
Confluence of the Nechako and Nautley rivers. **Photo source:** Mike Miles and Associates, 2007

# Rio Tinto Water Engagement Initiative
# Nautley River Backwatering Investigation Results
# Draft Report, Rev. 1


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## DISCLAIMER

This report has been prepared by Northwest Hydraulic Consultants Ltd. for the benefit of Rio Tinto Alcan Inc. for specific application to the Rio Tinto WEI Engagement for the Nechako River. The information and data contained herein represent Northwest Hydraulic Consultants Ltd. best professional judgment in light of the knowledge and information available to Northwest Hydraulic Consultants Ltd. at the time of preparation and was prepared in accordance with generally accepted geoscience practices.

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- Kirsten Lyle — Senior Project Manager, Ecofish Research Ltd.

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The following NHC personnel participated in the study:

- Barry Chilibeck — Project Manager
- Andre Zimmermann — Senior Geomorphologist
- Rachel Hay — Hydrologist
- Hanna Hamid — Hydrotechnical Engineer
- Vanessa McMaster — Hydrotechnical Engineer
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## ABBREVIATIONS

| Acronym / Abbreviation | Definition |
|---|---|
| Alcan | Aluminium Co. of Canada Ltd. |
| BC | British Columbia |
| LiDAR | Light detection and ranging |
| NHC | Northwest Hydraulic Consultants Ltd. |
| Rio Tinto | Rio Tinto Alcan Inc. |
| STMP | Summer Temperature Management Program |
| UBC | University of British Columbia |
| WEI | Water Engagement Initiative |
| WSC | Water Survey of Canada |

## SYMBOLS AND UNITS OF MEASURE

| Symbol / Unit of Measure | Definition |
|---|---|
| % | percent |
| cm | centimetre |
| km | kilometre |
| $km^2$ | square kilometres |
| m | metre |
| $m^3$ | cubic metres |
| $m^3/s$ | cubic metres per second |

# 1 INTRODUCTION

This technical report conveys the results of an investigation conducted by Northwest Hydraulic Consultants Ltd. (NHC) for Rio Tinto Alcan Inc. (Rio Tinto) in response to public engagement queries about backwatering and flooding on the Nechako and Nautley river systems and on Fraser Lake in west-central British Columbia (BC). When questions were raised during the Nechako Water Engagement Initiative's (WEI's) broad-based engagement process, the WEI Technical Working Group was notified, and Rio Tinto subsequently engaged NHC to investigate backwatering occurrences in the Nautley and make recommendations for future management options.

The primary focuses of this investigation are on backwatering, headcutting, and flooding, which are defined as follows:

- **Backwatering**: A hydraulic condition created when a feature at least partially obstructs a river's flow, causing an increase in upstream depth. Backwatering can also occur if the local water level is influenced by a downstream water level; for example, high lake or river levels may cause backwatering (or flooding) of tributary streams. Features that commonly obstruct the flow and cause backwatering include bedrock constrictions, ice jams, bridge piers, and river confluences, where the total flow contributed by both rivers must be conveyed through a single downstream channel.
- **Headcutting**: An erosional process caused by local oversteepening of the streambed or hydraulic gradient. The increase in hydraulic gradient increases the erosive potential of the flow, which can lead to erosion of the streambed if the river sediments can be mobilized by the flow. Streambed erosion caused by headcutting typically progresses in the upstream direction, as sediment is eroded from the upstream portion of the headcut and deposited downstream.
- **Flooding**: A hydrologic event where the amount of flow in a channel, reservoir, or lake exceeds its hydraulic capacity, causing the water to overflow and inundate surrounding areas.

NHC understands that a rock weir was constructed on the Nautley River in 1953 to mitigate headcutting erosion that coincided with the onset of flow regulation on the Nechako River. Flow regulation has effectively lowered the water level of the Nechako River, which can coincide with times when the Nautley River is high, thereby increasing the hydraulic gradient and erosive potential of the Nautley River upstream of its confluence with the Nechako River. The rock weir has since been the subject of numerous investigations, which are summarized in Section 2.2.

NHC also understands that the Nautley River may become backwatered in response to high flows on either or both the Nechako and Nautley rivers; it is presumed that backwatering can occur when flows in both the Nautley and Nechako rivers are high, or when Nautley River flows are low and Nechako River flows are high. Backwatering of the Nautley River can also increase the water level of Fraser Lake, which is located approximately 1 km upstream of the confluence of the two river systems. The details and results of NHC's investigation on the specific flow conditions that lead to backwatering are presented throughout this report.

# 2 BACKGROUND

This section presents descriptions of the hydrology and history of flow regulation on the Nechako River as well as a summary of the history of the Nautley River weir.

## 2.1 Hydrology and Flow Regulation

The Nechako River watershed covers approximately 47,000 $km^2$ of the Interior Plateau in BC's Central Interior. The river drains the leeward side of the Coast Mountain Range through a series of large lakes, until the Nechako joins the Fraser River at Prince George (Figure 2.1). The Nautley River is only approximately 1 km in length and flows within a sub-basin of the Nechako River watershed, draining an area of approximately 6,550 $km^2$. The Nautley flows from the outlet of Fraser Lake to its confluence with the Nechako River (Figure 2.2).

Flow regulation on the Nechako River began in 1952 with the construction of the Kenney Dam and flow diversion tunnel to the Kemano Generating Station near Kitimat, BC. Historically, the natural hydrograph of the Nechako River was driven by spring snowmelt (NHC, 2003). Peak annual flow typically occurred in June, with the receding limb of the annual hydrograph periodically re-supplied by large frontal rainstorms during the latter portion of summer and into fall. Spring flows exceeding 1,000 $m^3/s$ at Vanderhoof were not uncommon, and the estimated mean annual peak daily discharge was 658 $m^3/s$ (NHC, 2003).

The Nechako Reservoir was filled from 1952 to 1956, reducing the mean annual peak daily discharge of the Nechako River to 233 $m^3/s$. Since then, two water management strategies have been implemented; the first from 1957 to 1979 and the second from 1980 to the present. The mean annual peak daily discharge of the Nechako River during these periods has been 426 $m^3/s$ and 360 $m^3/s$, respectively, which represents an approximate 45% reduction from historic flows. The timing of peak flow has also been changed from June to August, as the current management plan was developed to control the stream temperature of the lower river during the sockeye salmon migration, which is referred to as the Summer Temperature Management Program (STMP).

Prior to flow regulation, the annual hydrographs of the Nechako and Nautley rivers would have had a similar shape, with the peak annual flows on both systems occurring in response to snowmelt during the spring freshet. However, as described above, the shape of the Nechako River hydrograph has been considerably altered by reservoir operations and the out-of-basin diversion (e.g., increasing late-summer flows during the STMP period). Dissimilarities in the present-day hydrographs and contrasting flow conditions in each river could lead to erosion (e.g., headcutting), backwatering, and flooding under certain flow conditions.

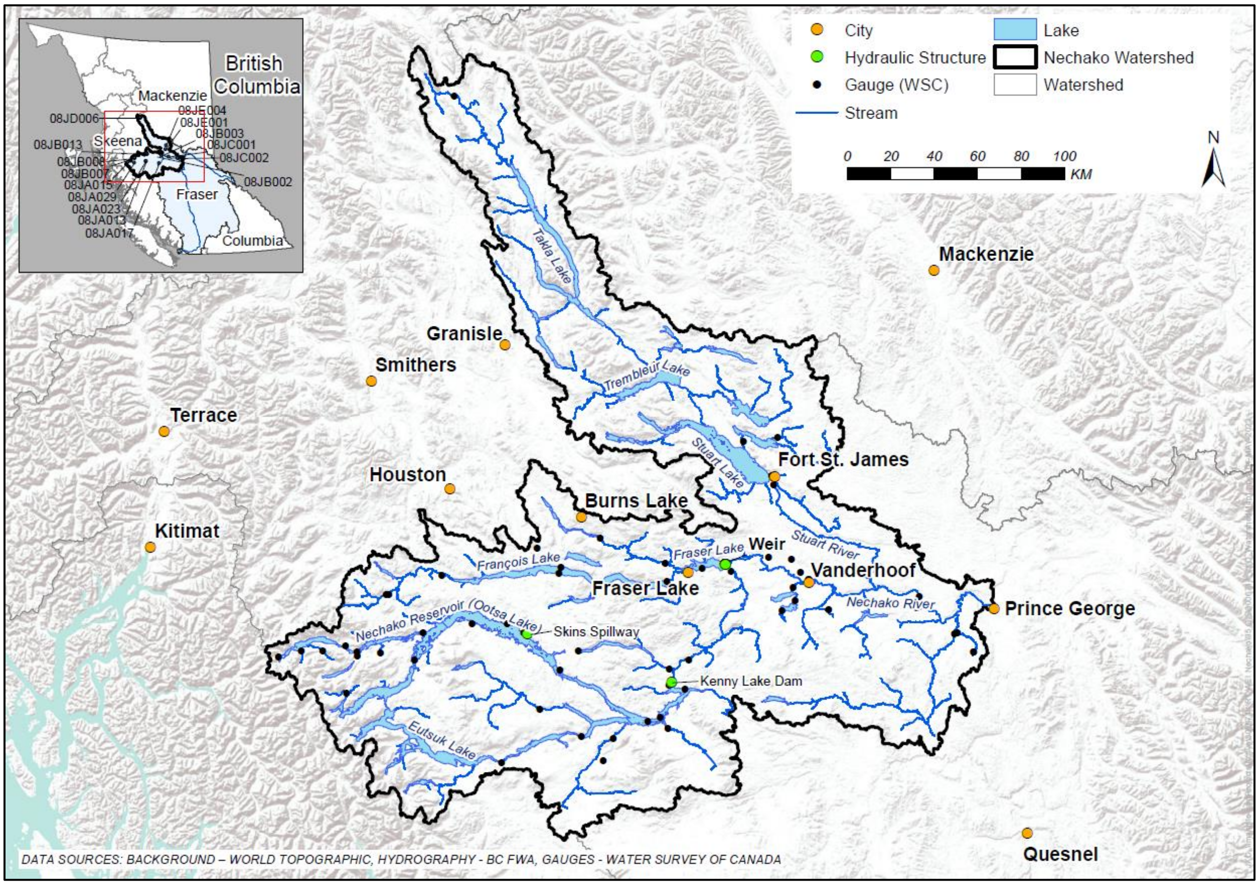



**Figure 2.1 Map of the study area. An outline of the Nechako watershed is shown on the main map, with relevant features identified. The inset map shows the location of the Nechako watershed within the entire Fraser River watershed.**

