sup>

Based on conditions at Hope and observations of the river at low flow it is expected that the velocity in November 1924 was in the range of 1.5 m/s to 2.0 m/s. Assuming a flow at the bridge of 1,310 m<sup>3</sup>/s the cross sectional area in November 1924 would have ranged between 873 m<sup>2</sup> and 655 m<sup>2</sup>. Table 3.2 summarizes the estimated range in hydraulic properties at the bridge site for the 1894 flood and 2008 high-water estimates. Using these values the mean velocity in June 2008 would have ranged between 5.5 m/s and 6.3 m/s, which agrees with the estimated velocity of 6 m/s determined in the field. Under these assumptions, an 1894 flood of 17,000 m<sup>3</sup>/s would have required a mean velocity of between 6.8 m/s and 7.5 m/s. Given the observations during the 2008 flood this seems reasonable. However, there is insufficient data to make more definitive estimates of the 1894 discharge from the available information.

### 3.4.4 POTENTIAL ADDITIONAL WORK

A quantitative estimate of the 1894 flood could be made by using a standard-step backwater analysis, similar to the approach also carried out near Hope in Section 3.2. This would require cross section surveys of the channel and canyon. It is expected that surveys would extend about 5 km downstream from the bridge to just above Sailor Bar. Approximately 10

to 12 cross sections should be sufficient. Based on the inspection on August 4, this reach is navigable by small boats at low water and is accessible from the north bank near Spuzzum. The starting water level at the downstream boundary would have to be estimated using the normal depth method.

There are practical difficulties to produce accurate cross sections. If the surveys were made at low water then the above water portions of the sections would need to extend in the order of 15 to 25 m vertically above the low water level. This would be time consuming and possibly hazardous in some locations using terrestrial survey methods. If the surveys were made during high-water using a boat and depth sounder, then the turbulence could introduce errors or loss of signal. Also, the narrow canyon will make it difficult or impossible to use GPS techniques (particularly Real-Time Kinematic methods) for horizontal positioning. Another approach would be to use conventional photogrammetric methods to determine the above-water portions of the ground topography in the canyon. Adequate topography may have been produced for previous highway and railway projects in the area.

## 4 FLOOD FREQUENCY ANALYSIS

### 4.1 OBJECTIVES

Flood frequency analyses are necessarily based on historic flood conditions in the basin. Several factors are known to affect the historic flood record on the Fraser River, including:

- Possible longterm trends in climate, land cover and runoff.
- Uncertainty in the estimates of extreme floods such as 1894 in terms of their magnitude and recurrence time period.
- Varying effects of flow regulation from upstream storage projects on tributaries.

This study assessed the effects of each factor on flood frequency estimates, particularly in terms of the return period associated with an 1894 peak flow. The analysis identified the most critical factors and provides guidance on where further efforts should be focused to refine the estimates.

Based on the review of historic data, we have restricted the flood frequency analysis to annual maximum discharges at Hope. In our opinion, the long-term water level record at Mission is non-stationary due to progressive bed degradation (NHC, 2006) and is unsuitable for frequency analysis. Furthermore, discharge measurements at Mission are subject to greater uncertainty than at Hope and the length of records is much shorter. Therefore, at this time it is better to use Hope as the reference station for flood frequency analysis and determine representative flows at Mission by correlation or routing to account for inflows from the Harsion River and Chilliwack River.

### 4.2 TRENDS

Figure 4.1 shows a time series plot of annual maximum daily discharges at Hope. Values for the period 1894 to 1911 were estimated from water levels at Mission using regression equation [2] described in Section 2.3. Also shown in Figure 4.1 is a plot of the cumulative departures from the mean for each year in the time series. The cumulative departure from the mean (CDM) is defined as follows:

$$CDM_i = \frac{\sum(Q_i - Q_m)}{Q_m} \quad [3]$$

where,  $Q_i$  is the annual maximum discharge in year  $i$ , and;

$Q_m$  is the mean annual maximum discharge for the entire time period.

This statistic is commonly used to detect changes in runoff patterns over time. If a period of years has higher than average floods, then the CDM will increase over time (positive slope). If a period of years has a persistently lower than average flows, then the CDM will decrease and show a negative slope.

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The long-term mean annual flood at Hope for the period 1894 to 2008 is 8,770 m<sup>3</sup>/s. However, Figure 4.1 also shows there are cyclical patterns of persistently higher and lower flows. For example, the flows were persistently higher than the long-term mean during the period:

- 1894 to 1903
- 1915 to 1925
- 1948 to 1976

Floods were lower than the long-term mean during the periods:

- 1904 to 1914
- 1926 to 1947
- 1977 to 2006

These cyclical variations have been associated with large scale decadal oscillations in the Pacific Ocean temperature and are characteristic of many rivers in British Columbia. Given the cyclical nature of these oscillations, there does not appear to be any strong justification to truncate the flow record. Therefore, the entire record has been used in the subsequent flood frequency analysis.

### 4.3 EFFECT OF 1894 FLOOD ON FLOOD FREQUENCY

Previous published flood frequency relations for the Fraser River at Hope characteristically show the 1948 and 1894 flood flows plotting as extreme outliers (Inland Waters Branch, 1970). One reason for this is that no adjustment was made to account for the actual plotting position of these floods in terms of their historic recurrence interval. An analysis was carried out to determine the effect of these outlier events on frequency estimates. This involved using the “historical analysis” option in the flood frequency program Hydro-Freq. This program sets an extended record length for the outlier events and an assumed threshold flow value, which sets a time interval for the selected historic floods. The program computes General Extreme Value, Log Normal III, Log Pearson III and Pearson III distributions. For the purposes of this study we have selected the Log Pearson III distribution for main presentation. The Log Pearson III distribution has been adopted by the US Geological Survey and FEMA for flood frequency analysis. Results of all distributions are presented in Table 4.1.

The data set used in this analysis included all published annual maximum daily discharges between 1912 and 2008 plus 1894. The historical review in Section 2 indicates the 1894 flood was the largest flood since at least 1876 and most probably since 1847. Initially, the threshold flow was set to 16,900 m<sup>3</sup>/s so that it was assumed no flood exceeded the 1894 flood magnitude during the historic period. Figure 4.2 shows the frequency plot based on the 162 year period. As shown below the frequency estimates are not very sensitive to the historic period that is adopted.

Historic Period	Record Length (years)	Daily Discharge at Hope (m <sup>3</sup> /s)		
		100-year	200-year	500-year
1894-2008	115	14,470	15,480	16,850
1876-2008	133	14,340	15,320	16,630
1847-2008	162	14,200	15,130	16,380

The return period of the 1894 flood, assuming a peak discharge of 17,000 m<sup>3</sup>/s, is greater than 500 years under all assumed time periods while the 1948 flood is close to a 200 year event.

The analysis was repeated setting the threshold value to 15,000 m<sup>3</sup>/s, which meant that other than the 1894 flood, no flood exceeded the 1948 discharge during the historic period. With the historic period set to 1847 (162 year record length), the predicted 200 year flood flow was 14,810 m<sup>3</sup>/s and the 500 year flood flow was 15,960 m<sup>3</sup>/s.

Maximum instantaneous flows are only marginally higher than daily flows and consequently only daily flows were analyzed. During the freshet, flow conditions at the Hope gauge are quite turbulent and water level fluctuations of up to 0.3 m are not unusual. Under these conditions, accurate determination of the instantaneous maximum discharge is difficult.

#### 4.4 EXPECTED MOMENT METHOD

Flood frequency analysis was conducted using the Expected Moment Algorithm (EMA) (England, 1999). In comparison to traditional tools, EMA provides more rigorous and more flexible statistical procedures for incorporating historic data in to flood frequency analysis conducted using the log-Pearson Type III distribution. EMA is of particular value in situations where estimates of the magnitude of historic floods are highly uncertain since EMA allows the user to specify a range of estimates for the historic value rather than a single, uncertain, value. EMA also allows specification of multiple thresholds, as may be needed in situations where a record of floods includes both systematic data, historic data, and paleoflood information.

EMA was applied to the record of annual daily maximum peak flows for the Fraser River at Hope comprising an estimate of the peak flow for the historic 1894 flood plus the published record from 1912 to 2008. It was assumed that the 1894 event was the largest since 1847, i.e. the largest flood in the 162-year period through 2008. Analyses were conducted assuming both a fixed value (17,000 m<sup>3</sup>/s) and a range for the 1894 daily peak discharge (17,000 ± 500 m<sup>3</sup>/s, and 17,000 ± 1,000 m<sup>3</sup>/s). Flood quantiles for return periods from 100- to 500-year as computed by EMA are provided below:

Scenario	Daily Discharge at Hope (m <sup>3</sup> /s)		
	100-yr	200-yr	500-yr
1894 = 17,000 m <sup>3</sup> /s	14,380	15,370	16,690
1894 = 17,000 ±500 m <sup>3</sup> /s	14,350	15,320	16,620
1894 = 17,000 ±1,000 m <sup>3</sup> /s	14,320	15,280	16,570

In this particular case, the specified ranges of uncertainty are insufficient to make any meaningful difference in the quantile estimates. The data and fitted Log Pearson III distribution are shown in Figure 4.3 for the scenario with a fixed value (17,000 m<sup>3</sup>/s) for 1894.

#### 4.5 RECORD EXTENSION USING MISSION DATA

Water level records at Mission for the period 1876, 1888 and 1895 to 1911 were used to extend the data set at Hope. This involved estimating the discharges at Hope from the annual maximum water levels at Mission using the correlation described in Section 2.2.2. This provided 18 years of additional records at Hope, including relatively large floods in 1876 and 1888. Results of this analysis are summarized below.

Historic Period	Record Length (years)	Daily Discharge at Hope (m <sup>3</sup> /s)		
		100-year	200-year	500-year
1876-2008	133	14,600	15,580	16,900
1847-2008	162	14,470	15,410	16,670

#### 4.6 EFFECT OF UPSTREAM REGULATION

The Fraser River basin contains no storage projects designed primarily for flood control. However, the hydroelectric power generation projects on the Stave River, Bridge River system and Nechako River provide some opportunity for regulating peak flood flows if losses in generation are accepted. The Bridge River system began operating in 1948 and continued to be implemented during the early 1950's. Kenney Dam on the Nechako River was built in 1952 and the Nechako reservoir has been fully regulated since 1957. Rio Tinto-Alcan is in charge of the reservoir operation and diverts a portion of flow to Kemano for power generation. As described in Section 1.3, the Fraser River Joint Advisory Board (1976) documented how the combined operation of Bridge River and Nechako River projects reduced the 1972 flood peak at Hope by approximately 1,130 m<sup>3</sup>/s. Without the relief provided in 1972 by the existing upstream storage, the peak flow at Hope would have been 14,030 m<sup>3</sup>/s versus the recorded peak of 12,900 m<sup>3</sup>/s. Therefore, the effect of regulation needs to be accounted for in the flood frequency analysis.

The operating procedures on the Nechako River system are known to have changed over time. Initially, powerhouse flows were lower than at present because of a lower installed generation capacity. In the early 1980's monthly minimum flows and cooling flows were imposed to reduce summer temperatures. Furthermore, Rio Tinto-Alcan has no legal obligation to operate the reservoir for flood reduction purposes. However, the present operating guidelines make a concerted effort to reduce winter releases which could aggravate ice jam flooding in Prince George. A study on the effects of the present operating procedures on flows at Vanderhoof has been carried out recently (NHC, 2008b) as part of a flood mitigation study. This involved reviewing reservoir operations and estimating the effects on peak flows at Vanderhoof by generating a simulated flow record for the period 1957 to 2006, reflecting observed present operating procedures. Results are still preliminary and are subject to review by the City and other stakeholders. This study, when completed, should assist in understanding the effects of the present operating procedures on peak flows during the freshet season.

As part of a floodplain mapping and flood control study presently being conducted for City of Prince George by NHC, Vanderhoof flows were routed to Isle Pierre and frequency analyses undertaken on both reported and simulated flows for Nechako River at Isle Pierre. Based on reported flows, the 200-year flood was estimated to be 1,300 m<sup>3</sup>/s but based on the simulated record the 200-year flood was 1,800 m<sup>3</sup>/s or almost 40% higher. However, the simulated record showed peak flows typically occurring later in the year, well after the Fraser freshet peak. It is not clear how the Nechako reservoir would be operated in very large floods and what the reservoir's capacity for flood reduction would be.

To properly account for the Nechako regulation in analyzing Hope flows, the recorded Nechako flows should be naturalized, or a record generated corresponding to unregulated conditions. A consistent operating procedure can then be imposed, reflecting an adopted future strategy. The naturalization process requires that the reservoir inflows, outflows, elevations and storage-elevation relationship are known. In case of the Nechako Reservoir, these computations would be quite complex since the reservoir amalgamated and redirected several watersheds. The rivers and lakes of Ootsa, Intata, Whitesail, Chelaslie, Tetachuk, Tahtsa and Natalkuz were linked forming a reservoir area of over 90,000 ha. For flood control work at Vanderhoof and Prince George it is imperative that Rio Tinto-Alcan adopt a clear set of operating procedures so that appropriate design flood values can be estimated. For downstream communities as far as the Lower Mainland, a detailed flow routing analysis of the Fraser River basin is required, compiling operating records from RioTinto-Alcan and BC Hydro. This analysis falls outside the present study but is strongly recommended.

The following analysis was made to provide a preliminary assessment on the likely effects of past flow regulation on flood frequency estimates:

- The annual maximum discharges for the period 1957 to 2008 were increased by 5 % and 10 % to represent hypothetical "natural flows". The values of 5 % and 10 % were based on the order of magnitude effects attributed to upstream storage in the Joint Advisory Board (1976) study.
- The flow records in the period 1894, 1912 to 1956 were left unchanged and were assumed to represent natural flows (effects from the initial phases of the Bridge River project were ignored).

- A frequency analysis was then carried out for the assumed “natural flow” records using the same historical analysis procedures that were used previously. It was assumed the 1894 flood was the largest flood since 1847 (162 year record length).

Results of the analysis are summarized below. The estimated values are relatively insensitive to the assumption about the degree of regulation in the post 1957 period.