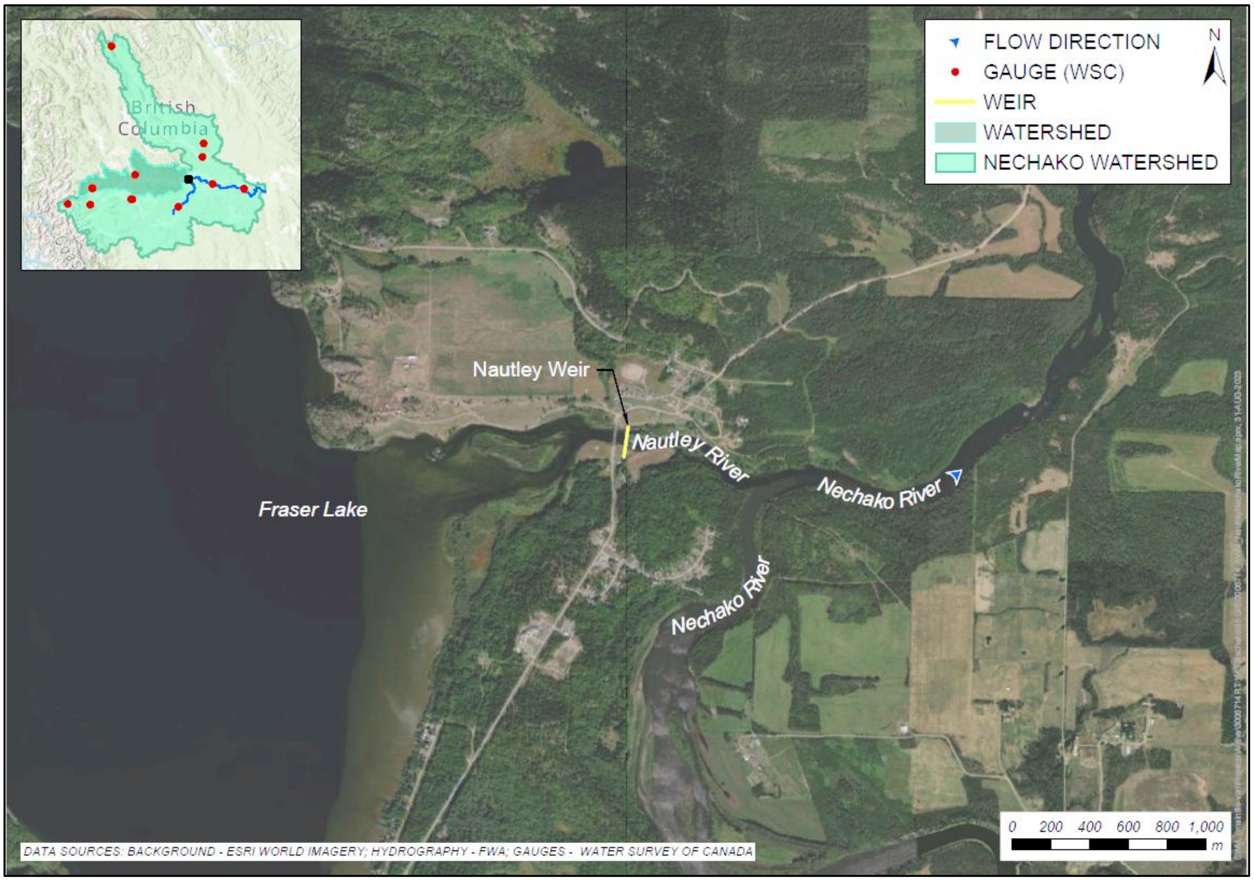



**Figure 2.2 Overview map of the Nautley River.**

## 2.2 Nautley Weir

A rock weir was constructed on the Nautley River in 1953 to mitigate headcutting erosion that began with the onset of flow regulation on the Nechako River (Photo 5.1). Flow regulation effectively lowered the water level of the Nechako River, thereby increasing the hydraulic gradient and erosive potential of the Nautley River upstream of the confluence. This erosional impact from lowered water levels in the Nechako River was most pronounced during the initial period of reservoir infilling (1952 to 1956), when Nechako River flows consisted only of tributary inflows downstream of Kenney Dam. During this period, rapids quickly formed on the Nautley River as headcutting erosion progressed upstream at a maximum rate of approximately 10 feet (3 m) per day (Wilson et al., 1972). In response, the owner operator of Kenney Dam, the Aluminium Co. of Canada Ltd. (Alcan), funded the construction of a rock weir as a control structure to prevent continued upstream headcutting on the Nautley River. The location of the weir is labelled on Figure 2.2 near the outlet of Fraser Lake.

A detailed review of the historical records related to the Nautley River weir is provided in Section 5, along with an overview of findings related to past and present erosion and weir stability.

# 3 STUDY OBJECTIVES

Based on the concerns raised during the broad-based engagement and Technical Working Group meetings of the Nechako WEI, a recognized need has emerged to better understand when and why backwatering occurs on the Nautley River. The objective of this study is to provide information regarding the hydraulic conditions driving backwatering propagation. This information may in turn be used to inform the development of operational strategies for the Nechako Reservoir to manage flooding along the Nautley River and Fraser Lake.

Specifically, this study sought to address the following questions:

1. When and why did the headcut occur on the Nautley River, and is the Nautley weir currently stable?
2. What flow conditions cause backwatering in the Nautley River, and has flow regulation on the Nechako River increased the frequency and magnitude of backwatering events?
3. Can backwatering of the Nautley River raise the water level and cause flooding on Fraser Lake?

# 4 DATA AND METHODS

This section describes the primary data sources and methods used in this study.

## 4.1 Data Sources

Various historical data were available for this study due to the cultural, environmental, and economic importance of the Nechako-Nautley River systems. Data utilized in this study derive from the following sources:

- Hydrometric data from available Water Survey of Canada (WSC) gauges, in particular:
    - Nechako River below Cheslatta Falls (08JA017; 1980 to present)
    - Nechako River at Vanderhoof (08JC001; 1915 to present)
    - Nautley River near Fort Fraser (08JB003; 1950 to present)
    - Fraser Lake at Lejac (08JB005; 1950 to 1978)[1].
- WSC rating curves for the hydrometric stations accessed through their online database (Government of Canada, 2023) and provided by the WSC
- Stage and discharge measurements at the hydrometric stations provided by the WSC
- Benchmark history reports for the hydrometric stations provided by the WSC

[1] The WSC Fraser Lake at Lejac (08JB005) gauging station was only active from 1950 to 1978; therefore, data from this station could not be used to investigate recent channel changes and backwatering events.

- Historical documents and engineering reports
- Historical air photos[2] provided by the University of British Columbia (UBC) Geographic Information Centre
- Aerial imagery collected by M. Miles and Associates Ltd. (2007a, 2007b) and NHC (Oct. 2018)
- Local observations and accounts from community members and residents.

## 4.2 Methods

NHC's methods and tasks for the study include the following:

- Review of historical air photos to identify geomorphic changes and flooding extents on the Nechako and Nautley rivers, including the downstream portion of Fraser Lake
- Analysis of available hydrometric data to identify the occurrence of flooding (i.e., backwatering) events in the Nautley River and Fraser Lake
- Review of historical engineering reports and recent surveys to establish a long-term account of the stability of the Nautley rock weir
- Review of WSC benchmark history to identify changes in channel geometry and water levels, including changes to the Nautley weir
- Review of local observations and accounts to relate these observations to specific hydraulic conditions (i.e., flows in the Nechako and Nautley rivers).

In addition, NHC developed a 1-D HEC-RAS hydraulic model of the Nechako River as part of concurrent work for Rio Tinto (River Analysis System; U.S. Army Corps of Engineers Hydrologic Engineering Center, version 6.2; NHC, In Review). The purpose of the model is to provide Rio Tinto with a tool to simulate river hydraulics, flow routing, and ice formation and to model the suitability of stream temperature and fish habitat. Details of the model are provided in NHC (In Review); a brief overview is provided in this report.

The entire model domain extends from just upstream of the Nautley River bridge to the confluence of the Nechako River (Figure 2.2), and along the Nechako from near Cheslatta Falls to 12 km downstream of Vanderhoof. River cross-sections are based on a digital elevation model developed using a combination of bathymetric survey and LiDAR data collected in 2021 (NHC, In Review). The model was calibrated and validated with WSC data, surveyed high-water marks, and aerial imagery collected during flood events (M. Miles and Associates Ltd., 2007a, 2007b). For this study, the model was used to investigate which hydraulic conditions contribute to the observed backwatering of the Nautley River.

[2] Selected historical air photos are provided in Appendix A.

# 5 HEADCUTTING AND THE NAUTLEY WEIR

This section provides a detailed review of the historical records related to the Nautley River weir, as well as an overview of findings related to past and present erosion and weir stability.

## 5.1 Historical Accounts of the Nautley Weir

There is a relatively long history of public concern related to erosion of the Nautley River, which could lower the outlet elevation (and hence the water level) of Fraser Lake. Numerous investigations have been conducted in response to these concerns, which have primarily been focused on evaluating the stability and effectiveness of the weir. This section summarizes the available documentation related to weir stability, erosion, and lake levels. For reference, Figure 5.1 shows the chronology of documented concerns regarding lowered lake levels and associated site inspections against the Fraser Lake at Lejac (08JB005) stage and Nautley River near Fort Fraser (08JB003) discharge time series.

In response to public concerns about erosion following the onset of flow regulation on the Nechako River, the Prince George District Engineer at the time, C. E. Wilson, and Assistant District Engineer, J. M. Anderson, prepared a report investigating the changes occurring at Fraser Lake, the Nautley River, and the Nautley River weir from its construction in 1953 to 1972 (Wilson et al., 1972). According to the report, the owners of Fraser Lake Sawmill initially reported to the Ministry of Lands, Forests and Water Resources in 1965 that Fraser Lake water levels were low and requested that the weir elevation be raised. On October 7, 1965, a subsequent inspection by the Prince George District Engineer, sawmill personnel, and the regional official of the Department of Fisheries confirmed that a segment of the weir had eroded by approximately 2 feet (60 cm)[3]. Fraser Lake Sawmill personnel repaired the weir soon thereafter, in October 1965, under the supervision of Alcan, with additional support from local equipment operators.

[3] Stage data from WSC gauge Fraser Lake at Lejac (08JB005) show no evidence of reduced lake levels during this period.

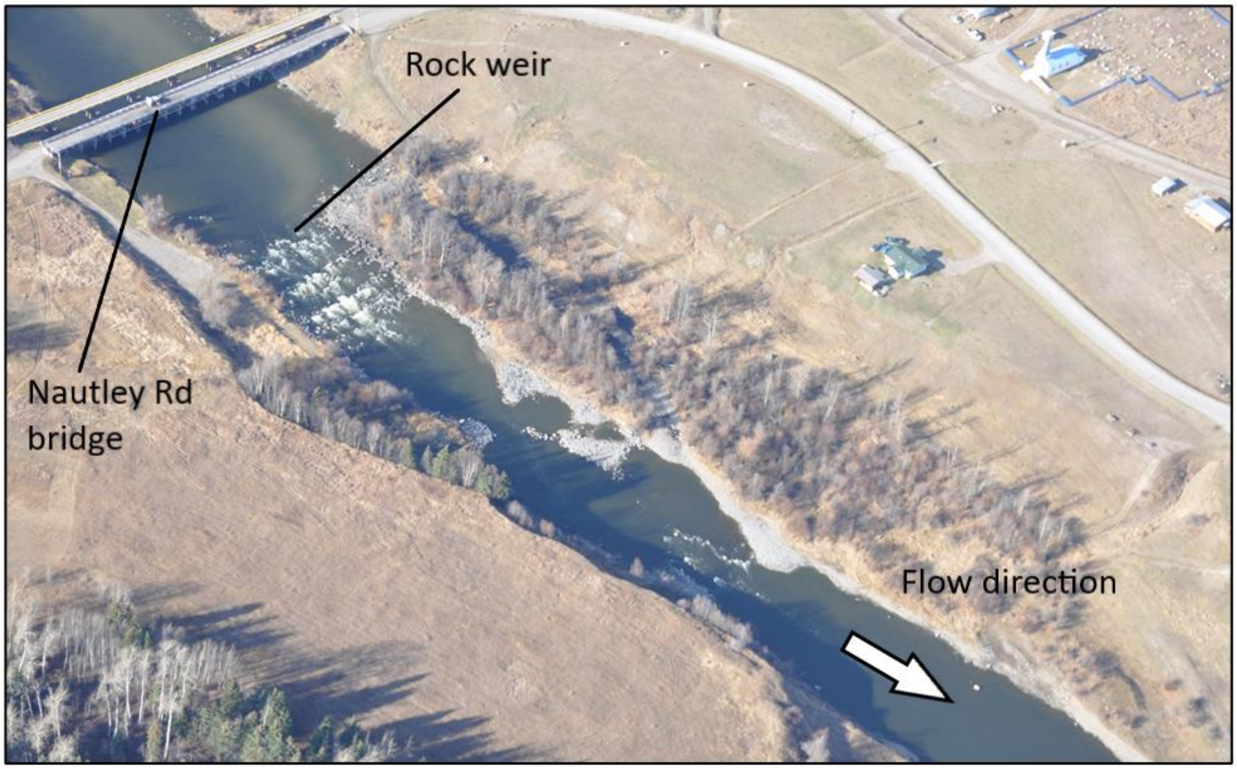



**Photo 5.1 The Nautley River and rock weir during low-flow conditions on October 21, 2018.**

On December 8, 1969, J. N. Leslie, Chairman of the Fort Fraser Improvement District, reported to the Comptroller of Water Rights that the weir was eroding and lake levels were abnormally low. The request was forwarded to the District Engineer's office to investigate. The District Engineer and a Prince George Water Rights Branch Engineer, V. J. Roth, visited the weir on December 14, 1969 and observed no evidence of "unusual level condition or obvious erosion of the rock baffles" (Wilson et al., 1972, p. 4). However, it was not possible to survey the weir due to snow cover. When asked for his input on the same day, the local Conservation Officer, D. V. Turner, had not observed unusual water levels either.

The District Engineer met complainant J. N. Leslie later on August 10, 1970, to inspect the weir. Mr. Leslie could not identify specific areas of concern on the weir structure. On October 22, 1970, the Lejac Indian School Administrator reported to the District Engineer's office that lake levels were concerning. The Regional Official of the Canada Department of Fisheries, J. Tuyttens, reported that he was not aware of any recurring weir erosion. Fraser Lake water level and Nautley River discharge data were also provided to the District Engineer by the Prince George WSC, Department of Energy, Mines and Resources office. These data showed "no significant drop in lake level noted for any particular flow, as might be expected if there had been erosion or settlement of the weir" (Wilson et al., 1972, p. 5). Despite there being no obvious signs of damage or erosion, Mr. Roth and the District Engineer completed a survey of the weir and adjacent river channel on March 2, 1971. Due to snow cover, the survey was completed using temporary benchmarks and was thus referenced to a local datum; surveyed elevations were subsequently transformed into geodetic elevations on May 10, 1971. The survey did not detect any notable erosion of the weir.

On December 6 and 8, 1971, the Fort Fraser Chamber of Commerce and the Fort Fraser Recreation Commission reported to the Minister of Recreation and Conservation that lake levels were "at least four feet below normal" (Wilson et al., 1972, p. 3). A final water level inspection at Beaumont Park was completed on February 16, 1972, confirming normal levels for the time of year measured in a hole through the ice (Wilson et al., 1972, p. 6). WSC gauge data of the Fraser Lake water level and Nautley River discharge data from the WSC gauges were subsequently analyzed, showing that there had been a gradual decrease in Fraser Lake water levels over a 3 year period and a concurrent drop in Nautley River flows. Further analysis of the data suggests that the weir eroded, albeit by a relatively limited amount. The WSC subsequently confirmed that the hydraulic control at the weir eroded by up to 0.4 feet (12 cm) between 1967 and 1972. This gradual decrease in the Fraser Lake water levels during the 5-year period aligns with the data presented in Figure 5.1, as the lowest winter lake levels declined from 0.59 m in 1967 to 0.48 m in 1971.

WSC stage data for Fraser Lake plotted in Figure 5.1 also show rapid fluctuations and lowered lake levels between December 1967 and January 1968. While a rapid decline in stage could indicate potential erosion or lowering of the weir, it is considered unlikely that the lake would re-fill as rapidly as seen in the data. Thus, the rapid fluctuations in stage data seen during the winter of 1967 to 1968 are considered sensor artifacts and are not likely representative of true fluctuations in lake levels.

More recently, in response to a public inquiry, Swiftwater Consulting (2017) investigated the stability of the Nautley River weir in 2017 and engaged T & T Surveys Ltd. to re-survey the weir. The results were compared to a 1993 survey completed by W. D. McIntosh Surveys Ltd. (described in Swiftwater Consulting, 2017). The study concluded that the weir had remained stable prior to 1993, and between 1993 and 2017, no notable erosion was identified.

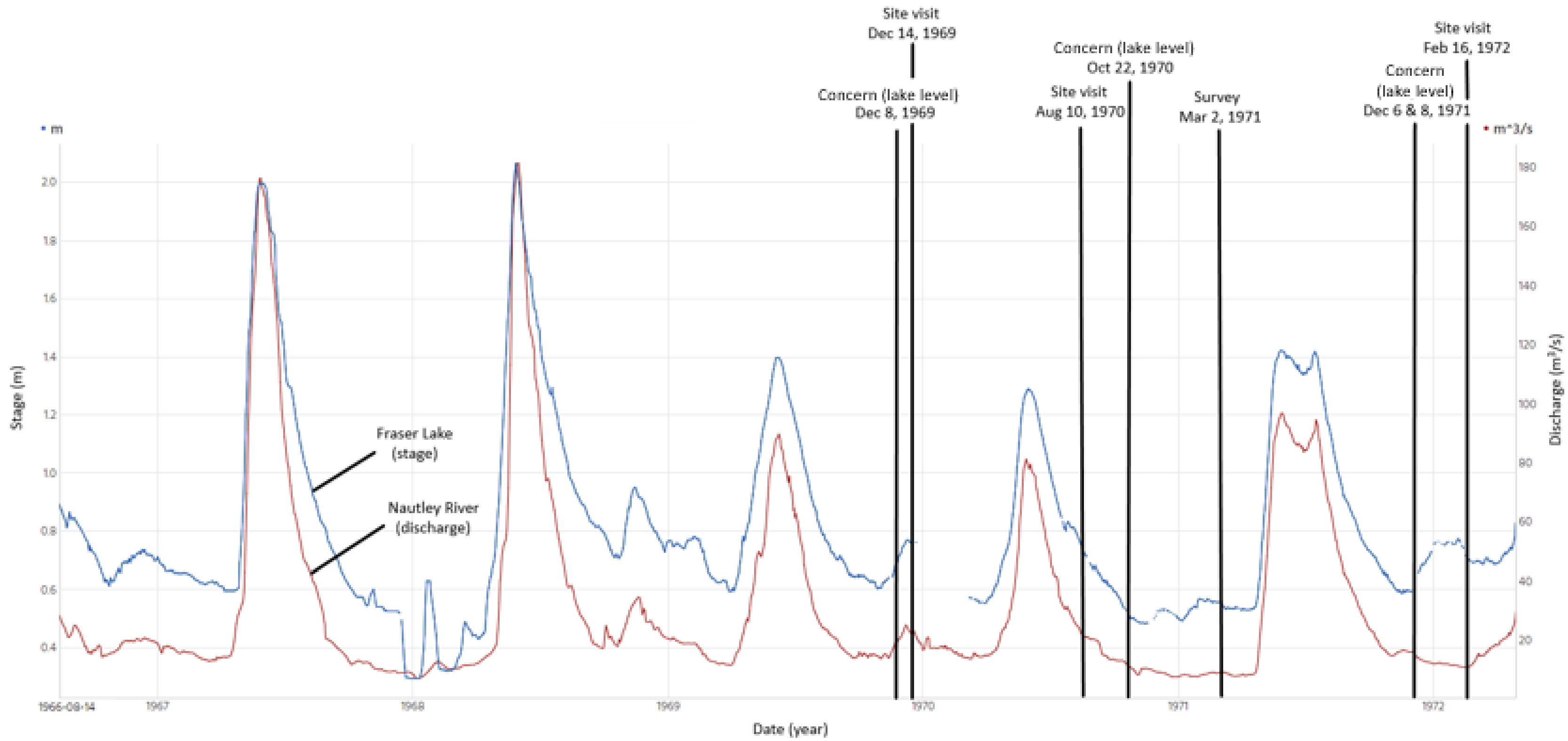



**Figure 5.1 Fraser Lake at Lejac (08JB005) stage (blue) and Nautley River near Fort Fraser (08JB003) discharge (red) time series plotted in relation to documented concerns about lowered lake levels and associated site inspections.**

## 5.2 Headcutting on the Nautley River

As flow regulation began effectively lowering water levels in the Nechako River, the Nautley River experienced a period of rapid headcutting erosion. This erosion was most pronounced during the initial period of reservoir infilling, from 1952 to 1956, when Nechako River flows comprised only tributary inflows downstream of Kenney Dam. During this time, rapids quickly formed on the Nautley River as headcutting erosion progressed upstream at a maximum rate of approximately 10 feet (3 m) per day (Wilson et al., 1972). Figure 5.2 provides a photo comparison of the Nechako and Nautley river confluence before and after the period of reservoir filling and the onset of headcutting erosion on the Nautley River. Additional historical photos are provided in Appendix A.

The bed of the Nautley River was relatively coarse prior to the headcutting, composed primarily of gravels and cobbles, based upon the assumption that the existing substrate upstream of the weir is similar to pre-existing conditions downstream. Mobilization and erosion of the streambed would have required relatively high flows on the Nautley River, combined with low flows on the Nechako River. It is therefore likely that headcutting erosion on the Nautley was initiated once flows increased on the Nautley River in the spring of 1953. This timing coincides with the first freshet during the period when the reservoir was being filled (1952-1956), when the amount of flow conveyed by the Nechako River at the confluence would have been exceptionally low (Figure 5.3). In fact, comparison of the discharge records at the WSC Nechako River at Vanderhoof (08JC001) and Nautley River near Fort Fraser (08JB003) gauges shows that Nechako River discharge essentially comprised only Nautley River inflows during the spring of 1953, meaning that only a negligeable amount of flow was being conveyed within the Nechako River upstream of the confluence[4] (Figure 5.3).

Surveys of the Nautley weir conducted by Wilson et al. (1972), W. D. McIntosh Surveys Ltd. (1993) and Swiftwater Consulting (2017) have determined that minimal changes have occurred to the elevation of the weir over the last few decades. However, Wilson et al. (1972) ultimately concluded that there had previously been a gradual decline in Fraser Lake water levels based on hydrometric data collected at the WSC Nautley River near Fort Fraser (08JB003) and Fraser Lake at Lejac (08JB005) stations, corresponding to up to 0.4 ft (12 cm) of erosion between 1967 and 1972 (see discussion in Section 5.1).

To update the analysis, NHC plotted discharge measurements from Nautley River near Fort Fraser (08JB003; 1988 to present) relative to a single stage-discharge rating curve to investigate whether the weir or channel geometry have changed in recent years and whether there has been a change in water level for a given flow. Figure 5.4 plots all data points (i.e., discharge measurements) relative to a single rating curve, while Figure 5.5 plots the same data binned by discharge intervals. These plots indicate that the weir has remained relatively stable since 1988, although minor erosion and lowering of the water levels, on the order of -0.03 to -0.05 m, may have occurred over the last 35 years (Figure 5.5). Despite this apparent, minor lowering, the data suggest that the headcut has not continued to advance upstream in any appreciable way, and the overall geometry of the channel and weir appears to have

[4] Note that the WSC Nechako River below Cheslatta Falls (08JA017) station was not yet established.

remained relatively stable in recent years. It does not appear that headcutting erosion is currently impacting the function of the weir or upstream water levels.

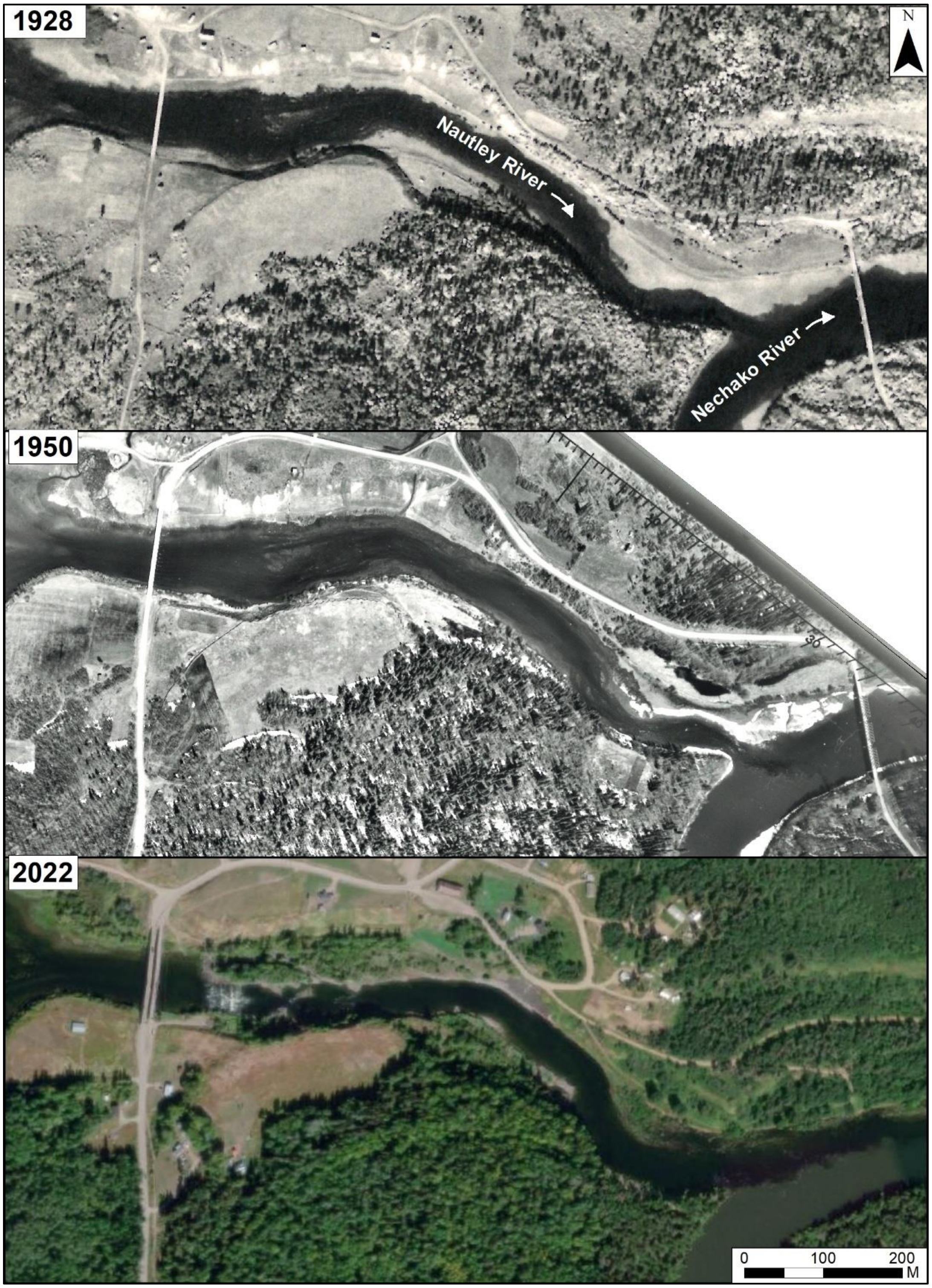



**Figure 5.2 Photo comparison of the Nechako and Nautley river confluence before and after the period of reservoir filling (1952-1956) and the onset of headcutting erosion on the Nautley River. Photos: 1928 (A732-24), 1950 (BC1046:35), and ESRI Basemap imagery (2022-08-12).**