Historic Period	Assumed Regulation at Hope	Daily Discharge at Hope (m <sup>3</sup> /s)		
		100-year	200-year	500-year
1847-2008 (162 years)	5 %	14,430	15,320	16,420
1847-2008 (162 years)	10 %	14,730	15,610	16,760

#### 4.7 RECOMMENDED INTERIM FLOOD FREQUENCY ESTIMATES

Until further investigations are completed we tentatively recommend the following flood frequency estimates and approximate 95% confidence limits be adopted at the Hope gauge:

- 100 year daily maximum: 14,700 m<sup>3</sup>/s (+ 1,100 and -900 m<sup>3</sup>/s)
- 200 year daily maximum: 15,600 m<sup>3</sup>/s (+ 1,300 and -1,000 m<sup>3</sup>/s)
- 500 year daily maximum: 16,800 m<sup>3</sup>/s (+ 1,600 and -1,200 m<sup>3</sup>/s)

These values are based on the log Pearson Type III distribution using an extended record length of 162 years. The daily records between 1957 to 2008 were adjusted by +10% to account for upstream storage effects, making the time series more representative of natural flows. The magnitude of the reduction in peak flows due to present-day Nechako operations is not well defined at this time. There is no good basis for adjusting the flood frequency estimates further until this issue is clarified. Based on these flows, the 1894 flood had a return period of slightly more than 500 years and the 1948 flood was close to a 200 year event.

A significant reduction in flood risk may be achievable if formal upstream reservoir operating agreements can be established for flood mitigation. Detailed studies should be completed to determine if reservoir operating rules can be introduced to ensure a reduction in peak flows of about 1000 m<sup>3</sup>/s (i.e. similar to 1972) for a full range of flood scenarios, including floods generated in part from heavy rainfall during the melt period.

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## 5 FUTURE CONDITIONS

### 5.1 LAND COVER

Long-term change in the hydrologic response of the Fraser basin is inevitable with the massive loss of tree cover from the mountain pine beetle infestation. A Variable Infiltration Capacity (VIC) macro-scale hydrologic model of the basin is currently under development by researchers associated with the Pacific Climate Impacts Consortium. The model will be used to evaluate the effects of the infestation on the hydrologic regime of the Fraser. The same model may provide a suitable basis for assessing the potential impacts of climate change.

### 5.2 CLIMATE CHANGE

The impact of future climate change on flood flows on the Fraser River is highly uncertain. Flood flows will be affected by the manner in which combined changes in temperature and precipitation impact hydrologic processes integrated over the basin (Pacific Climate Impacts Consortium, 2007; Climate Impacts Group, 2004; Columbia Mountains Institute for Applied Ecology, 2003 and Christensen et al, 2004).

The Fraser is a snow-dominant basin. Research to-date on snow-dominant basins shows that warming, which is expected with high certainty in the 21<sup>st</sup> century, will on average increase the proportion of winter precipitation falling as rain, and will result in a reduction in the accumulation of winter snowpack, earlier melt of that smaller pack, and a reduction in the volume of the spring freshet. While a decrease in peak flow for most freshets could be expected, what is unclear is whether climate change, which could result in higher melt rates and/or increased spring precipitation, could in some circumstances increase peak flows.

The picture is also complicated by the uncertain impacts of climate change on absolute precipitation amounts (as distinct from the mix of rain and snow). The current generation of global climate models (GCMs) show a range of results, with some models showing a small decrease in annual precipitation while others show a modest increase. The emerging consensus, however, seems to be for a modest increase in annual precipitation, with that increase mostly occurring in the winter months. Increased winter precipitation in the Fraser basin would tend to increase winter snow accumulation hence offsetting, to an unknown degree, the impacts of warming.

A detailed examination of the impacts of climate change on flood flows in the Fraser basin should be considered. Such work would ideally take advantage of the VIC hydrologic model currently under development for examination of pine beetle infestation impacts in the basin, as discussed above. Simulations with the VIC model should be conducted using meteorological outputs from a range of GCMs/emission scenarios for a range of future land cover scenarios. The intent would be to develop information on the sensitivity of Fraser basin floods to climate change. This would be an important step in developing potential flood management responses to climate change for the lower Fraser valley.

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## 6 CONCLUSIONS AND RECOMMENDATIONS

### 6.1 CONCLUSIONS

#### *1. 1894 and 1948 Flood Estimates:*

The Laidlaw-Hope hydraulic model confirmed that the WSC rating curve extension in use in 1948 was accurate and that the maximum daily flow in 1948 was about 15,200 m<sup>3</sup>/s. The model also confirmed the 1894 flood discharge was approximately 17,000 m<sup>3</sup>/s at Hope. The accuracy of the high water marks is probably about  $\pm 0.3$  m corresponding to a flow range of about 16,000 m<sup>3</sup>/s to 18,000 m<sup>3</sup>/s.

#### *2. Return Period Estimates for the 1894 and 1948 Floods*

Historic evidence suggests that the flood of 1894 was the largest flood event since at least 1847. Frequency analyses were performed using the HydroFreq and EMA software. Confidence limits were developed based on the Log Pearson Type III distribution. Assuming the 1894 flood was not exceeded in 162 years, the 1894 flood had a return period of approximately 500 years. The return period of the 1948 flood is in the order of 200 years.

#### *3. Nechako and Bridge River Regulation*

The Nechako and Bridge River reservoirs have significantly affected the peak flows of the Fraser River at Hope in the past. During the 1972 flood, careful operation of the reservoirs reduced the peak flow at Hope by approximately 1,130 m<sup>3</sup>/s (about 8%). However, operating procedures have changed over time and the magnitude of the present reduction in peak flows (if any) is not known. Further assessment and discussions are required to resolve this issue. The benefits of adopting alternative operating policies for flood control should be explored.

#### *4. Climate Data and Basin Changes*

1894 precipitation and temperature data is available for a few stations in the Fraser basin. The data does not explain the magnitude of the 1894 flood unlike the data for 1948, which indicated extreme precipitation and unusual temperatures (cold spring with sudden very warm conditions). The impact of potential extreme weather conditions should be evaluated to determine the maximum flow that can be expected for a certain snow water equivalent index.

The effects of climate change in BC were summarized by Pacific Climate Impacts Consortium (2007). The impacts of climate change on Fraser River peak flows need to be investigated. Extensive work is underway to investigate the impacts of pine beetle infestations and may significantly affect flood estimates.

#### *5. Risk assessment analysis*

The level of risk and appropriate design criteria for frequency and freeboard requirements for dikes and developments should be assessed. It may be appropriate to vary the design standard for different areas based on a cost benefit approach.

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## 6.2 RECOMMENDATIONS

Based on the scoping study findings the following specific recommendations are provided:

1. Refine the effects of present day operating procedures at upstream storage projects on the peak flows on the Fraser River at Hope. Review agreements with Rio Tinto - Alcan and BC Hydro to ensure the projects will be operated to maximize flood control benefits during critical periods.
2. Assess the climatic conditions required to generate an 1894 flood in the basin using a comprehensive hydrological model. Determine the probability associated with these meteorological conditions.
3. Assess expected effects of land cover changes, specifically Mountain Pine Beetle damage, on flood hydrology.
4. Assess expected effects of climate change on flood hydrology.
5. Assess the level of flood risk along the Lower Fraser River and develop appropriate design frequency criteria. Develop site specific freeboard standards for dikes and developments.
6. Review additional historic archival information. This work may help refine the return period estimate of 500-years for the 1894 flood.

Additional detailed hydraulic investigations at Alexandra Bridge will not significantly improve the estimate of the 1894 flood. Therefore, we do not recommend carrying out further surveys or high-water measurements.

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## **TABLES**

**Table 2.1: WSC Published Hydrometric Data**

WSC Gauge	Name	Drainage Area (km <sup>2</sup> )	Water Level	Discharge
08MF005	Fraser R. at Hope	205,000	1912-2007	1912-2007
08MF035	Fraser R. near Agassiz	218,000	1949-1995	1966-1986
08MH024	Fraser R. at Mission	228,000	1876,1882,1894-2007	1965-2007

**Table 2.2: Published Maximum Stage and Discharge-Fraser River at Hope**

Rank	Year	Date	Stage (m)	Daily Discharge (m <sup>3</sup> /s)
1	1948	May 31	10.973	15,200
2	1972	Jun 16	10.141	12,900
3	1950	Jun 20	9.909	12,500
4	1964	Jun 21	9.601	11,600
5	1955	Jun 29	9.391	11,300
6	1997	Jun 05	9.536	11,300
7	1999	Jun 22	9.396	11,000
8	2007	Jun 10	9.30	10,850
9	1974	Jun 22	9.318	10,800
10	2002	Jun 21	9.190	10,600

**Table 2.3 Published Maximum Water Level and Discharge-Fraser River at Mission**

Rank	Year	Date	Water Level (m GSC)	Daily Discharge (m <sup>3</sup> /s)
1	1894	Jun 05	7.92	
2	1948	May 31	7.61	
3	1950	Jun 20	7.45	
4	1882	Jun 21	7.34	
5	1972	Jun 29	7.15	14,400
6	1964	Jun 05	7.01	
7	1876	Jun 22	7.00	
8	1936	Jun 05	6.97	
9	1967	Jun 04	6.97	13,500
10	1903	Jun 21	6.93	

**Table 2.4: Fraser Freshet Flooding 1862-1911**

Year	Recorded GH (m)	Water Level Description	Damage
1862		Steamboat captains reported that water levels were as high as ever observed. At New Westminster the water level was 0.3 m higher than observed before.	At Douglas, large portions of the town were inundated.
1866		Water level at Yale was 15 m above the low(?) water mark.	Portions of road between Yale and Lytton were inundated.
1870		Water level at Hope reached a maximum of 6.6 m above low water.	Large tracts of land in New Westminster were flooded. In Chilliwack and Sumas, farmlands were flooded.
1871		Water level at New Westminster reached within 7.5 cm of the high water mark (of 1862?). Water level at Yale was higher than it had been since 1866.	Road between Yale and Lytton flooded in several places. Alexandra Bridge was closed for repairs.
1875		Water level at Quesnel was 1.2 m higher than was ever known before or 9.9 m above the low water mark.	Warehouses and other buildings flooded (at Quesnel).
1876	6.93	Water level at Mission crested at 6.83(?) m. Highest water ever experienced by the European decent population up to that time. In late June, <b>flood levels on the lower Fraser and Columbia Rivers were the highest between 1847 and 1894</b> (Karanka and Associates).	Almost all of the settler's lands were flooded, except for Sardis. Crops were lost and fences floated away. Chilliwack-Sumas country was one vast lake. Pitt Meadows was flooded. Large areas not considered subject to flooding were inundated. Boston Bridge (built 1863) washed away. (It was 99 m long and 10.2 m above the bed.)
1877			Dike at Matsqui (poorly built) failed.
1878			Dike at Matsqui failed.
1879		0.6 m higher than in 1878.	Flooded greater part of Sumas. Bridge built in 1877 at Luck-a-Kuck failed.
1880			Dike at Matsqui failed.
1882	7.26	0.3 m higher than in 1876. In some parts of Chilliwack water level was 0.45 m higher than in 1876. Mission water level crested at 7.15 m.	Large areas of Chilliwack and Sumas were flooded. Crops were destroyed, bridges washed away and roads blocked with floating logs. Water more destructive than in 1876.
1890			Flooding of Fort Langley, Matsqui, Sumas, Pitt Meadows, Chilliwack etc.
1892			Sloughs were overflowing and much of the prairies were submerged.
1894	7.85	Flood of record.	Largest known flood to date. Reviewed in nhc (2006).
1895	6.00	5.9 m at Mission.	
1896	6.63	Within 69 cm of 1894 WL.	Large but not as destructive as previous floods. Matsqui dike failed. Low-lying areas were flooded.
1900	6.43	6.33 m at Mission, highest since 1894.	Some crop damage.
1903	6.86	6.75 m at Mission.	Bridges suffered damage, vast areas flooded.
1908	6.10		Flooding of low lying areas.
1911	5.82	0.3 m less than in 1908, river peaked at 5.73 m at Mission.	Some flooding at Sumas and opposite New Westminster.

- Notes:
1. Add 0.073 m to Mission gauge height to convert to GSC datum before 1887, then 0.043 m.
  2. Descriptive information taken from Septer, 2001.

**Table 3.1: Fraser River - Laidlaw to Hope MIKE11 Model Results**

CALIBRATION - 1972 (12,900 m3/s)

Run

Gauge Name	MIKE Station	Peak Level (June 16 1972)	A		B	
			W.L	$\Delta h$	W.L	$\Delta h$
HWM Ruby Creek (gauge #60)	FRASER 0.00	30.11	30.53	0.42	30.53	0.42
	FRASER 236.67	30.11	30.63	0.52	30.65	0.54
HWM Hope Gauge	FRASER 14908.00	38.10	37.77	0.33	38.02	0.08
Fraser River @ Hope (08MF005)	FRASER 14908.00	38.07	37.77	0.30	38.02	0.05

**Average Absolute Error**

**0.31**

**0.06**

VALIDATION - 1967 (10,800 m3/s)

Gauge Name	MIKE Station	Peak Level (June 22 1967)	B	
			W.L	$\Delta h$
HWM Ruby Creek (gauge #60)	FRASER 0.00	29.44	29.8	0.36
	FRASER 236.67	29.44	29.89	0.45
HWM Hope Gauge	FRASER 14908.00	-	37.22	
Fraser River @ Hope (08MF005)	FRASER 14908.00	37.24	37.22	0.02

**Average Absolute Error**

**0.02**

RESULTS - 1948 (15,200 m3/s)

Gauge Name	MIKE Station	Peak Level (May 31 1948)	B	
			W.L	$\Delta h$
HWM Ruby Creek (gauge #60)	FRASER 0.00	-	31.22	
	FRASER 236.67	-	31.36	
HWM Hope Gauge	FRASER 14908.00	38.89	38.83	0.06
Fraser River @ Hope (08MF005)	FRASER 14908.00	38.90	38.83	0.07

**Average Absolute Error**

**0.07**

RESULTS - 1894 (17,000 m3/s)

Gauge Name	MIKE Station	Peak Level (June 4 1894)	B	
			W.L	$\Delta h$
HWM Ruby Creek (gauge #60)	FRASER 0.00	30.54	31.69	1.15
	FRASER 236.67	31.09	31.84	0.75
HWM Hope Gauge	FRASER 14908.00	-	39.42	
Fraser River @ Hope (08MF005)	FRASER 14908.00	39.72	39.42	0.30