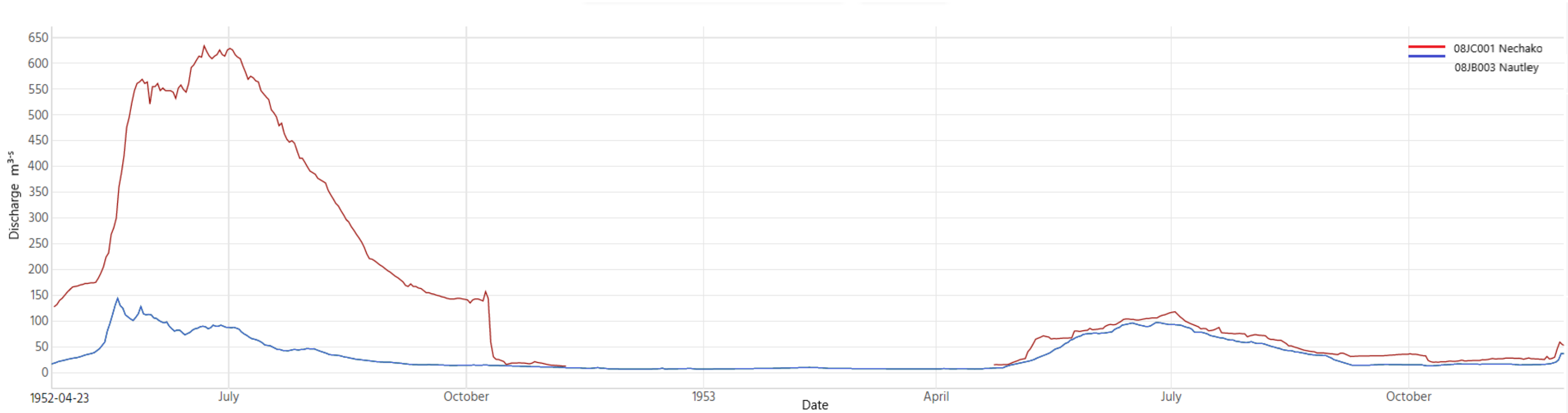



**Figure 5.3 Nautley River near Fort Fraser (08JB003) and Nechako River at Vanderhoof (08JC001) discharge record ($m^3/s$) before, during, and after Kenney Dam construction in 1952 and 1953.**

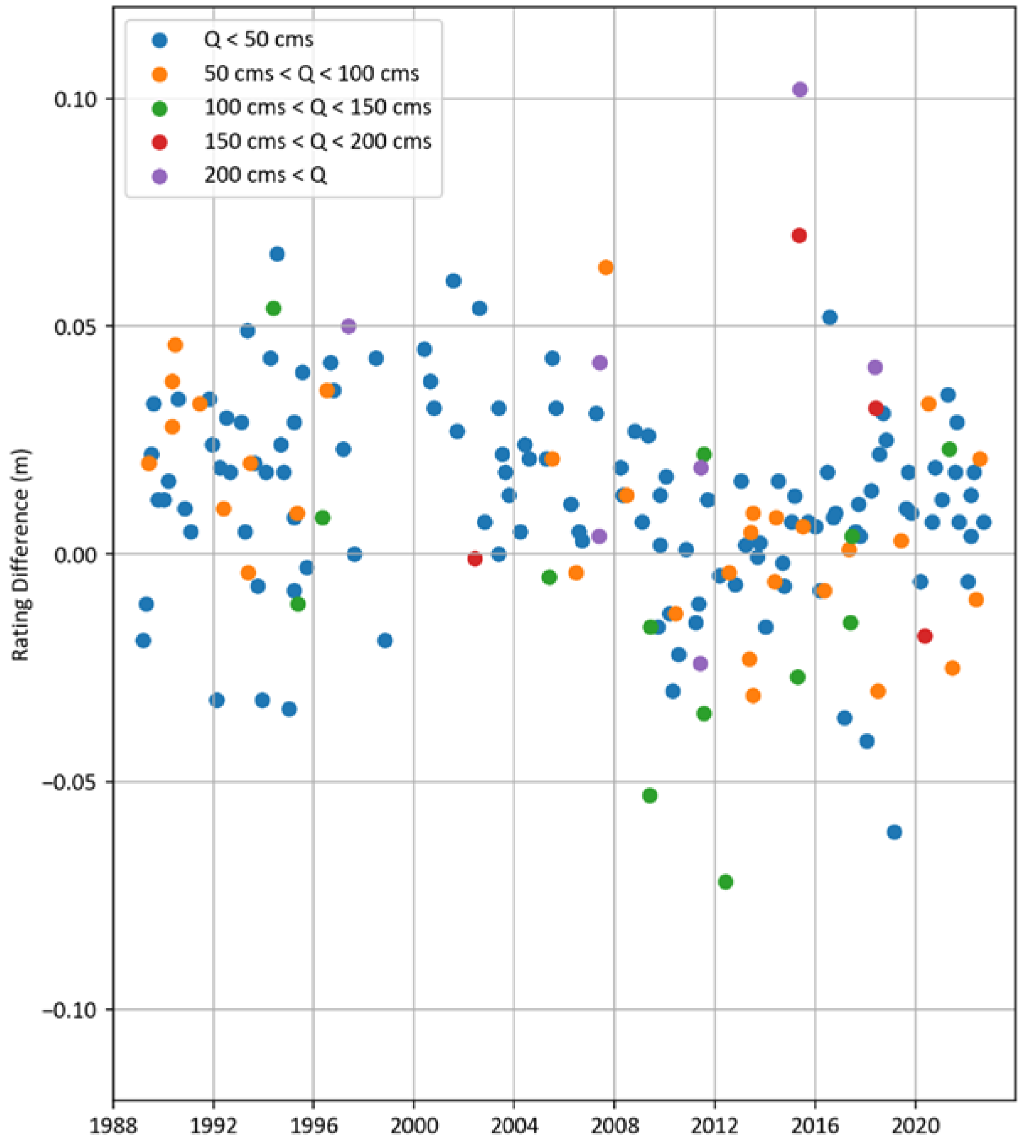



**Figure 5.4 Specific gauge analysis for WSC station Nautley River near Fort Fraser (08JB003). Plotted points represent WSC discharge measurements by year and the deviation from the stage-discharge rating curve (m). Ranges in flow are colour-coded. Note that the data have been truncated to exclude points prior to 1988 and above a threshold value of +0.15 m to highlight subtle changes in recent years; for the full dataset, see Figure 6.1.**

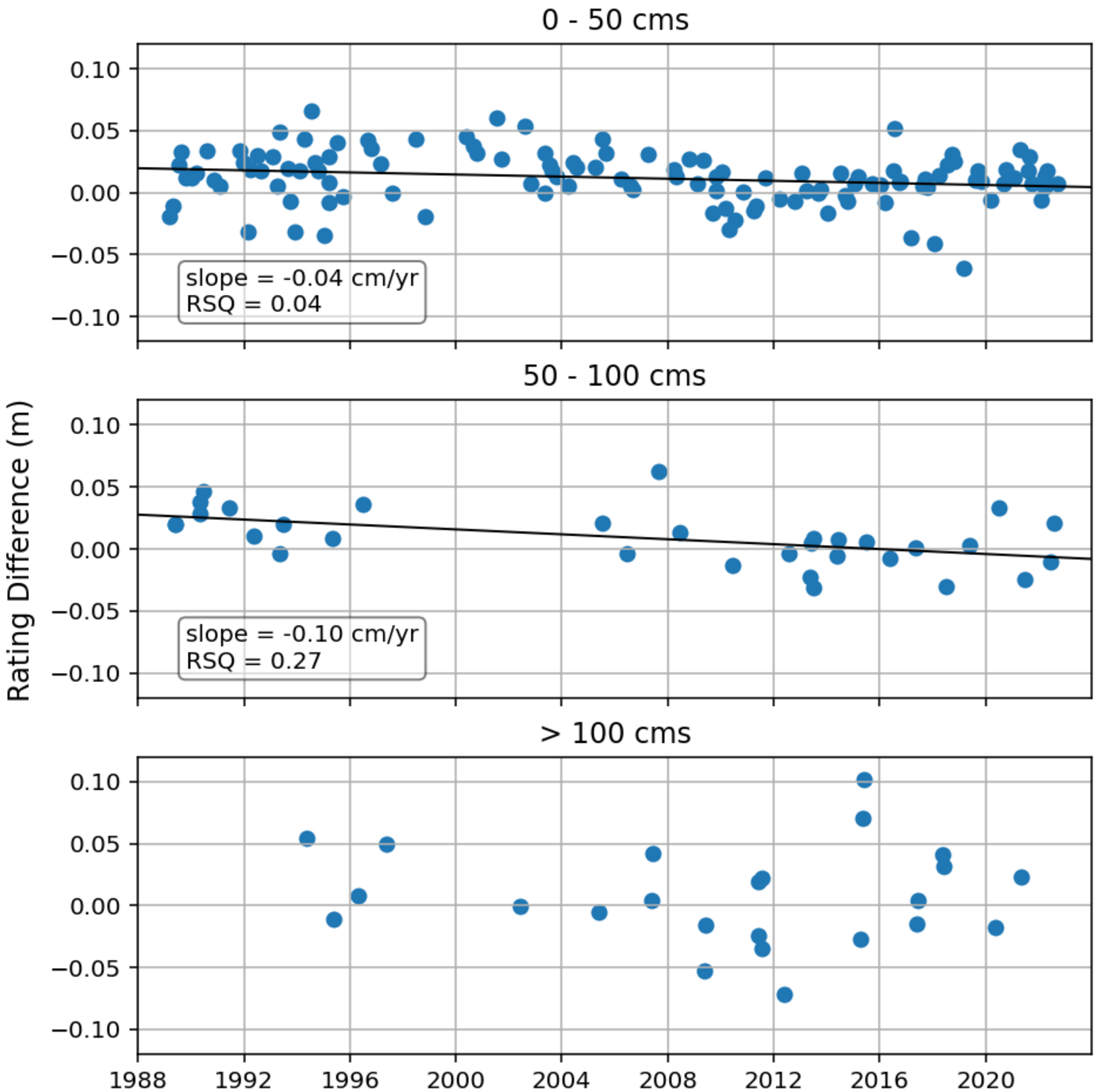



**Figure 5.5 Specific gauge analysis for WSC station Nautley River near Fort Fraser (08JB003) binned by discharge intervals. Plotted points represent WSC discharge measurements by year and the deviation from the stage-discharge rating curve (m). Trendlines are shown where the trends are statistically significant [$p < 0.05$]. Note that the data have been truncated to exclude points prior to 1988 and above a threshold value of +0.15 m to highlight subtle changes in recent years; for the full dataset, see Figure 6.1.**

# 6 BACKWATERING OF THE NAUTLEY RIVER

This section presents evidence of backwatering on the Nautley River, descriptions of key mechanisms that may cause backwater propagation, a discussion of the flow conditions during the observed backwater events, and the results of the hydraulic modelling conducted to investigate which flow conditions contribute to backwatering in the Nautley River.

## 6.1 Evidence of Backwatering

The Nautley River is known to be impacted by backwatering during certain flow conditions, which can cause flooding around Fraser Lake (e.g., Fleming, 2023; Wilson and Anderson, 1972). While occurrences of backwatering on the Nautley River are not well documented, station notes as well as water level and discharge records from the WSC Nautley River near Fort Fraser (08JB003) gauge indicate that there have been at least three backwatering events over the period of record (1972 to 2022)[5]. These events can be seen on Figure 6.1, which plots discharge measurements at the WSC Nautley River near Fort Fraser (08JB003) relative to a single stage-discharge rating curve; thus, data points that plot as positive values had a higher water level (or stage) than would be expected for a given discharge, indicating backwatered conditions. These data show that the Nautley River near Fort Fraser (08JB003) gauge was backwatered on June 27, 2007, October 14, 2011, and June 12, 2015, which coincides with local accounts of flooding around Fraser Lake in 2007 and 2015. The flow conditions on the Nechako and Nautley rivers during these events are further described in Section 6.2.

During subsequent email correspondences between NHC and the WSC data custodian, the Prince George supervisor confirmed that the Nautley River gauge was backwatered during these periods (Fleming and Water Survey Canada, 2023). The WSC has corrected the Nautley River discharge record to remove the effect of backwatering; however, the three discharge measurements collected in June 2007, October 2011, and June 2015 provide evidence that backwatered conditions were present, as these discharge measurements are readily identifiable as high outliers on Figure 6.1. Local residents also reported observations of flooding in May or June of some years (unspecified) when "several homes/farms adjacent to the Nautley River have their access road/driveway submerged" and standing water was impacting properties throughout area (Kurtz, 2020).

Aerial imagery collected by M. Miles and Associates Ltd. on June 26, 2007, a timing which roughly corresponds to the 2007 data point on Figure 6.1, also shows backwatered conditions on the Nautley River (Photo 6.1). The backwatered conditions can be inferred from the photo due to the relatively flat-water surface that is seen to extend from the confluence of the two rivers at the bottom left side of the image upstream into Fraser Lake at the top right side of the image. Under typical, non-backwatered conditions, a marked drop in the water surface elevation occurs as the water flows out of Fraser Lake and down over the Nautley River rock weir (Photo 5.1).

[5] Note that only one measurement was taken in 1972; the more complete data record begins in 1986.

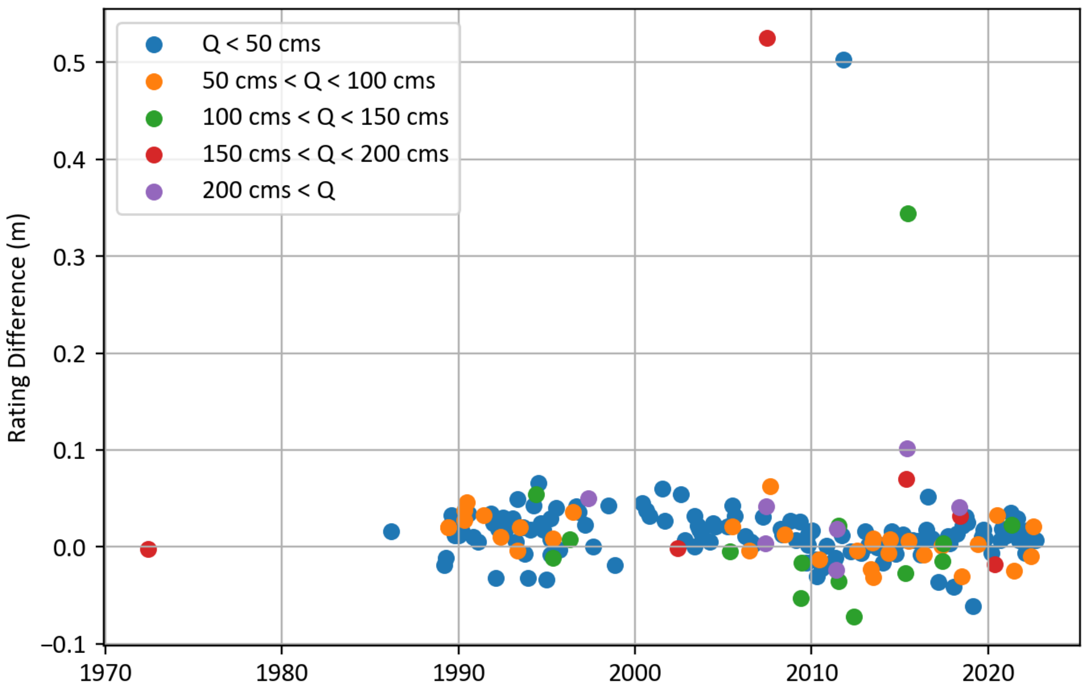



**Figure 6.1 Specific gauge analysis for the WSC station Nautley River near Fort Fraser (08JB003). The plotted points represent WSC discharge measurements ($m^3/s$) by year and the deviation from the stage-discharge rating curve (m). Ranges in flow are colour-coded.**

**Photo 6.1 Photo of the confluence of the Nechako and Nautley rivers taken on June 26, 2007, showing backwatered conditions on the Nautley River. The discharge at WSC Nechako River below Cheslatta Falls (08JA017) and Nautley River near Fort Fraser (WSC 08JB003) was approximately 548 $m^3/s$ and 169 $m^3/s$, respectively. The Nechako River is seen on the left, the Nautley River is on the right, and the photo is facing upstream. Source: M. Miles and Associates (2007b).**

## 6.2 Key Mechanisms Causing Backwatering

The following key mechanisms may cause backwatering in the Nautley River:

1. Contrasting flow conditions between the Nechako and Nautley rivers, where high flows in the Nechako River could raise the water level at the confluence and inundate the lower reaches of the Nautley River. These conditions would be expected to occur during periods of relatively low flow out of the Nautley watershed, but high flows out of the reservoir.
2. High flows in both the Nechako and Nautley rivers, where the total flow contributed by both rivers may become constricted as it is conveyed downstream through a single channel, causing the flow velocity to decrease and depth to increase upstream of the constriction.
3. Ice formation and jamming within or downstream of the Nautley River, where the accumulation of ice could constrict the waterway opening, causing an increase upstream water level.

Contrasting flow conditions caused by the onset of flow regulation on the Nechako River are discussed in Section 2.1, and therefore are not further described in this section.

Regarding the second mechanism listed above, the water level downstream of the Nechako and Nautley river confluence is likely influenced by a natural bedrock feature on the Nechako River, located approximately 1.4 km downstream from the confluence (Photo 6.2; Figure 6.2). At this location, shallow and exposed bedrock is present along the bed and banks of the river channel, exerting a physical control on the geometry of the waterway (and hence the flow capacity past this point). As shown in Photo 6.2 and Figure 6.2, the bedrock confines the width of the river valley relative to upstream, which in turn may create a flow constriction during high-flow events. Thus, under certain flow conditions, the water level at the confluence of the Nautley and Nechako rivers is likely controlled, at least in part, by the bedrock constriction, where a localized reduction in the capacity of the channel to convey high flows can cause an increase in upstream water levels.

Ice formation and jamming, the third key mechanism identified above, is known to occur on the Nechako River (NHC, 2021). Ice jamming can cause upstream water levels to increase very rapidly and can lead to extensive overbank flooding and channel erosion. This natural process likely occurred more frequently prior to the onset of flow regulation, since flow regulation has generally decreased winter flows, limiting the ability of the flow to mobilize and form substantial ice jams (NHC, 2021). Discharge measurements collected by the WSC at the Nautley River near Fort Fraser (WSC 08JB003) gauge include a note that ice-affected conditions occur on the Nautley River; however, these measurements do not indicate that ice formation or jamming caused increased water levels (i.e., backwatering or flooding).

NHC is unaware of any reports that suggest ice jamming on the Nautley River is an issue, nor was ice jamming raised as an issue during the WEI during broad-based engagement to date. As a result, NHC did not assess the potential for ice jam formation and associated backwatering in greater detail as part of this study. While the backwatering events observed in 2007, 2011, and 2015 did not coincide with the seasons when ice jams could form, the formation and jamming of ice within or downstream of the Nautley River cannot be ruled out as a potential mechanism for causing future backwatering events under different environmental conditions. Nevertheless, the current flow regime has not resulted in ice jams that backwater the Nautley River, and it is likely that much higher winter flows would be required to cause ice jams sufficiently large to backwater the Nautley River, since approximately a 3 m rise in water level would be required.

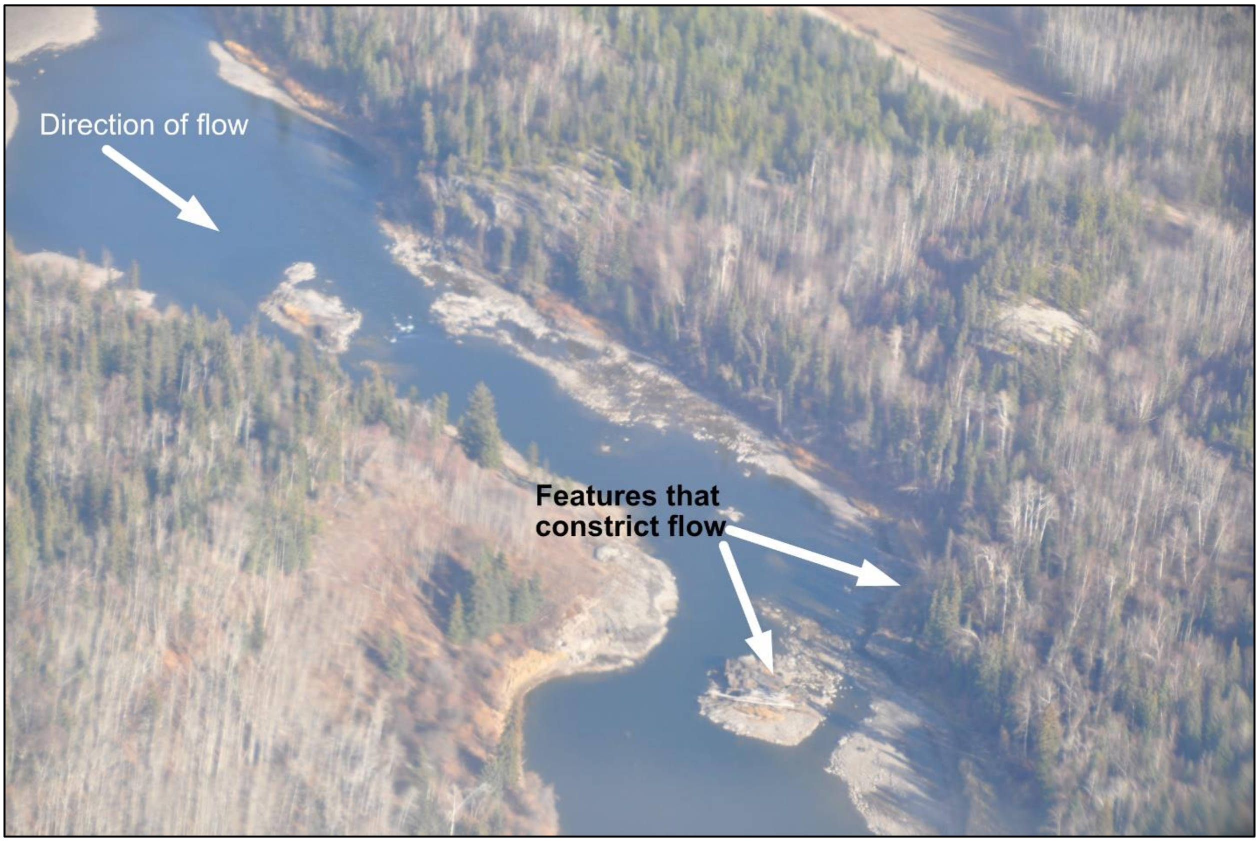
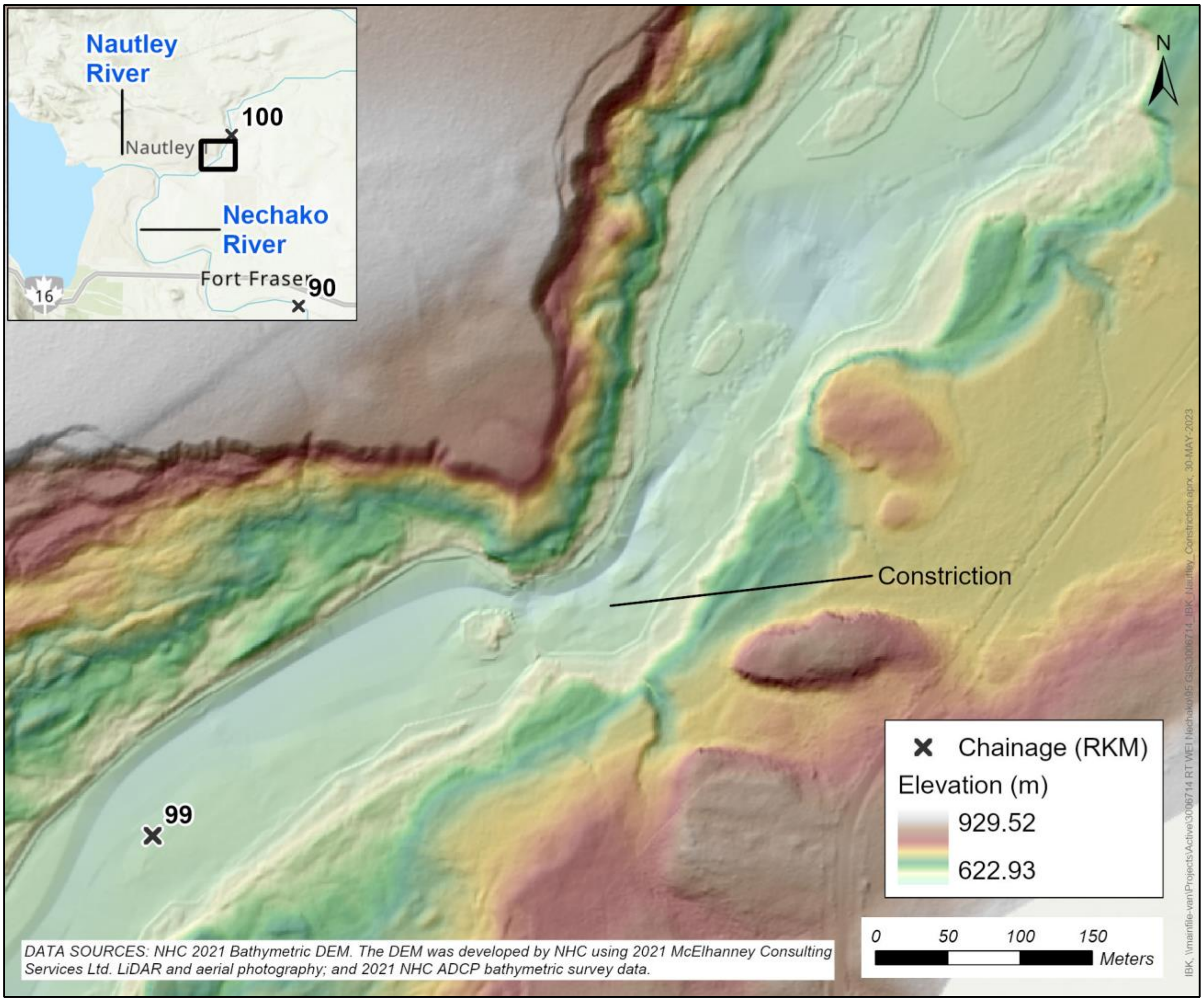