**Average Absolute Error**

**0.30**

**Table 3.2: Hydraulic Geometry at Alexandra Bridge**

Date	$Q_{\text{Hope}}$ ( $\text{m}^3/\text{s}$ )	Water Level at Bridge (m)	Top Width at Bridge (m)	Cross Sectional Area ( $\text{m}^2$ )
Nov 1924	1,310	60.0	53.5	660 – 875
May 25, 2008	9,660	75.0	72.0	1,540 – 1,760
June 5, 1894	17,000 ?	82.9	111.0	2,280 – 2,500

**Table 4.1: Summary of Frequency Analyses**

**Sensitivity to Record Length:**

Return Period	Record length=162 years 1847-2008: Threshold=16,900 cms				Record length=133 years 1876-2008: Threshold=16,900 cms				Record length=115 years 1894-2008: Threshold=16,900 cms				Record length=97 years 1912-2008: No historical analysis			
	GEV	LN3	LP3	P3	GEV	LN3	LP3	P3	GEV	LN3	LP3	P3	GEV	LN3	LP3	P3
2	8,435	8,501	8,463	8,386	8,427	8,501	8,460	8,375	8,425	8,501	8,458	8,367	8,431	8,469	8,466	8,430
5	10,022	10,110	10,047	10,037	10,013	10,115	10,064	10,051	10,030	10,118	10,079	10,063	9,972	9,964	9,949	9,962
10	11,073	11,125	11,067	11,123	11,083	11,134	11,106	11,165	11,121	11,140	11,140	11,202	10,940	10,875	10,857	10,907
20	12,081	12,068	12,030	12,146	12,125	12,082	12,096	12,222	12,189	12,090	12,154	12,287	11,831	11,703	11,688	11,768
25	12,400	12,362	12,334	12,468	12,459	12,377	12,410	12,555	12,532	12,387	12,475	12,629	12,106	11,958	11,944	12,034
50	13,385	13,257	13,268	13,444	13,496	13,277	13,377	13,569	13,603	13,291	13,471	13,674	12,933	12,725	12,720	12,828
100	14,363	14,133	14,197	14,400	14,540	14,159	14,344	14,565	14,687	14,176	14,470	14,704	13,721	13,464	13,471	13,590
200	15,337	14,999	15,131	15,339	15,595	15,031	15,319	15,547	15,788	15,051	15,482	15,721	14,477	14,185	14,208	14,326
500	16,622	16,137	16,381	16,562	17,009	16,177	16,633	16,828	17,273	16,203	16,851	17,051	15,431	15,117	15,168	15,269

**Sensitivity to Record Extension:**

Return Period	Record length=162 years 1847-2008: Threshold=16,900 cms				1876-2008, incl Mission WL Ext Record length=133 years Threshold=16,900 cms				1857-2008, incl Columbia Flow Ext Record length=151 years No historical analysis			
	GEV	LN3	LP3	P3	GEV	LN3	LP3	P3	GEV	LN3	LP3	P3
2	8,435	8,501	8,463	8,386	8,542	8,599	8,571	8,506	8,865	8,847	8,839	8,766
5	10,022	10,110	10,047	10,037	10,209	10,263	10,238	10,239	10,283	10,262	10,253	10,245
10	11,073	11,125	11,067	11,123	11,312	11,309	11,311	11,367	11,094	11,092	11,090	11,157
20	12,081	12,068	12,030	12,146	12,371	12,279	12,324	12,424	11,787	11,829	11,836	11,988
25	12,400	12,362	12,334	12,468	12,707	12,581	12,643	12,755	11,991	12,053	12,064	12,244
50	13,385	13,257	13,268	13,444	13,741	13,499	13,625	13,757	12,577	12,718	12,742	13,009
100	14,363	14,133	14,197	14,400	14,768	14,396	14,602	14,735	13,099	13,349	13,388	13,743
200	15,337	14,999	15,131	15,339	15,791	15,281	15,583	15,694	13,565	13,953	14,010	14,453
500	16,622	16,137	16,381	16,562	17,141	16,443	16,898	16,938	14,108	14,723	14,806	15,361

GEV: General Extreme Value  
LN3: 3 Parameter Log Normal  
LP3: Log Pearson Type III  
P3: Pearson Type III

**Sensitivity to Threshold Value:**

Return Period	Record length=162 years 1847-2008: Threshold=16,900 cms				Record length=162 years 1847-2008: Threshold=15,000 cms				Record length=162 years 1847-2008: Threshold=14,000 cms			
	GEV	LN3	LP3	P3	GEV	LN3	LP3	P3	GEV	LN3	LP3	P3
2	8,435	8,501	8,463	8,386	8,416	8,495	8,459	8,385	8,416	8,486	8,459	8,385
5	10,022	10,110	10,047	10,037	9,962	10,084	10,006	9,992	9,962	10,055	10,006	9,992
10	11,073	11,125	11,067	11,123	10,986	11,082	10,986	11,037	10,986	11,036	10,986	11,037
20	12,081	12,068	12,030	12,146	11,968	12,006	11,904	12,016	11,968	11,941	11,904	12,016
25	12,400	12,362	12,334	12,468	12,280	12,293	12,192	12,322	12,280	12,223	12,192	12,322
50	13,385	13,257	13,268	13,444	13,239	13,167	13,071	13,250	13,239	13,076	13,071	13,250
100	14,363	14,133	14,197	14,400	14,192	14,020	13,940	14,155	14,192	13,909	13,940	14,155
200	15,337	14,999	15,131	15,339	15,141	14,862	14,806	15,042	15,141	14,728	14,806	15,042
500	16,622	16,137	16,381	16,562	16,393	15,965	15,958	16,193	16,393	15,800	15,958	16,193

## FIGURES

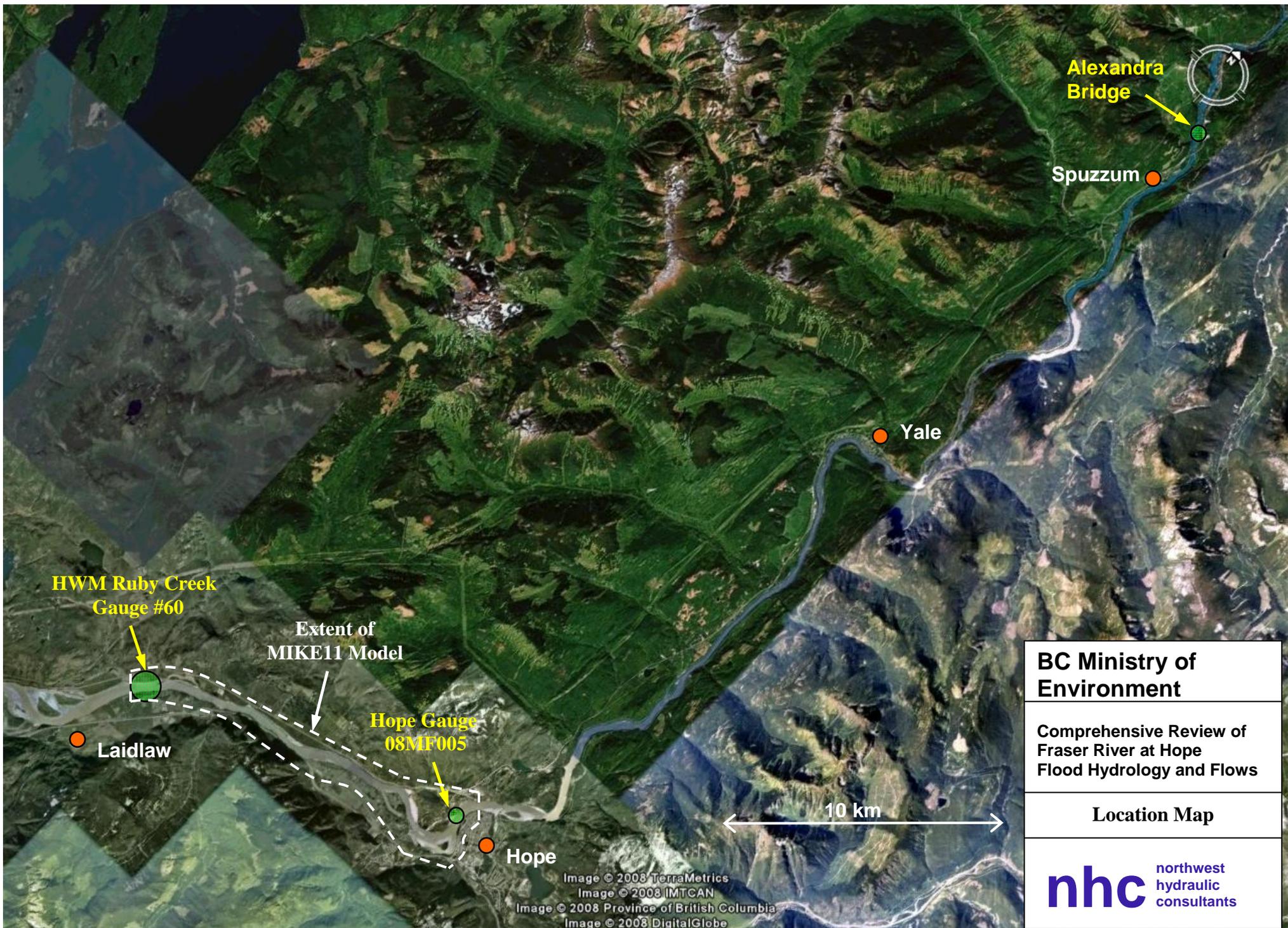
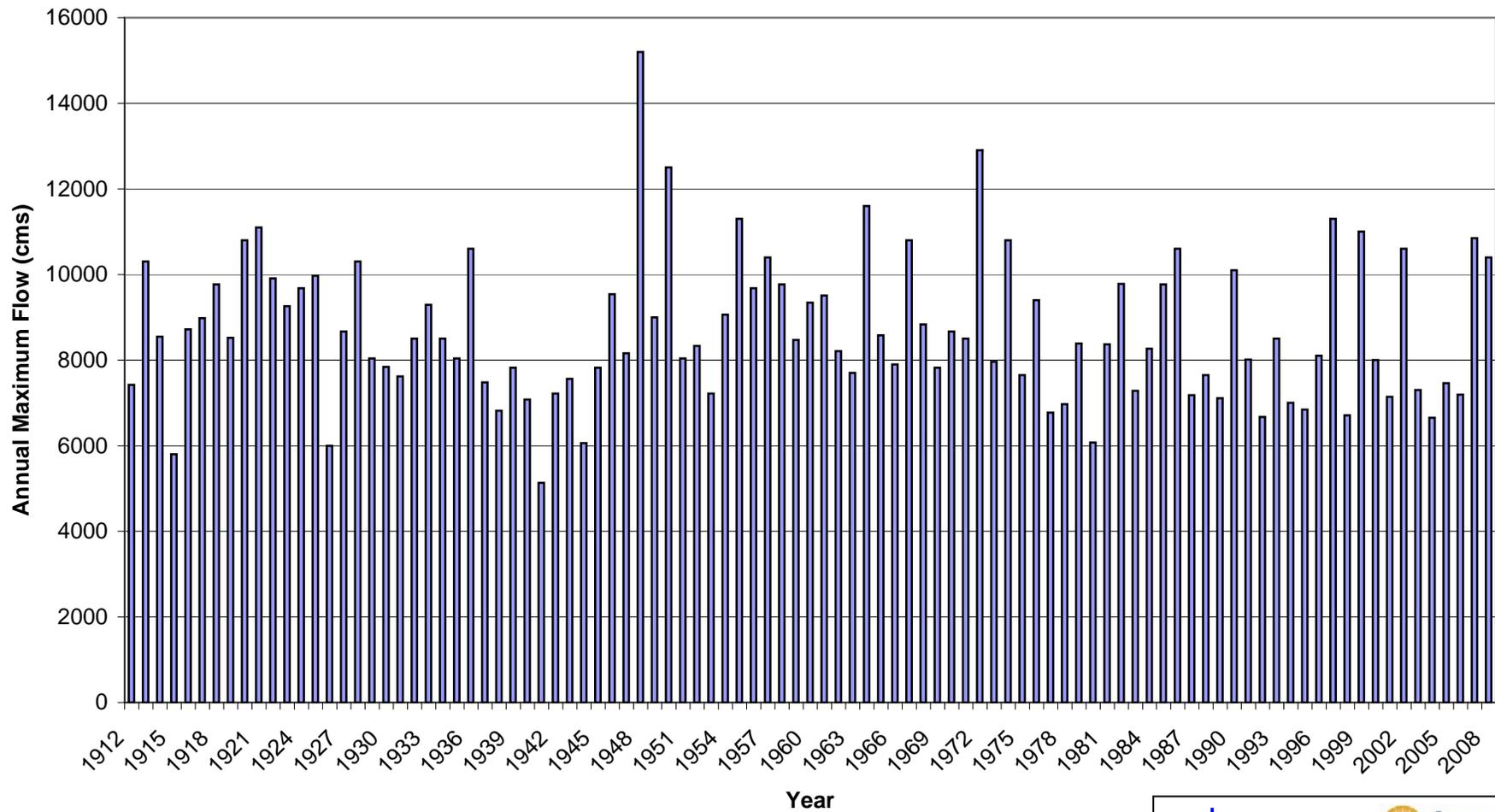
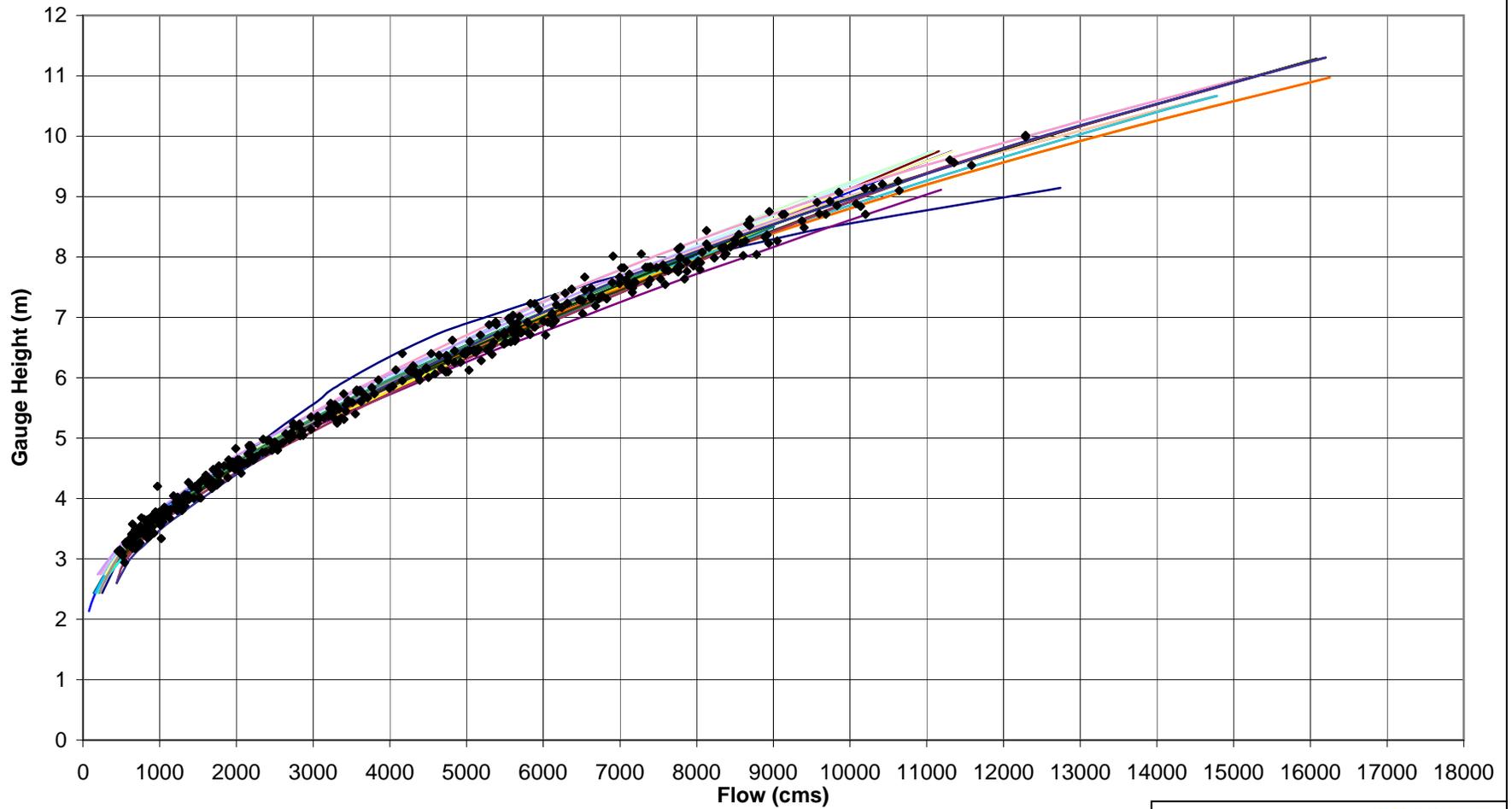