**Photo 6.2 Photo taken of the Nechako River at low flow (49 $m^3/s$) showing bedrock outcrops along the bed and banks of the channel approximately 1.4 km downstream of the Nechako and Nautley river confluence. Photo taken on October 21, 2018.**




**Note:** RKM = river kilometre

**Figure 6.2 LiDAR topography and surveyed bathymetry from 2021 showing the channel constriction caused by bedrock located approximately 1.4 km downstream of the confluence of the Nautley and Nechako rivers.**

## 6.3 Flow Conditions During Backwatering Events

NHC compared stage and discharge records from the gauges at the Nechako River below Cheslatta Falls (08JA017), Nechako River at Vanderhoof (08JC001), and the Nautley River near Fort Fraser (08JB003) stations to determine the relative flow contributions from the Nechako and Nautley rivers during observed backwatering events in 2007, 2011, and 2015. As presented in Table 6.1, the flows during the three backwatering events do not necessarily correspond to the highest flows on the Nechako or Nautley rivers in recent history. For all three backwatering events, the discharge at the Nechako River below Cheslatta Falls (08JA017) gauge was over 450 $m^3/s$, while the discharge of the Nautley River was 165 $m^3/s$ or less. Nechako River flows in the 300 to 400 $m^3/s$ range at the Nechako River below Cheslatta Falls (08JA017) gauge did not appear to cause notable backwatering of the Nautley River in July 2018 and 2022, when the Nautley River discharge was approximately 40 to 100 $m^3/s$. High flows on the Nautley River in May 1997, reaching 265 $m^3/s$, also did not appear to cause notable backwatering when the discharge of the Nechako River was 157 $m^3/s$ and 532 $m^3/s$ at the Nechako River below Cheslatta Falls (08JA017) and Nechako River at Vanderhoof (08JC001) gauges, respectively. While the discharge at Vanderhoof is often roughly equivalent to the discharge of the Nechako River at Cheslatta plus the discharge of the Nautley River, additional inflows appear to have been present in May 1997 due to higher-than-normal tributary inflows and runoff associated with the spring snowmelt[6].

**Table 6.1 Summary of relatively high flows on the Nechako and Nautley rivers since 1995.**

| Date | Maximum Daily Discharge | | | Backwater |
|---|---|---|---|---|
| | Nautley River Near Fort Fraser (WSC 08JB003) | Nechako River Below Cheslatta Falls (08JA017) | Nechako River at Vanderhoof (WSC 08JC001) | |
| May 19, 1997 | 265 $m^3/s$ | 157 $m^3/s$ | 532 $m^3/s$ | No |
| May 31, 2007 | 238 $m^3/s$ | 156 $m^3/s$ | 477 $m^3/s$ | No |
| June 27, 2007 | 165 $m^3/s$ | 553 $m^3/s$ | 766 $m^3/s$ | Yes |
| October 14, 2011 | 12 $m^3/s$ | 455 $m^3/s$ | 473 $m^3/s$ | Yes |
| June 12, 2015 | 146 $m^3/s$ | 488 $m^3/s$ | 665 $m^3/s$ | Yes |
| July 28, 2018 | 38 $m^3/s$ | 292 $m^3/s$ | 349 $m^3/s$ | No |
| July 20, 2022 | 99 $m^3/s$ | 407 $m^3/s$ | 491 $m^3/s$ | No |

NHC then further compared stage and discharge records from WSC hydrometric stations to confirm whether these events in 2007, 2011, and 2015 did produce an increase in water level on the Nautley River (i.e., to confirm backwatered conditions were present) and to investigate the magnitude of the rise in stage. The resulting plots for the 2007, 2011, and 2015 backwatering events are shown on Figure 6.3, Figure 6.4, and Figure 6.5, respectively. As seen on Figure 6.3, the stage of the Nautley River increased by approximately 53 cm during the 2007 backwatering event. Note that on the plot, the water level of the Nautley River rose despite a decreasing (or receding) trend in the Nautley River discharge. These coinciding data trends also indicate data adjustments made by WSC staff to correct for known backwatering impacts by decoupling the stage-discharge relationship during the backwatering periods. Figure 6.4 and Figure 6.5 show that the stage of the Nautley River increased by approximately 51 cm and 35 cm during the 2011 and 2015 backwatering events, respectively.

For comparison, Figure 6.6 presents plots for the stage and discharge records during the 2022 high-flow event, when discharge reached over 400 $m^3/s$ in the Nechako River below Cheslatta Falls (08JA017) and flows in the Nautley River were approximately 100 $m^3/s$ (Table 6.1). Despite the relatively high flows on the Nechako River and moderate flows on the Nautley River, these flow conditions did not appear to

[6] Large flows were observed at other gauged waterways in the area, including at Corkscrew Creek (08JC017) and Nadina River at Outlet of Nadina Lake (08JB008) and on May 15 and 17, 1997, respectively, confirming that high flows were occurring in the region during this period.

cause noticeable backwatering. The flow conditions in 2022 were not that dissimilar to those in 2015, when backwatering occurred; the differences in flow conditions between the two events provide insight into the threshold flow conditions that lead to backwatering, as further discussed in Sections 6.4 and 8.

Figure 6.7 combines these observations and illustrates the observed flow events summarized in Table 6.1, along with the model results described in Section 6.4. The figure illustrates how backwatering of the Nautley River can be produced when the discharge of the Nechako River exceeds a threshold condition relative to the discharge of the Nautley River.

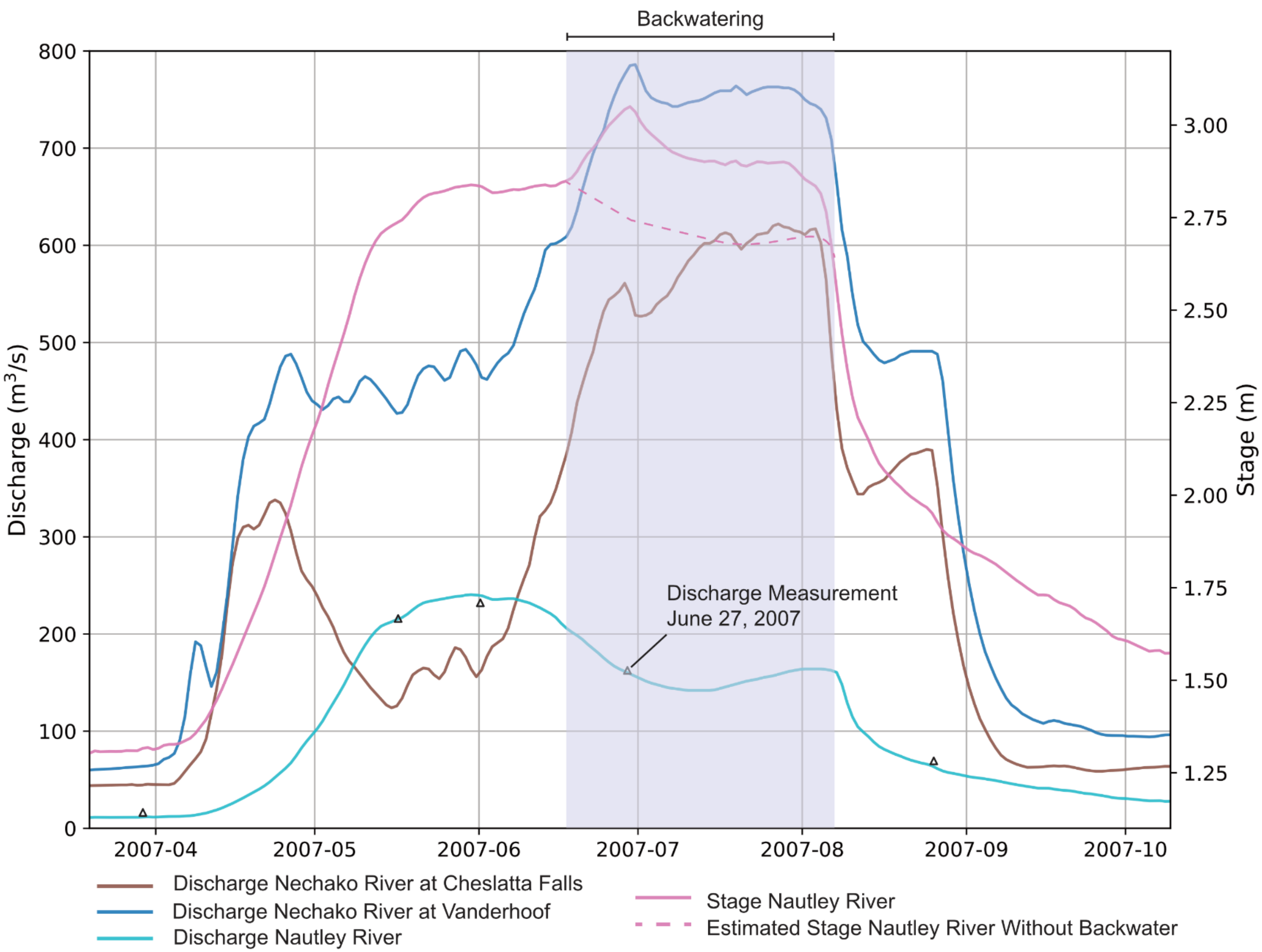



**Figure 6.3 Rise in water level (stage) on the Nautley River caused by the 2007 backwatering event. Note the increasing Nautley stage (pink), despite receding Nautley discharge (teal), indicates backwatered conditions. The dashed pink line shows what the Nautley River stage would have resembled without backwatering.**

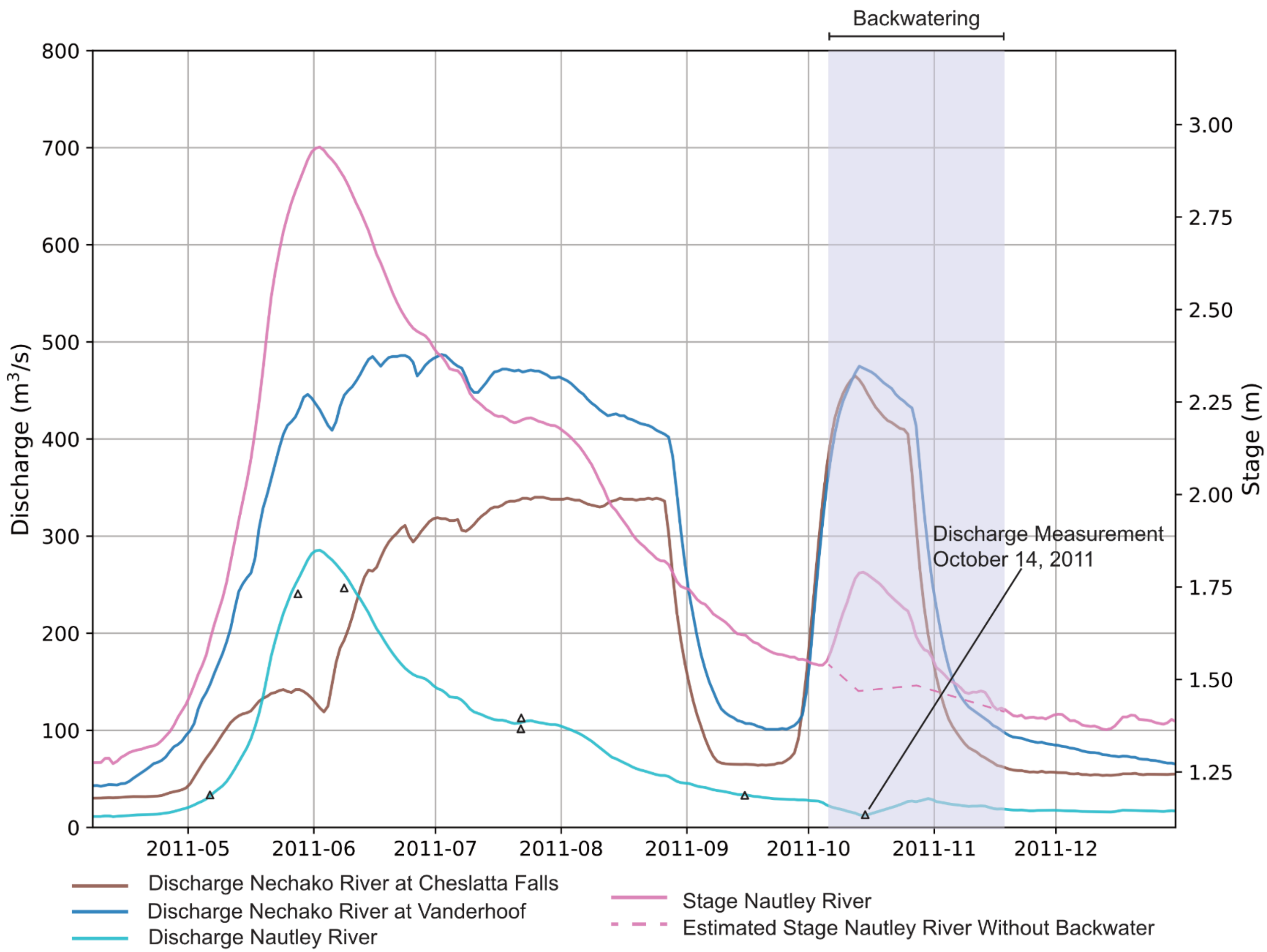



**Figure 6.4 Rise in water level (stage) on the Nautley River caused by the 2011 backwatering event. Note the increasing Nautley stage (pink), despite receding Nautley discharge (teal), indicates backwatered conditions. The dashed pink line shows what the Nautley River stage would have resembled without backwatering.**

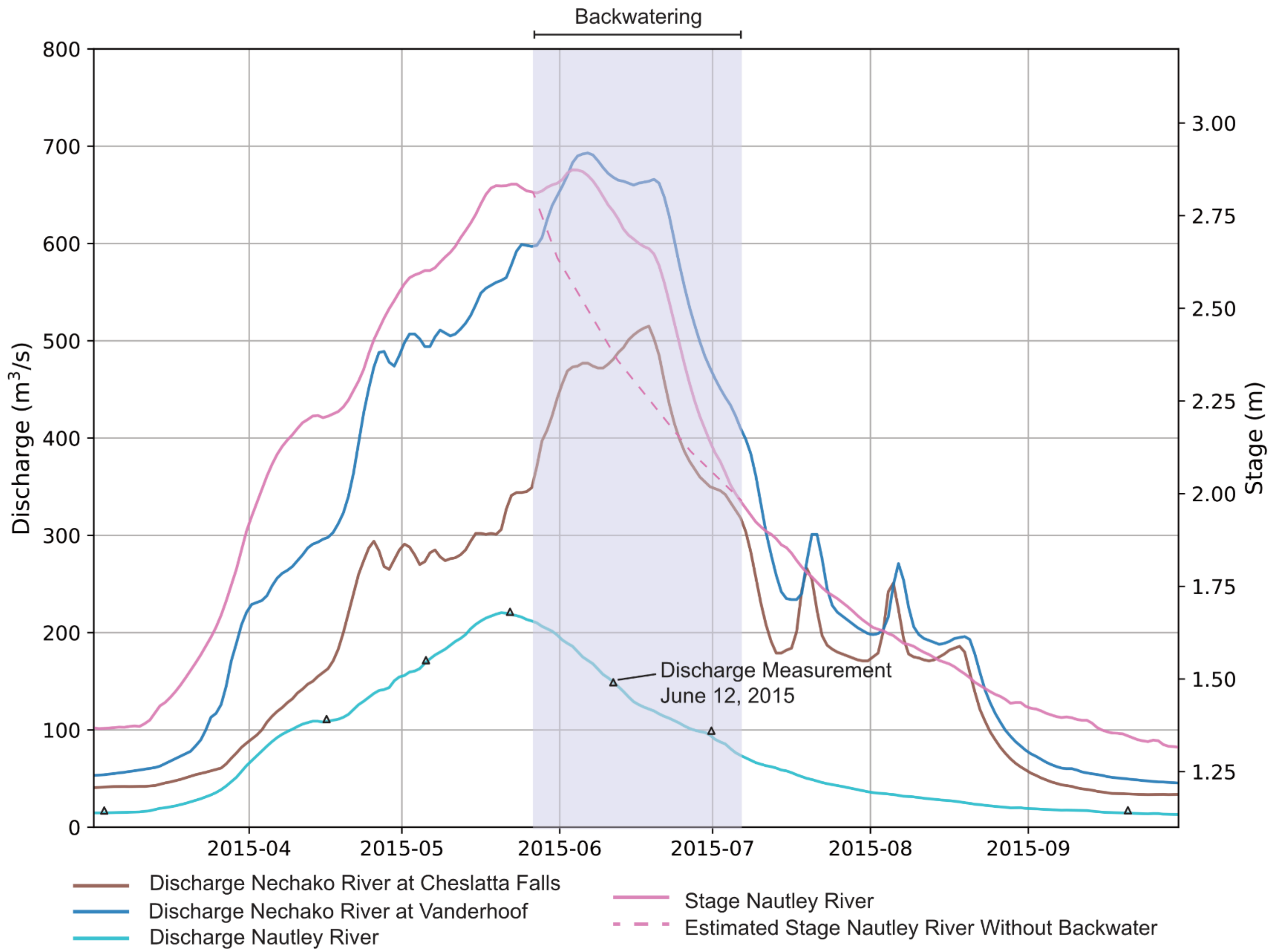



**Figure 6.5 Rise in water level (stage) on the Nautley River caused by the 2015 backwatering event. Note the increasing Nautley stage (pink), despite receding Nautley discharge (teal), indicates backwatered conditions. The dashed pink line shows what the Nautley River stage would have resembled without backwatering.**

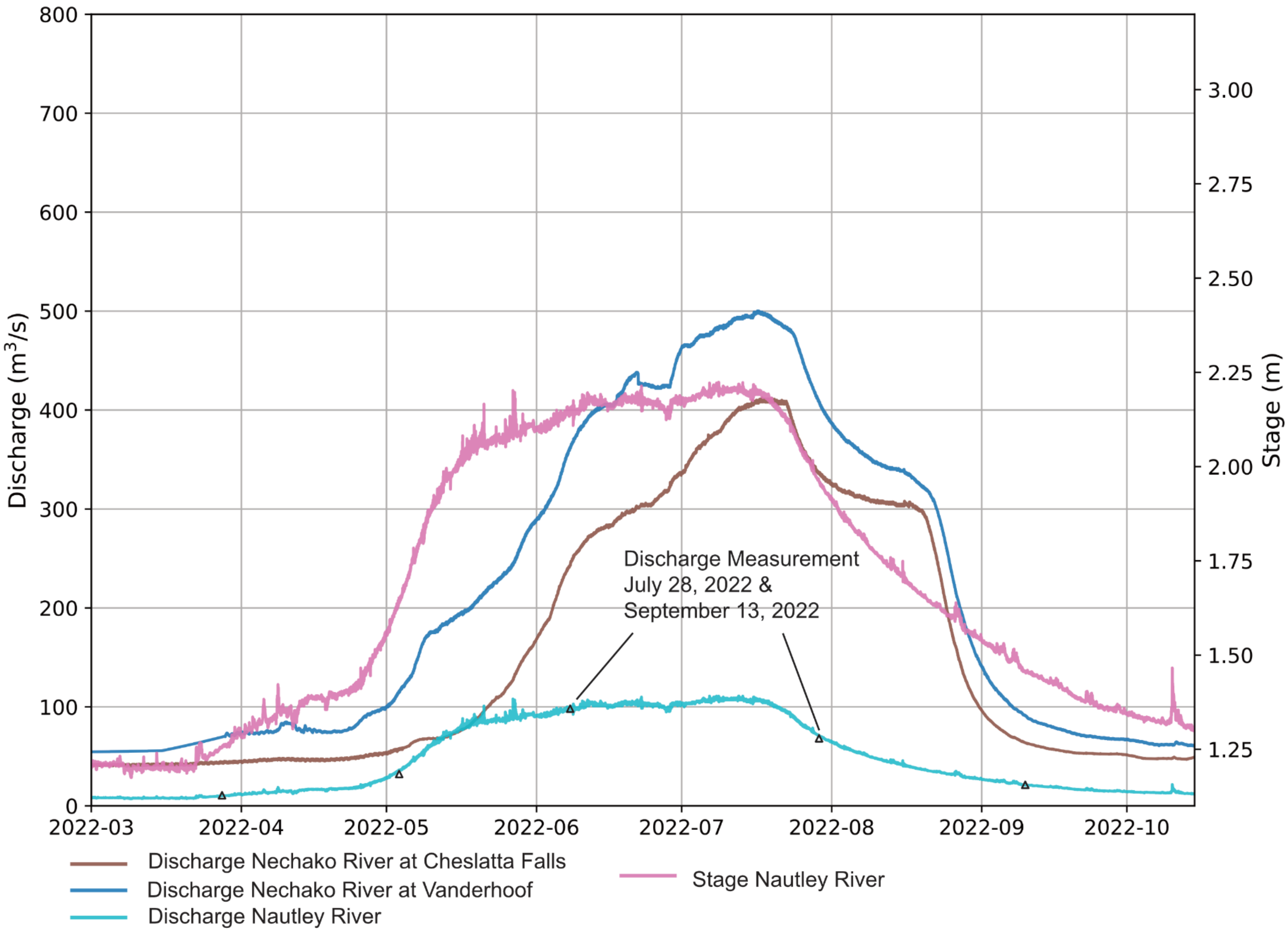



**Figure 6.6 Discharge data from the high-water event in 2022 showing no discernable rise in water level (stage) on the Nautley River and demonstrating this event did not cause backwatering. Note, data since 2021 are preliminary, and Nautley River data are at an hourly timestep.**