Figure 2.1

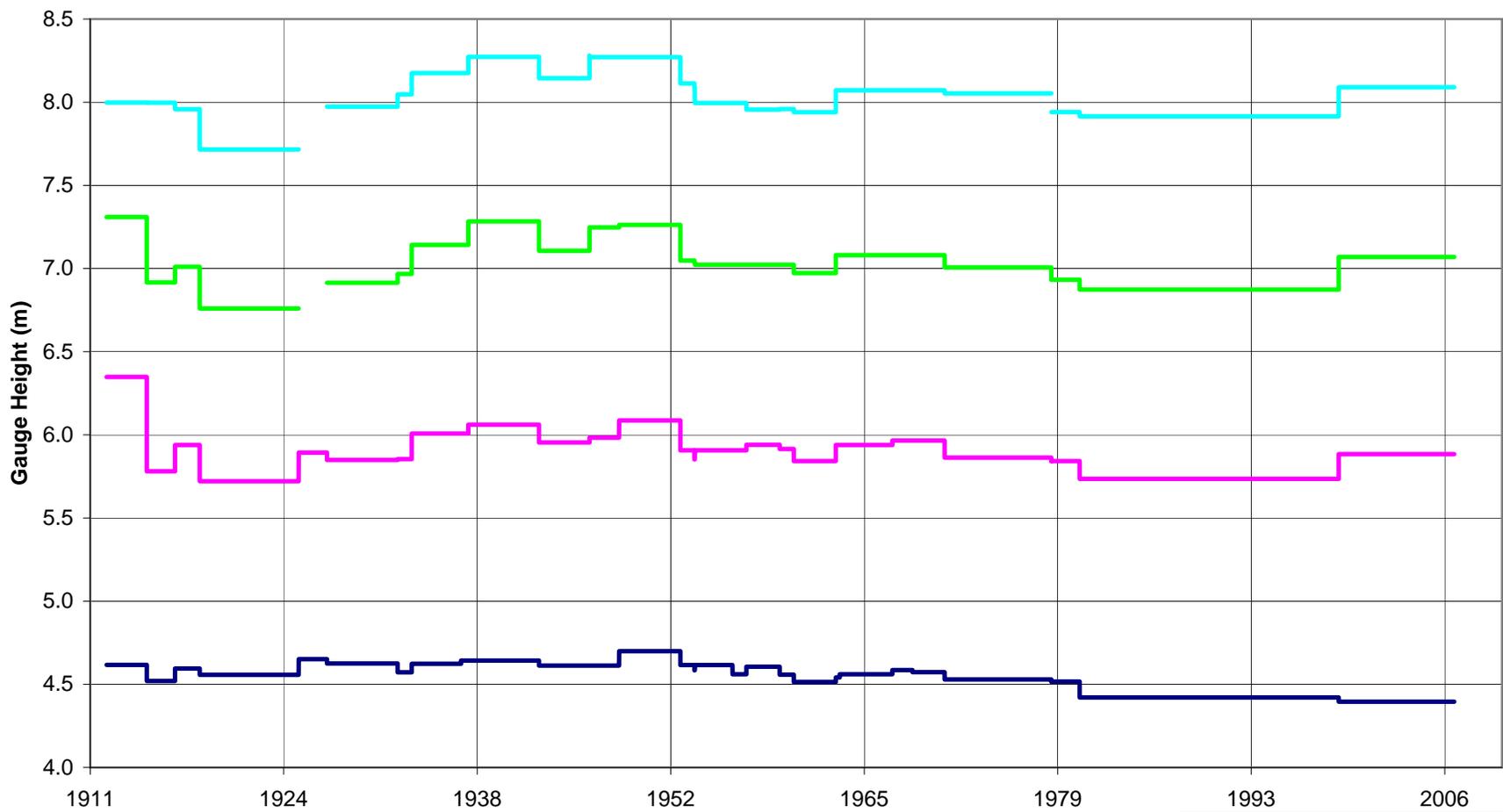


 	
Fraser River at Hope Recorded Flows	
August 2008	Figure 2.2

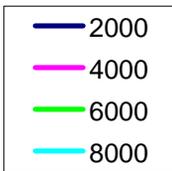


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|----------|----------------|----------|----------|----------|
| — Feb-12 | — Jan-15       | — Jan-16 | — Jan-17 | — Oct-18 |
| — Oct-25 | — Oct-27       | — Oct-32 | — Oct-33 | — Mar-37 |
| — Oct-37 | — Oct-42       | — May-46 | — Jun-48 | — Sep-52 |
| — Oct-52 | — Oct-53       | — Jun-56 | — Jun-57 | — Oct-59 |
| — Oct-60 | — Oct-62       | — Oct-63 | — Jan-64 | — Oct-67 |
| — Mar-69 | — Jun-71       | — Jan-79 | — Jan-81 | — Jan-87 |
| — Jan-06 | ◆ Measurements |          |          |          |

 	
<b>Fraser River at Hope</b> Historic Rating Curves and Flow Measurements	
August 2008	Figure 2.3



Flow (cms):



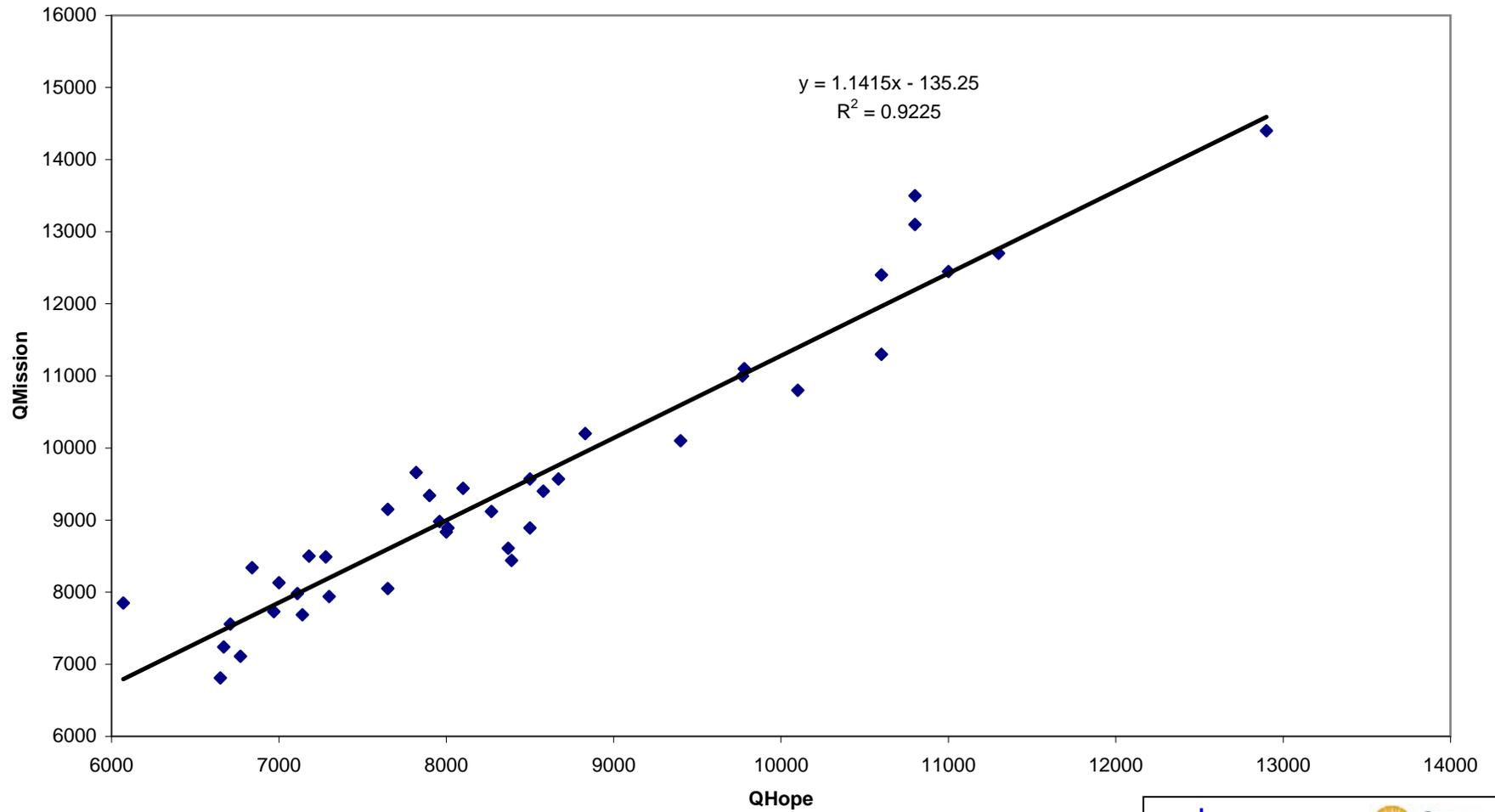
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Fraser River at Hope  
Specific Gauge Curve based on WSC  
Rating Curves

August 2008

Figure 2.4



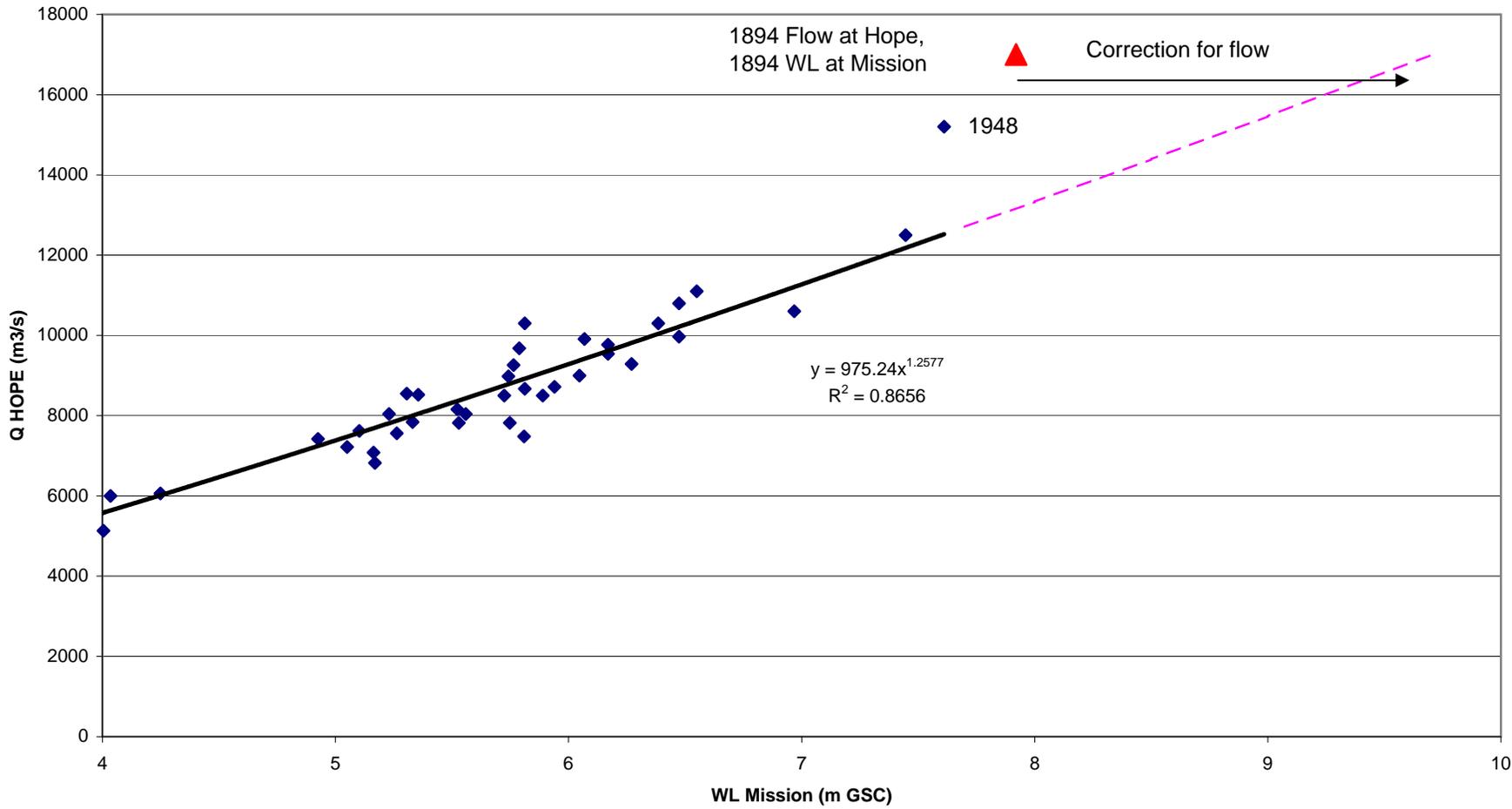
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Correlation between Annual Maximum Discharge at Hope and Mission 1965 to 2008

August 2008

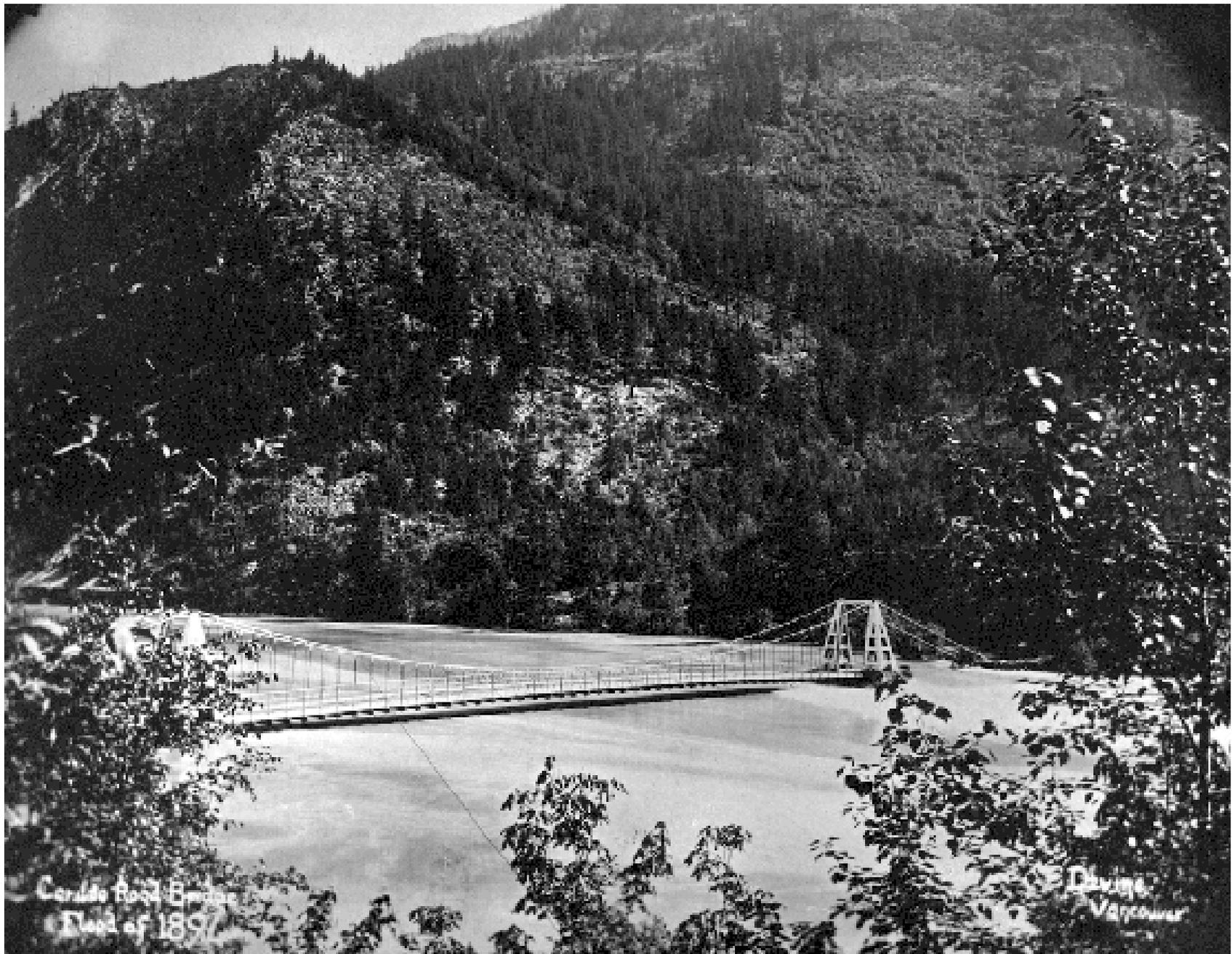
Figure 2.5



 	
Correlation between Mission Water Levels and Hope Discharge 1912 to 1950	
August 2008	Figure 2.6

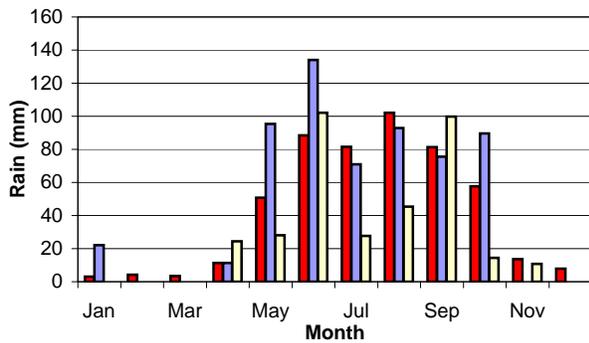


**Figure 2.7:** Alexandra Bridge Completed in 1863

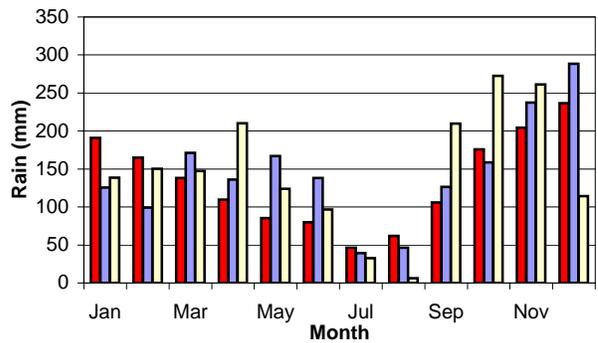


**Figure 2.8:** Alexandra Bridge during Flood of 1894

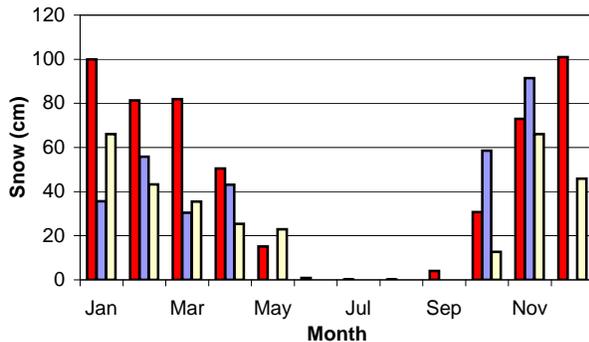
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Monthly Rainfall**



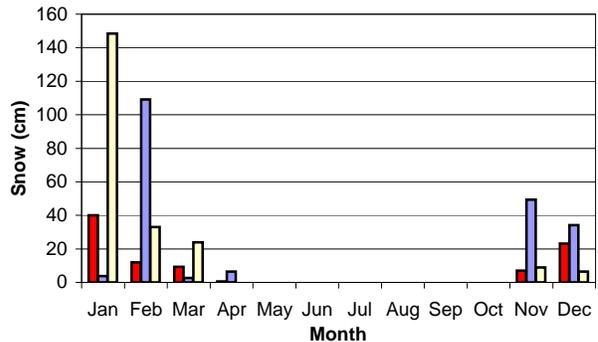
**1100120 Agassiz  
Monthly Rainfall**



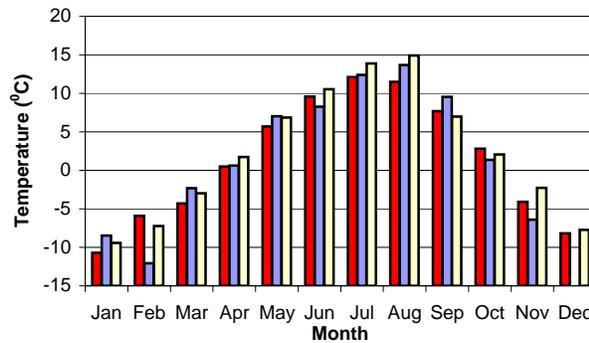
**1090660 Barkerville  
Monthly Snowfall**



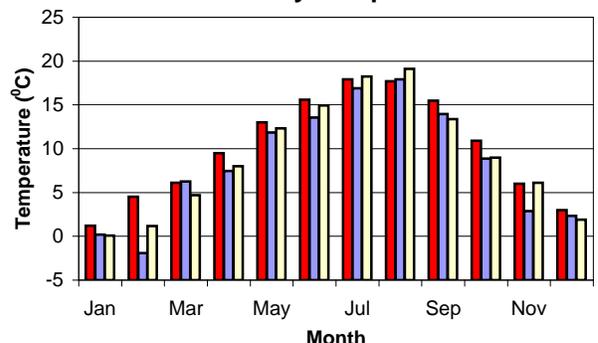
**1100120 Agassiz  
Monthly Snowfall**



**1090660 Barkerville  
Mean Monthly Temperature**



**1100120 Agassiz  
Mean Monthly Temperature**



■ - 1951-1980 Mean  
■ - 1893  
■ - 1894

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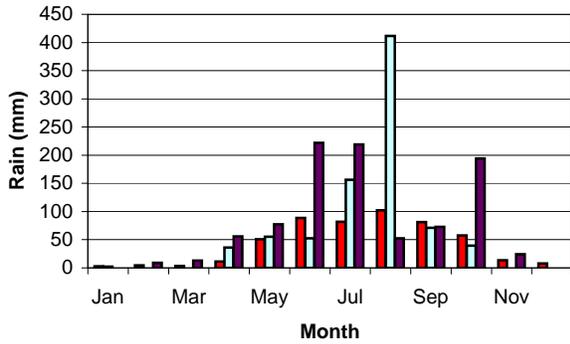


1893-1894 Barkerville and Agassiz  
Climate Data Comparison  
With Mean Values

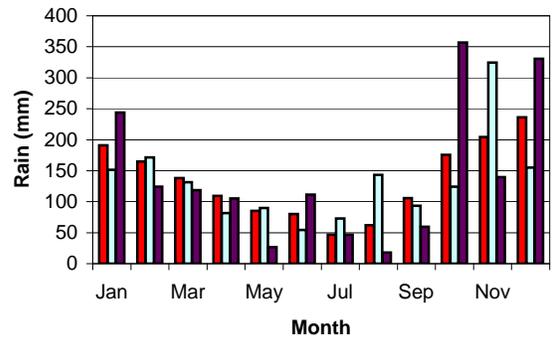
August 2008

Figure 3.1

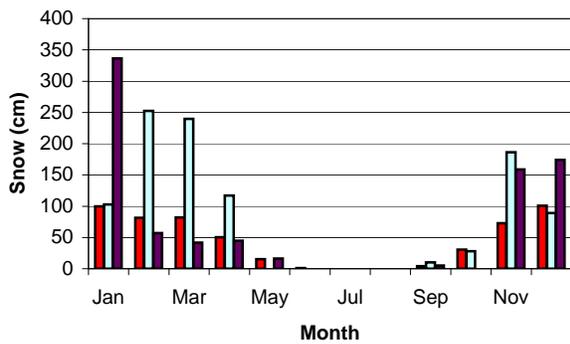
**1090660 Barkerville  
Monthly Rainfall**



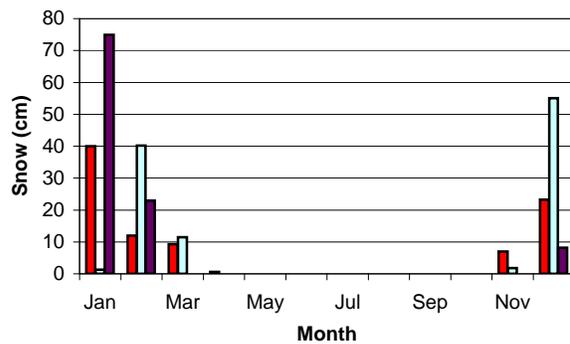
**1100120 Agassiz  
Monthly Rainfall**



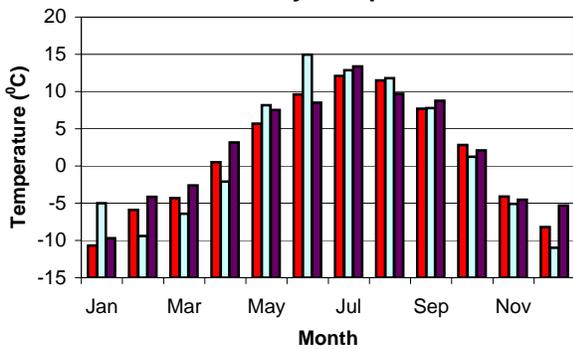
**1090660 Barkerville  
Monthly Snowfall**



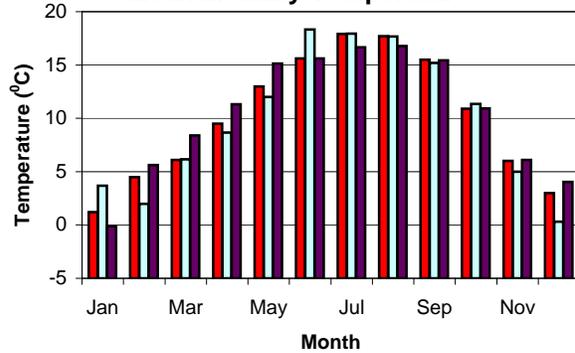
**1100120 Agassiz  
Monthly Snowfall**



**1090660 Barkerville  
Mean Monthly Temperature**



**1100120 Agassiz  
Mean Monthly Temperature**



■ - 1951-1980 Mean  
■ - 1948  
■ - 1947

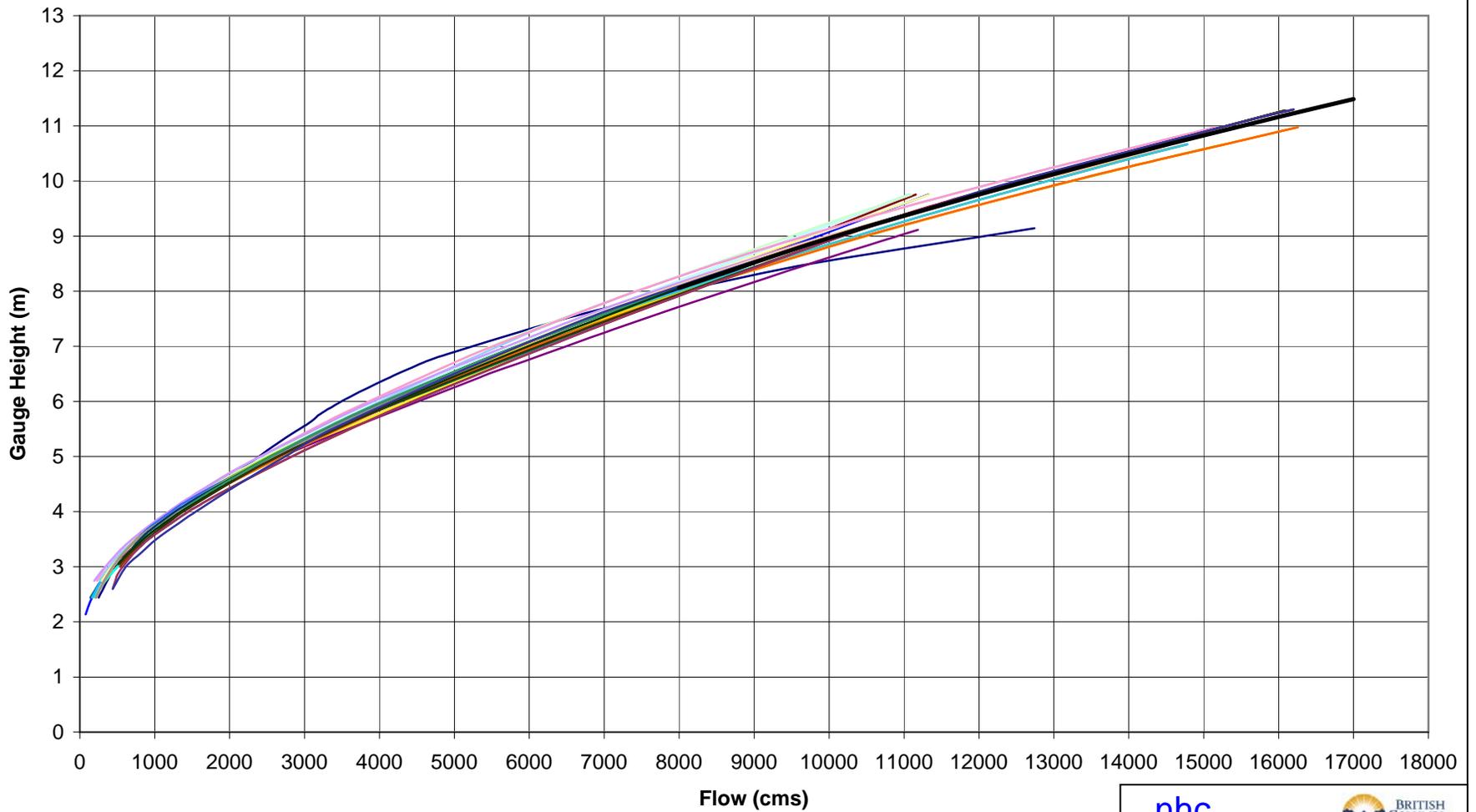
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1947-1948 Barkerville and Agassiz  
Climate Data Comparison  
With Mean Values

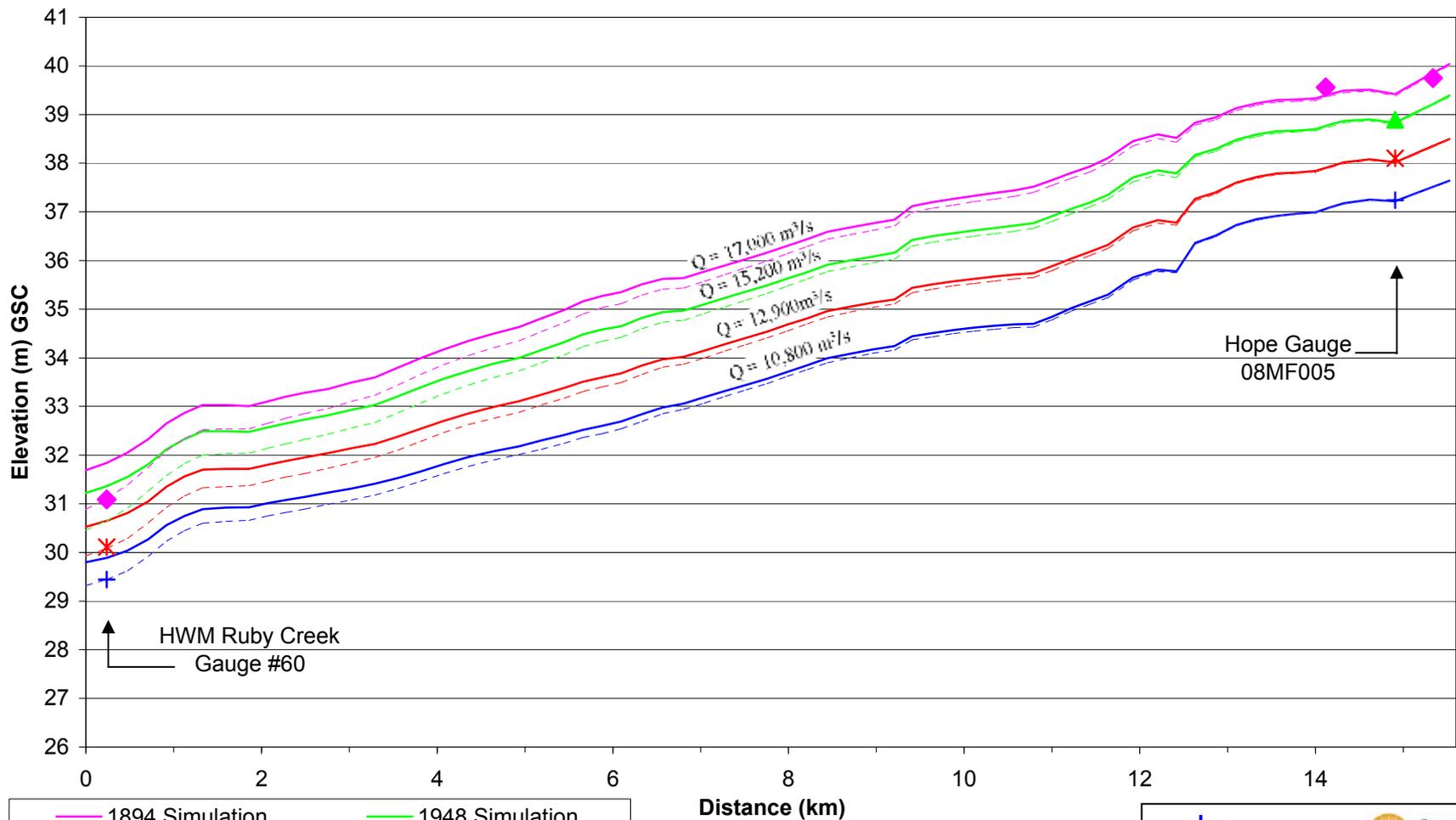
August 2008

Figure 3.2



- |          |          |          |          |          |          |          |          |
|----------|----------|----------|----------|----------|----------|----------|----------|
| — Feb-12 | — Jan-15 | — Jan-16 | — Jan-17 | — Oct-18 | — Oct-25 | — Oct-27 | — Oct-32 |
| — Oct-33 | — Mar-37 | — Oct-37 | — Oct-42 | — May-46 | — Jun-48 | — Sep-52 | — Oct-52 |
| — Oct-53 | — Jun-56 | — Jun-57 | — Oct-59 | — Oct-60 | — Oct-62 | — Oct-63 | — Jan-64 |
| — Oct-67 | — Mar-69 | — Jun-71 | — Jan-79 | — Jan-81 | — Jan-87 | — Jan-06 | — MIKE11 |

 	
<b>MIKE11 Rating Curve Extension VS Historic Curves</b>	
August 2008	Figure 3.3

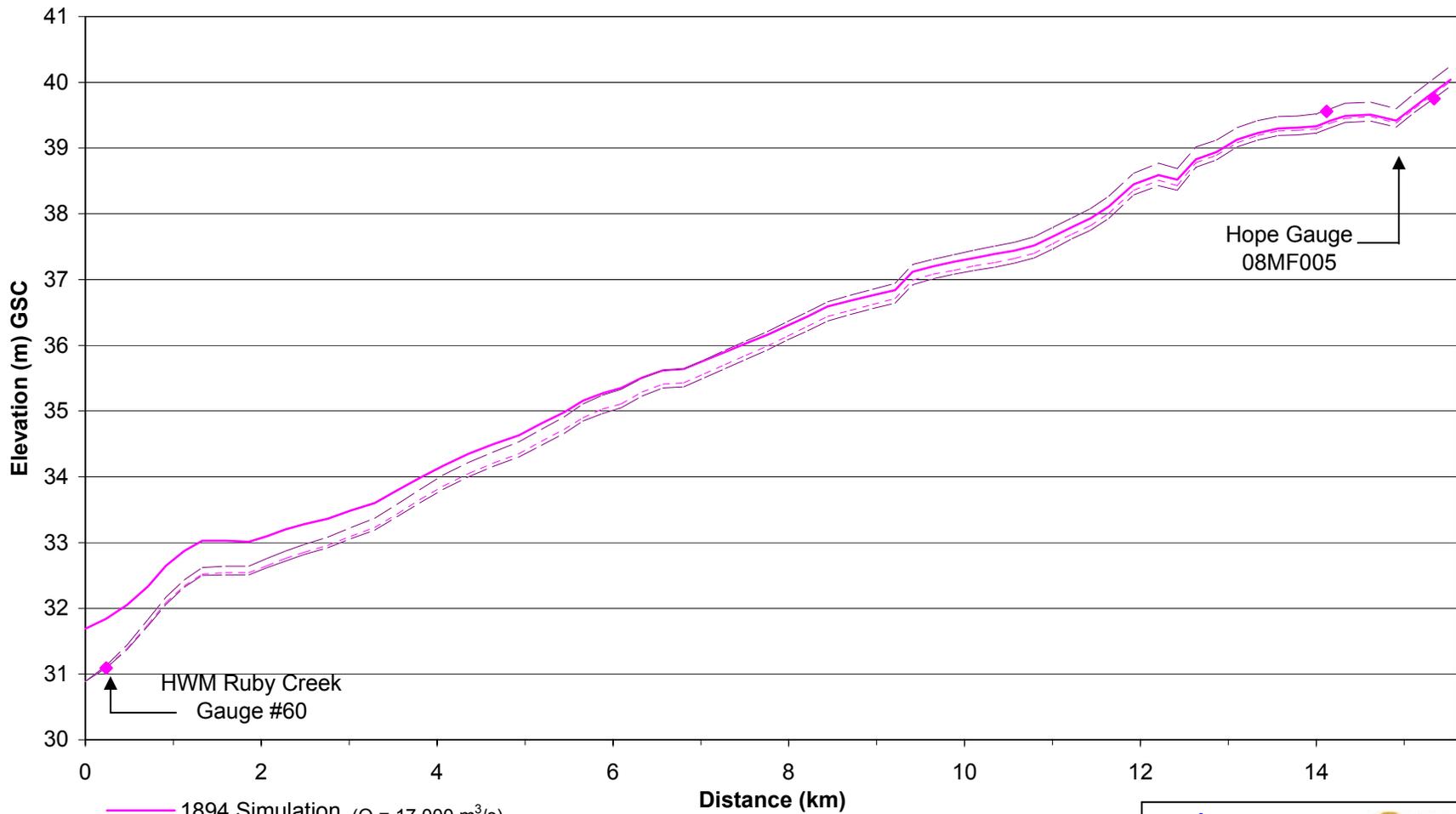


nhc  BRITISH COLUMBIA  
The Best Place on Earth

Laidlaw to Hope  
MIKE11 Water Surface Profiles

August 2008	Figure 3.4
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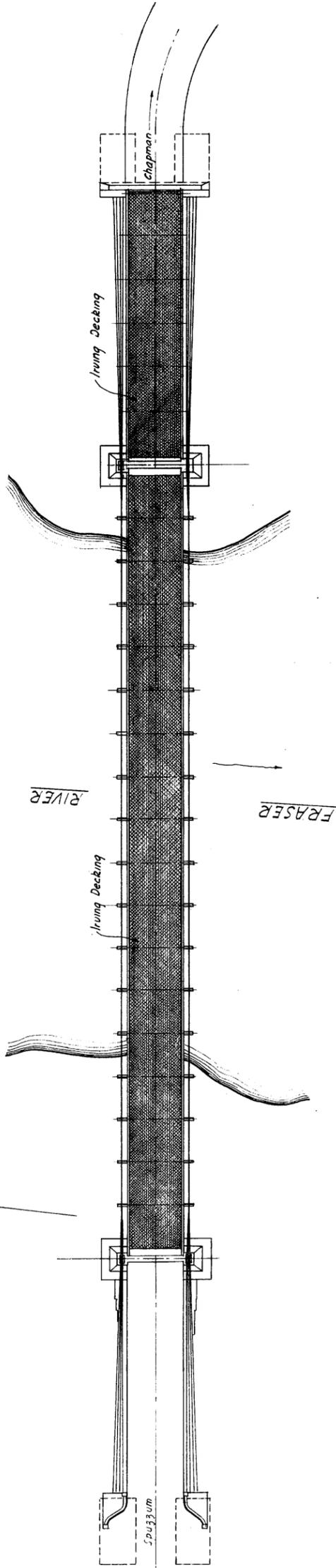
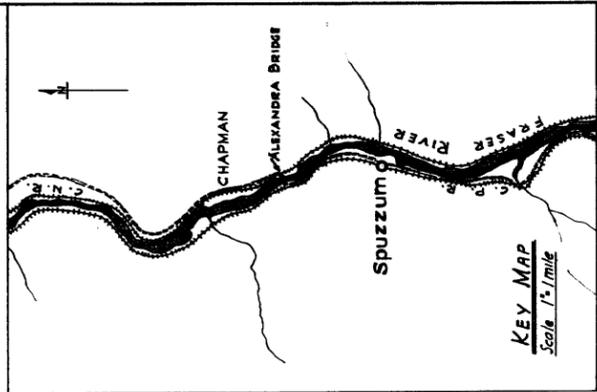
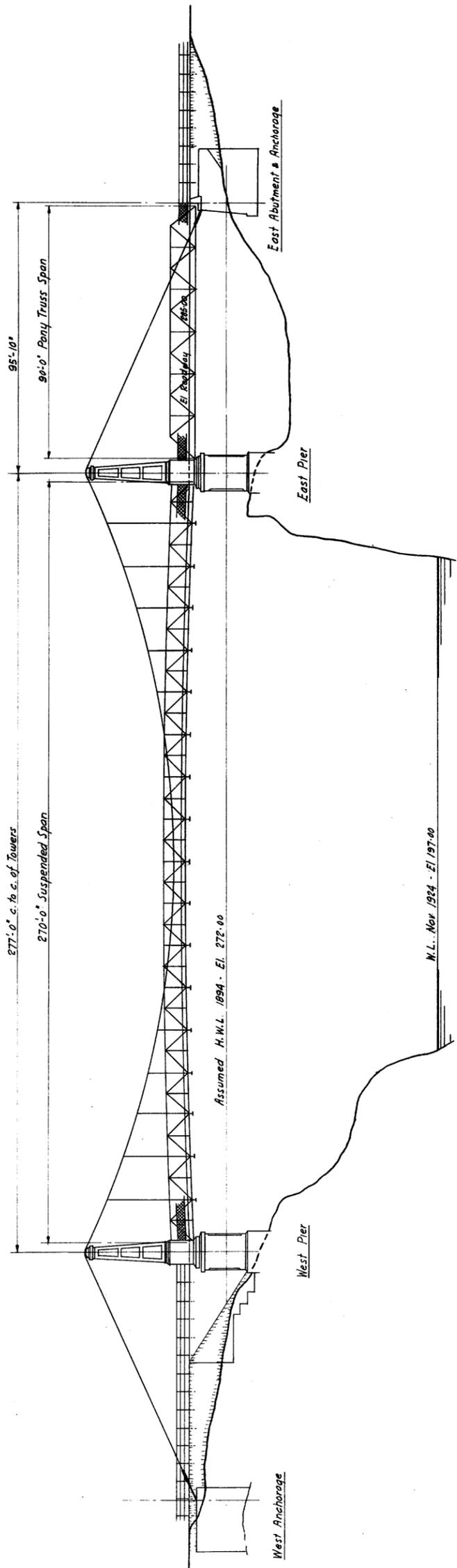
Note: Water surface profiles generated using Laidlaw 2007 rating curve (solid) and using Ruby Creek HWM (dashed)



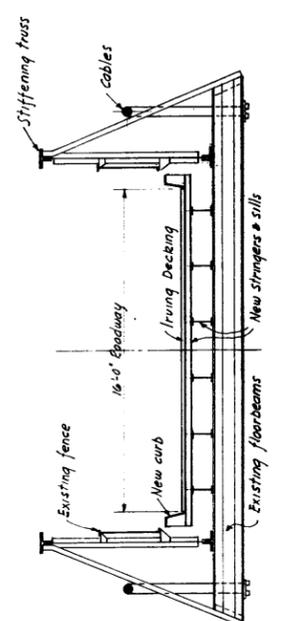
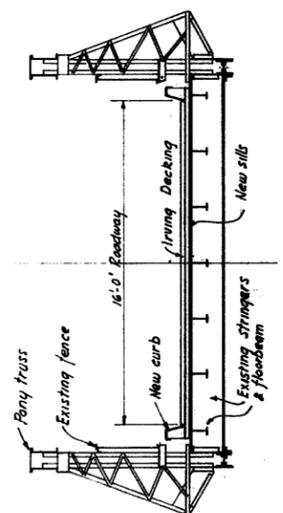
- 1894 Simulation (Q = 17,000 m<sup>3</sup>/s)
- - - 1894 Simulation (Q = 17,000 m<sup>3</sup>/s)
- ◆ 1894 High Water
- - - 1894 Simulation (Q = 17,700 m<sup>3</sup>/s)
- - - 1894 Simulation (Q = 16,800 m<sup>3</sup>/s)

Note: Water surface profiles generated using Laidlaw 2007 rating curve (solid) and using Ruby Creek HWM (dashed)

 	
Laidlaw to Hope MIKE11 Water Surface Profiles 1894 Simulations	
August 2008	Figure 3.5



- LIST OF DRAWINGS**
- 572-24 General Arrangement
  - " -25 Details for Suspended Span
  - " -26 Details for Pony Truss Span
- REFERENCE DRAWINGS (Existing Bridges)**
- 572-1 General Arrgt
  - 2 East Pier & Tower
  - 3 West Pier
  - 4 East Abutment
  - 5 Details
  - 6 Stiffening Truss
  - 7 Pony Truss



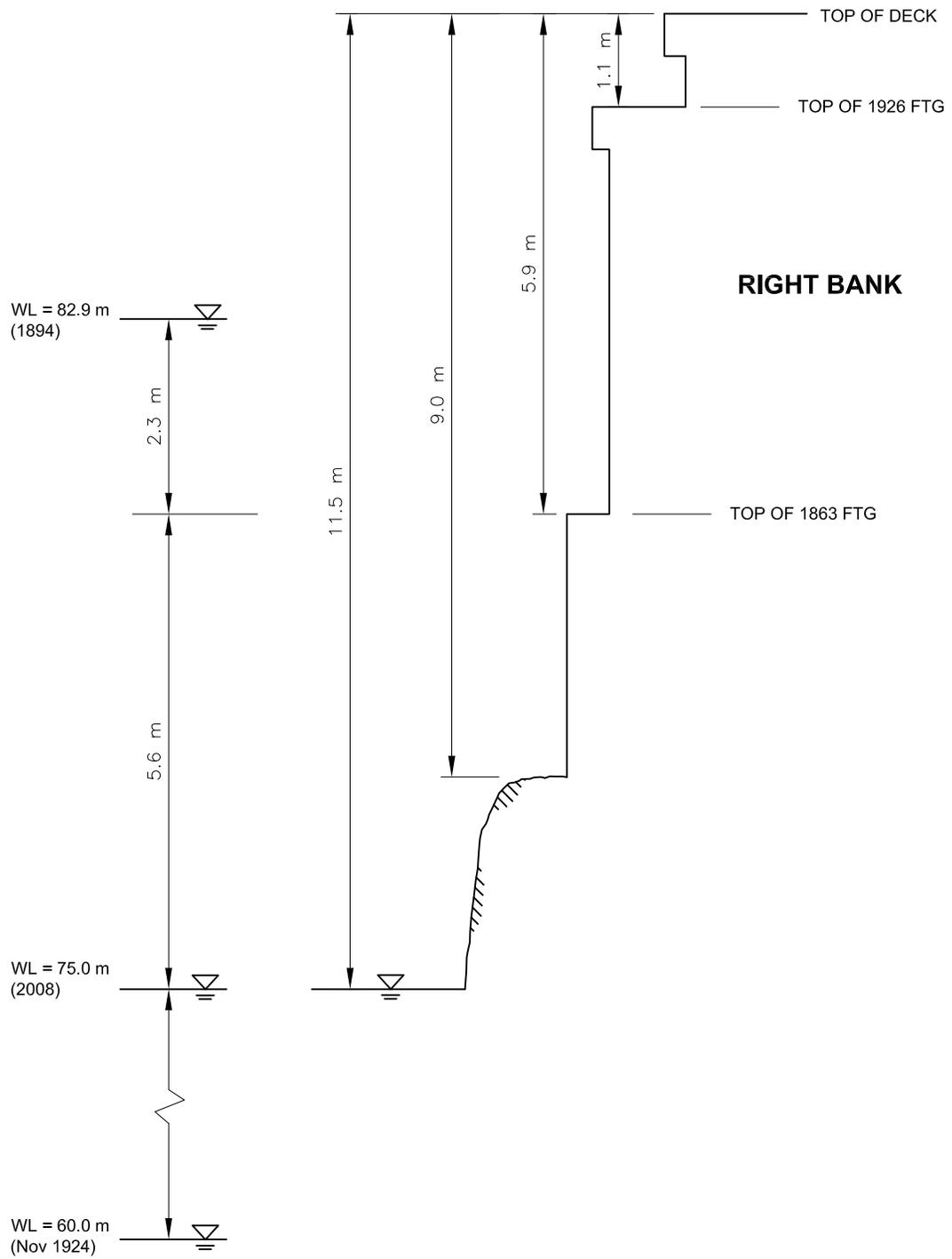
**ALEXANDRA BRIDGE**  
**OVER THE FRASER RIVER**  
**AT SPUZZUM**  
**PROPOSED PERMANENT DECK**  
**GENERAL ARRANGEMENT**  
 Scale: 1" = 20 ft & as shown.

1927

GOVT. OF BRITISH COLUMBIA  
 DEPT. OF PUBLIC WORKS  
 VICTORIA

Made by J.G.F. 16/10/27	DRAWING NO.
Checked by J.A. 17/10/27	572-24
Chief Engineer	

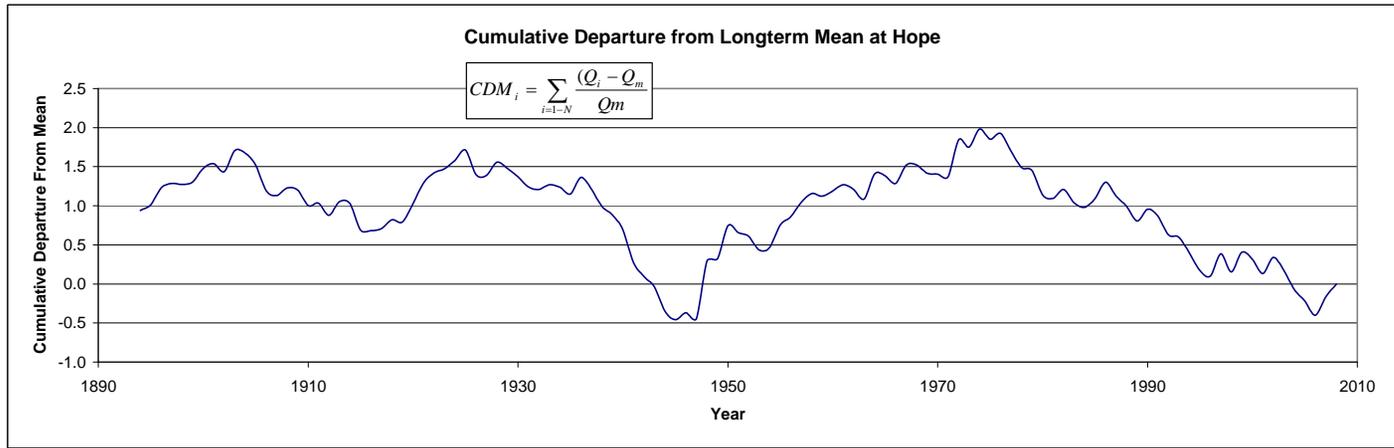
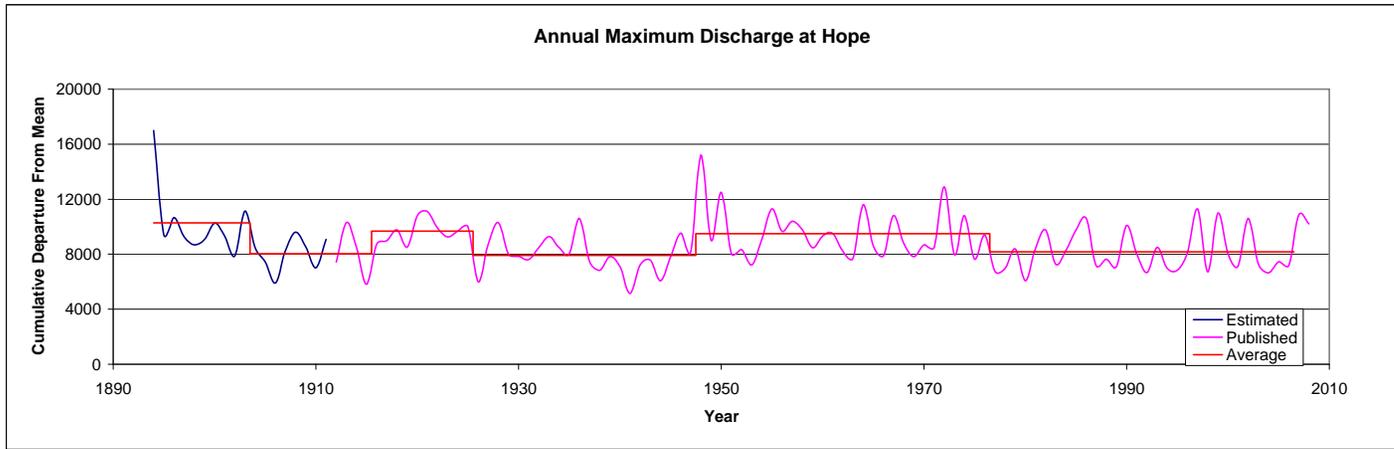
Figure 3.6



- NOTES:**
1. Measurements taken on 25 May, 2008.
  2. Same day flow measurement of 9,659 m<sup>3</sup>/s obtained by WSC at Hope.

<b>BC Ministry of Environment</b>			
COMPREHENSIVE REVIEW OF FRASER RIVER FLOOD HYDROLOGY AND FLOWS			
<b>Alexandra Bridge</b>			
<b>Right Bank Abutment</b>			
Figure 4.4	REV. NO.: 0	DRN. BY: PS	Jul-25-08
<b>northwest hydraulic consultants</b>			

**FIGURE 3.7**



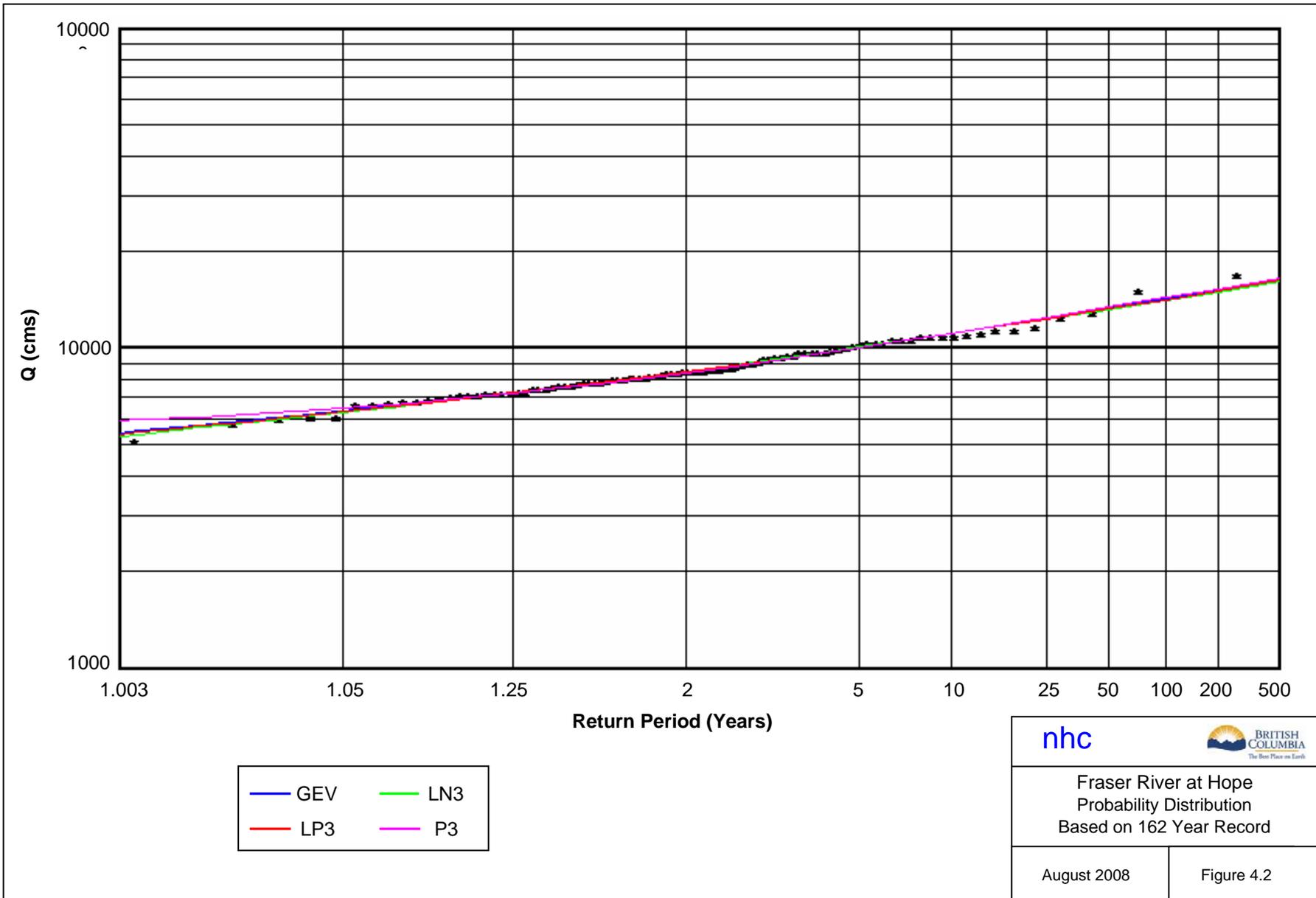
nhc

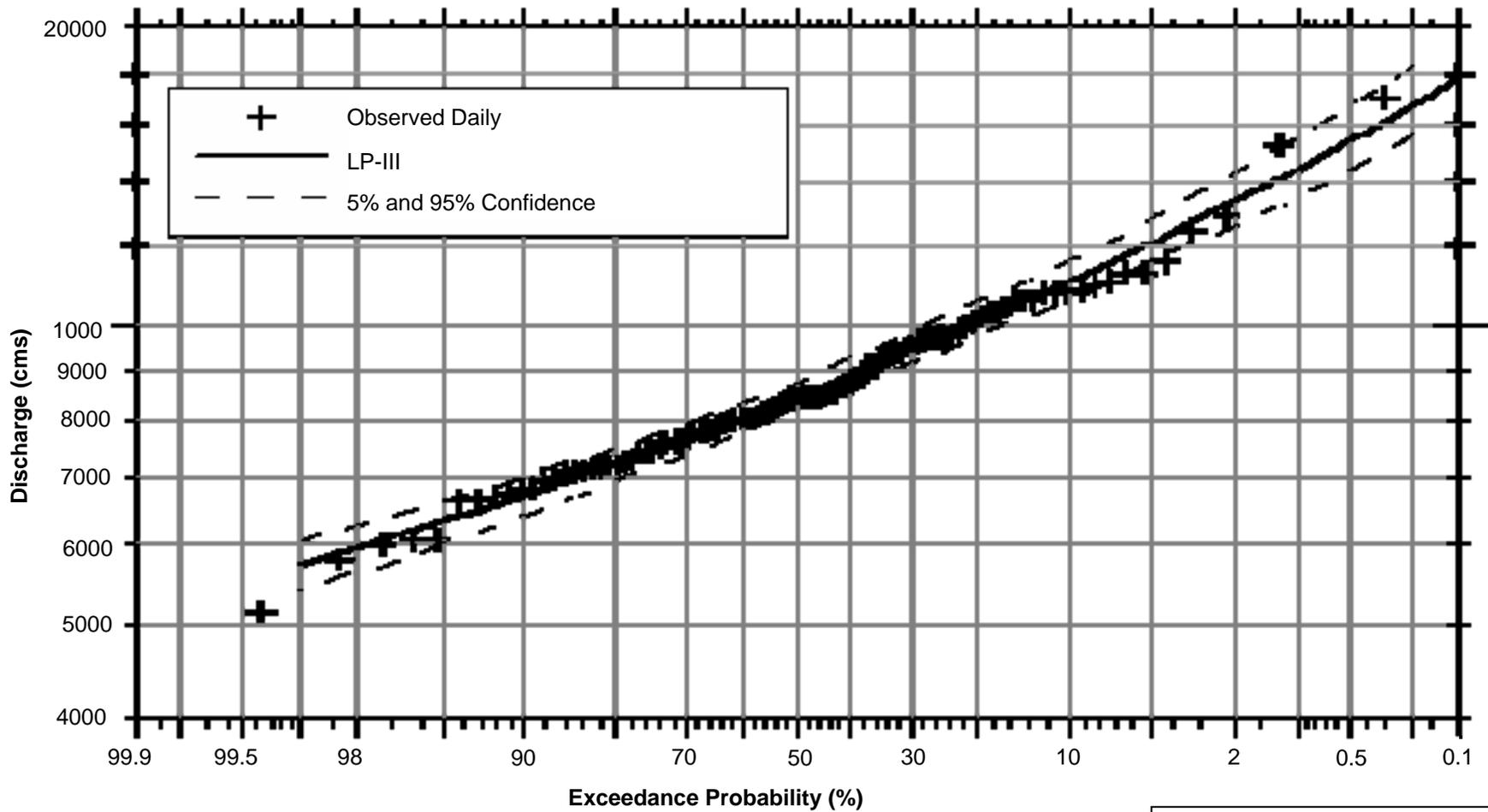


Trends in Annual Maximum Discharge  
at Hope 1894 to 2008

August 2008

Figure 4.1





nhc



Fraser River at Hope (1847-2008)  
 Frequency Analysis  
 Annual Maximum Daily Discharge

August 2008

Figure 4.3

**APPENDIX A**

**COLONEL WHYTE'S MEMEORANDUM DATED 1934**

## REPORT FORM

## WATER POWER BRANCH

OTTAWA

Report on Fraser river at Hope 1894 high water marksAt point  
1400 ft  
above  
bridge.

Mr. C. Landstrom CPR Sec Foreman Hope (our observer) was 14 years old at time and lived at Haig Station on CPR. He states canoe with mail had to go over flat at landing (yale road). He estimates flat was covered 2 feet deep.

The elev of flat is ~~36.77~~<sup>23.57</sup> or 1894 h.w. would be ~~30.77~~<sup>25.57</sup> ft above g.h. this date (13.2 ft) or g.h. 38.77 feet.

Flat is about 200 ft downstream from section bank house at Haig Station and 1400 ft more or less above bridge. Slope from bridge to this point is very small at stage 13.2 ft.

At point  
2600 ft  
about 1/2 mile  
below  
bridge.

Mr. Cottrell showed me where step of old store house was in front of Post office & his store. 1894 h.w. came to door knob of this warehouse according to several old timers. The estimated position of door knob was shown by Mr. Cottrell and found to be 24.94 ft above present w. l. of 13.2 ft. which would make g.h. 38.14 ft for 1894 flood. Slope from bridge to this point is more than from above bridge.

Data by Mr. Beard was not found to check and as he was only 7 at time and the roads have no doubt been filled in are not considered reliable.

Report on Fraser river at Hope

1894 high water marks

At point  
1400 ft.  
above  
bridge.

Mr. C. Landstrum, C.P.R. Sec. Foreman, Hope (our observer) was 14 years old at time and lived at Haig Station on C.P.R. He states canoes with mail had to go over flat at landing (Yale road). He estimates flat was covered 2 feet deep.

The elev. of flat is 23.57 or 1894 hw would be 25.57 ft. above gh this date (13.2 ft.) or gh 38.77 feet.

Flat is about 200 ft. downstream from section bunk house at Haig Station and 1400 ft. more or less above bridge. Slope from bridge to this point is very small at stage 13.2 ft.

At point  
2600 ft.  
about  
 $\frac{1}{2}$  mile  
below  
bridge.

Mr. Cottrell showed me where step of old store house was in front of Post Office and his store. 1894 hw came to door knob of this warehouse according to several old timers. The estimated position of door knob was shown by Mr. Cottrell and found to be 24.94 ft. above present W.L. of 13.2 ft. which would make gh 38.14 ft. for 1894 flood. Slope from bridge to this point is more than above bridge.

Data by Mr. Beard was not found to check and as he was only 7 at time and the roads have no doubt been filled in are not considered reliable.

"G.H. Whyte"

*Original filed with  
back station description  
in hydro office*

NOT FOR DISTRIBUTION

## **APPENDIX B**

### **ADDITIONAL HISTORIC DATA SOURCES BY J. WATT**



"KJ Watt" <kjwatt@telus.net>

05/05/2008 12:56 PM

To "Monica Mannerstrom" <MMannerstrom@nhc-van.com>

cc

bcc

Subject Flood of 1894 etc

History:

✉ This message has been replied to.

Hi Monica,

Thanks for the note. You ask some tough questions -- how much time do you have to spend answering them?

Here are a few comments and sources off the top of my head and handy from my desk.

A basic point of caution -- or encouragement -- is that the research we did for *High Water* really just skated over the kind of detail you'll be looking for, I think. Massive amounts of material exist that we merely peered at quickly and hoped to have time to return to look at in detail.

In terms of historic floods, it is hard to really assess them because the documentary record is so sketchy for the period: only twenty-five mixed-race HBC employees came here in 1827, and by 1858 before the beginning of the gold rush, there were less than 200 people of European ancestry in the Fraser Valley. They were just trying to live and weren't writing too much about what was around them. To complicate matters, the First Nations lineages of knowledge about this place were so disrupted after 1858 that a great deal of knowledge was lost -- memories of historic floods included. Having said that, it would be a good idea to follow up with First Nations historians on this point, and I have a couple of contacts if that would be useful.

I do know from my work with the HBC records that after the first cultivation of the floodplain around Fort Langley in 1833 or so, the area was flooded almost every year. I don't know what this means in terms of volume because, of course, there was no dyking at that time.

My sense is that the floods of 1876 and 1882 rivalled the flood of 1894 but the flood of 1894 was considered more significant because of the infrastructure that had been built -- the flood of 1882, for example, flooded Matsqui Prairie and considerably enlarged Sumas Lake. Certainly 1876 was significant enough to hire Edgar Dewdney as consultant to try to come up with a remedy for flooding in the Chilliwack area.

Probably the best source for info about 1876 are microfilm versions of the Daily British Colonist (published in New West) beginning around the end of May. I think the peak of water that year was mid-June. By 1882 (I think) the newspaper has changed its name to the Daily Colonist. Other info about 1876 could come from Edgar Dewdney's reports and meditations on high water in 1876 -- BCARS holds most of it: (maps CMB 1525/CMB 1526); Dewdney's letters GR 866 (we used box 2); and his complete report must exist as well although I have never read it in its entirety (likely in GR-1693 microfiche)

Other info is in:

- GR-1569 BC Inspector of Dykes (holds info about flood relief 1894)
- GR-1011 BC Inspector of Dykes (1895-1974)
- GR -1665 BC Provincial Secretary (1887-1953) -- holds info about flood control and FV relief work 1894
- GR-0972 BC Inspector of Dykes (1874-1981) -- transferred from the Inspector of Dykes in Surrey, 1981
- MS-1493 PHD thesis (1964) by WRD Sewell: "Economic and Institutional aspects of adjustment to Floods in the Lower Fraser Valley" -- haven't read it, but it might be useful because it is forty years closer to some of the older documents than we are.

- GR-0868 BC Department of Lands and Works 1881-1883)
- Special Collections at UBC holds the BC Electric Papers -- including a great deal of info about the development of the Sumas area -- and the BCE had a good handle on the fluctuations of water there.
- Closer to home, and available in many libraries is John Edgar Gibbard's 1937 typescript of his MA thesis entitled "Early History of the Fraser Valley: 1818-1885." I have not read in in many years, and I wasn't thinking about floods when I looked at it, so I can't be sure there is anything useful there, but it is quite a reliable document and might turn up something for you.
- Somewhere in Ottawa the records of the Dominion Power and Water Bureau must be housed -- they could be of inestimable value to your ongoing work.

It is likely that you could answer the question about the relative severity of the flood of 1894 fairly definitively (is that an oxymoron?) after two or three days with these documents in BCARS.

Hope that helps.

Let me know if I can be of any assistance in this work.

All the best,

Jane

---

K. Jane Watt, PhD  
Historian  
Box 1053  
Fort Langley BC  
V1M 2S4

604.882.2790