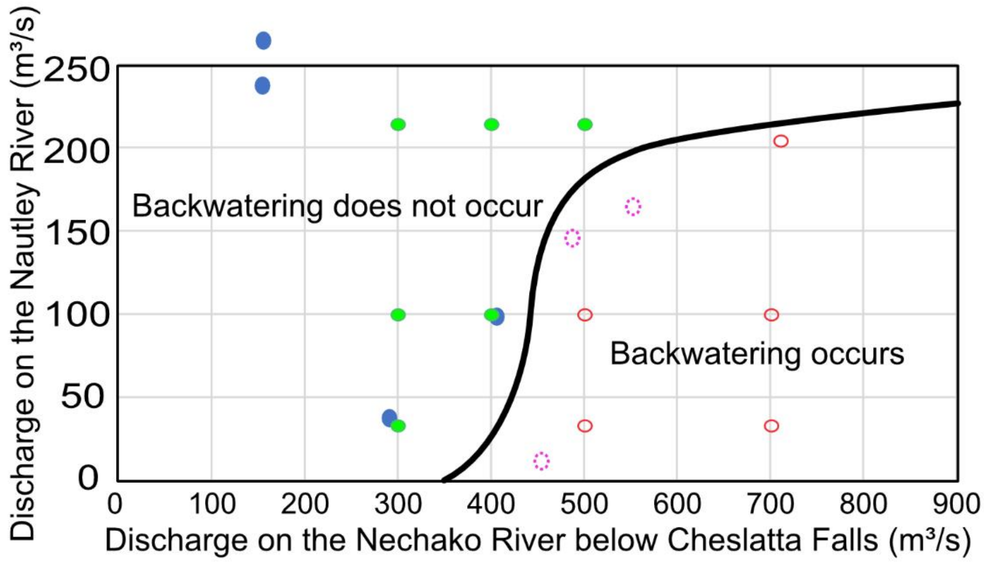



**Figure 6.7 Illustration of discharges on the Nautley and Nechako Rivers that did (dashed purple circles) and did not (solid blue ovals) cause backwatering, overlayed on model results described in Section 6.4. The green solid circles represent model runs that did not experience backwatering, while the red open circles represent model runs that did show backwatering.**

## 6.4 Hydraulic Controls on Backwatering

NHC used the 1-D HEC-RAS hydraulic model of the Nechako River to simulate various flow conditions and investigate which hydraulic conditions contribute to backwatering on the Nautley River. The flow scenarios modelled as part of this study are presented in Table 6.2. NHC chose the low, moderate, and high flows to better define the boundary between backwatering and non-backwatering conditions. For each scenario, Nautley River flows were held constant, while Nechako flows were varied from moderate to high flows.

**Table 6.2 Summary of flow scenarios modelled to investigate backwatering on the Nautley River.**

| Modelled Scenario | Nautley Flow ($m^3/s$) | Nechako Flow Upstream of Confluence ($m^3/s$) | Nechako Flow Downstream of Confluence ($m^3/s$) |
|---|---|---|---|
| Low-flow scenario | 33 | 300 | 333 |
| | | 400 | 433 |
| | | 500 | 533 |
| | | 700 | 733 |
| Moderate-flow scenario | 100 | 300 | 400 |
| | | 400 | 500 |
| | | 500 | 600 |
| | | 700 | 800 |
| High-flow scenario | 215 | 300 | 515 |
| | | 400 | 615 |
| | | 500 | 715 |
| | | 700 | 915 |

The simulated water surface profiles for the low-flow, moderate-flow, and high-flow scenarios on the Nautley River are presented in Figure 6.8, Figure 6.9, and Figure 6.10, respectively. These plots can be used to assess when backwatered conditions are present, which is shown as a flattening of the water surface profile from the confluence to the Nautley bridge. Under low-flow conditions in the Nautley River at 33 $m^3/s$ (Figure 6.8), backwatering occurs once Nechako River flows exceed approximately 350 to 400 $m^3/s$, not including Nautley flows. Under moderate-flow conditions in the Nautley River at 100 $m^3/s$ (Figure 6.9), backwatering appears to occur once Nechako River flows exceed approximately 500 to 600 $m^3/s$. Finally, under high-flow conditions in the Nautley River at 215 $m^3/s$ (Figure 6.10), backwatering occurs once Nechako River flows exceed approximately 900 $m^3/s$, which represents an extremely high flow for the post-regulation period. All flows below approximately 900 $m^3/s$ do not appear to cause backwatering under the high-flow scenario on the Nautley River (at 215 $m^3/s$).

NHC has further summarized and compared the model results to observed flow conditions during the 2007, 2011, and 2015 backwatering events (Table 6.1) in Section 8.1 and in Figure 6.7.

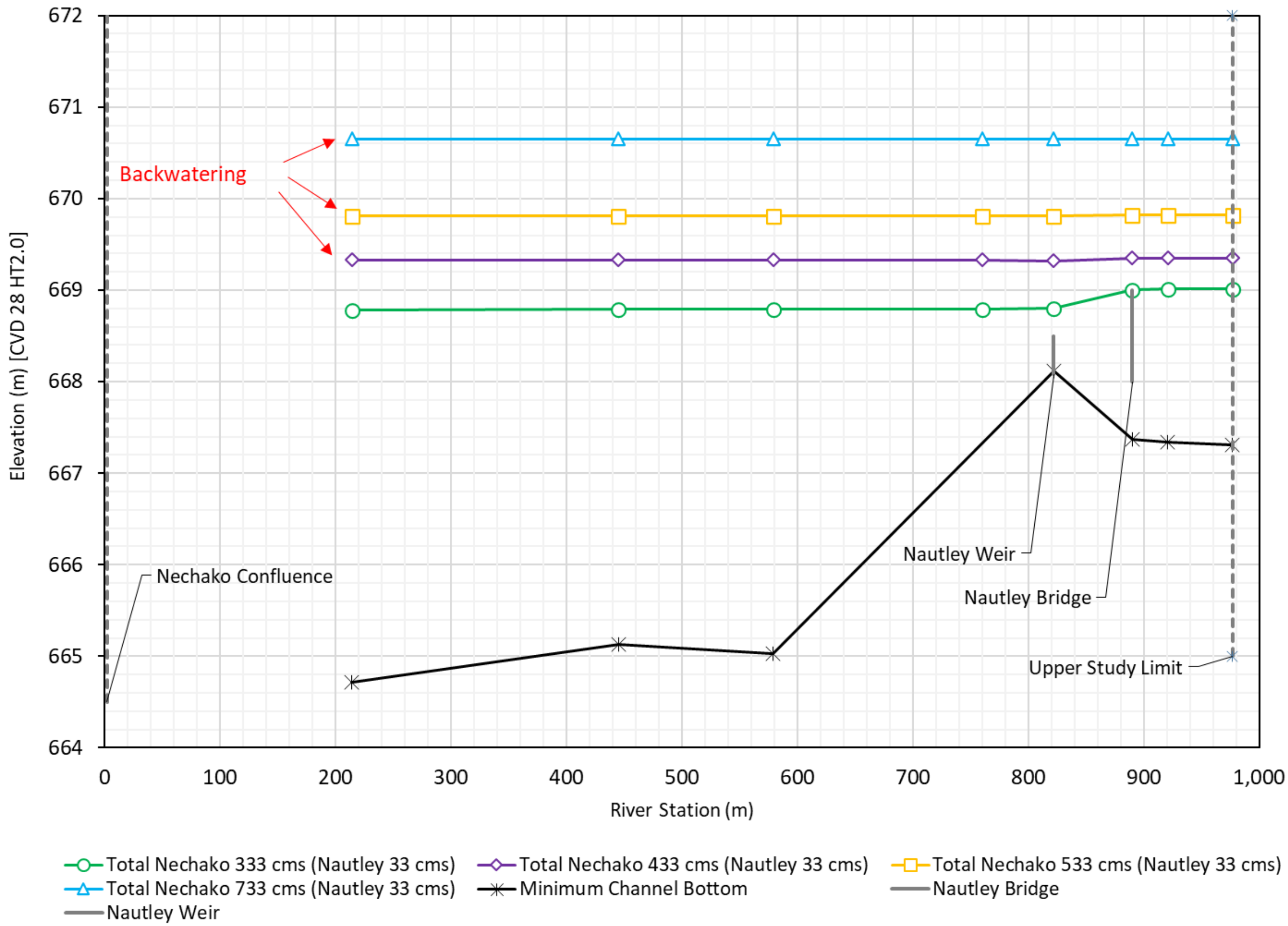



**Figure 6.8 Simulated water surface profiles for the low-flow scenario on the Nautley River (33 m$^3$/s).Nechako River inflows are varied, from 333 m$^3$/s to 733 m$^3$/s (Note: cms = cubic metres per second).**

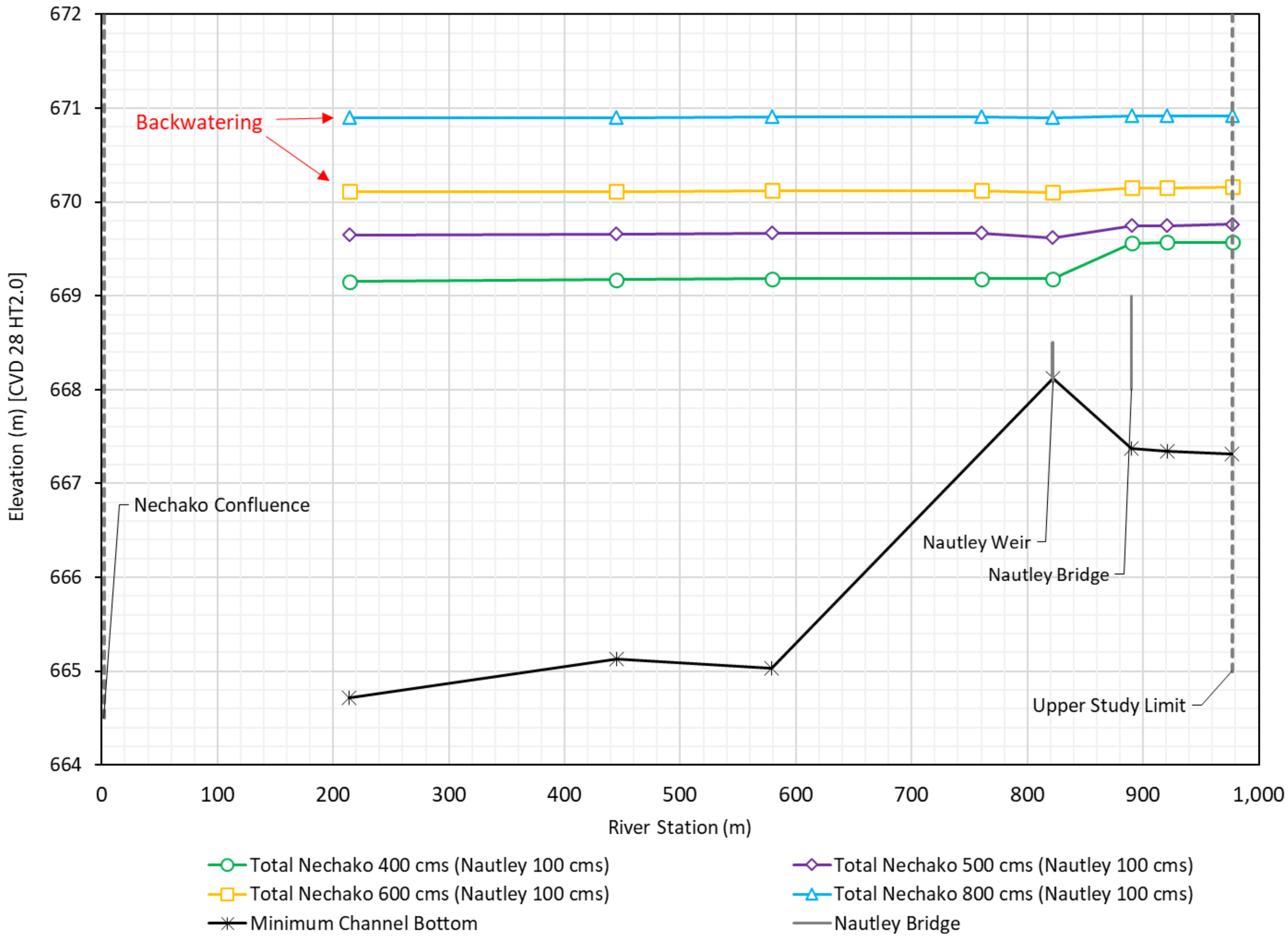



**Figure 6.9 Simulated water surface profiles for the moderate-flow scenario on the Nautley River (100 m³/s). Nechako River inflows are varied, from 300 m³/s to 700 m³/s.**

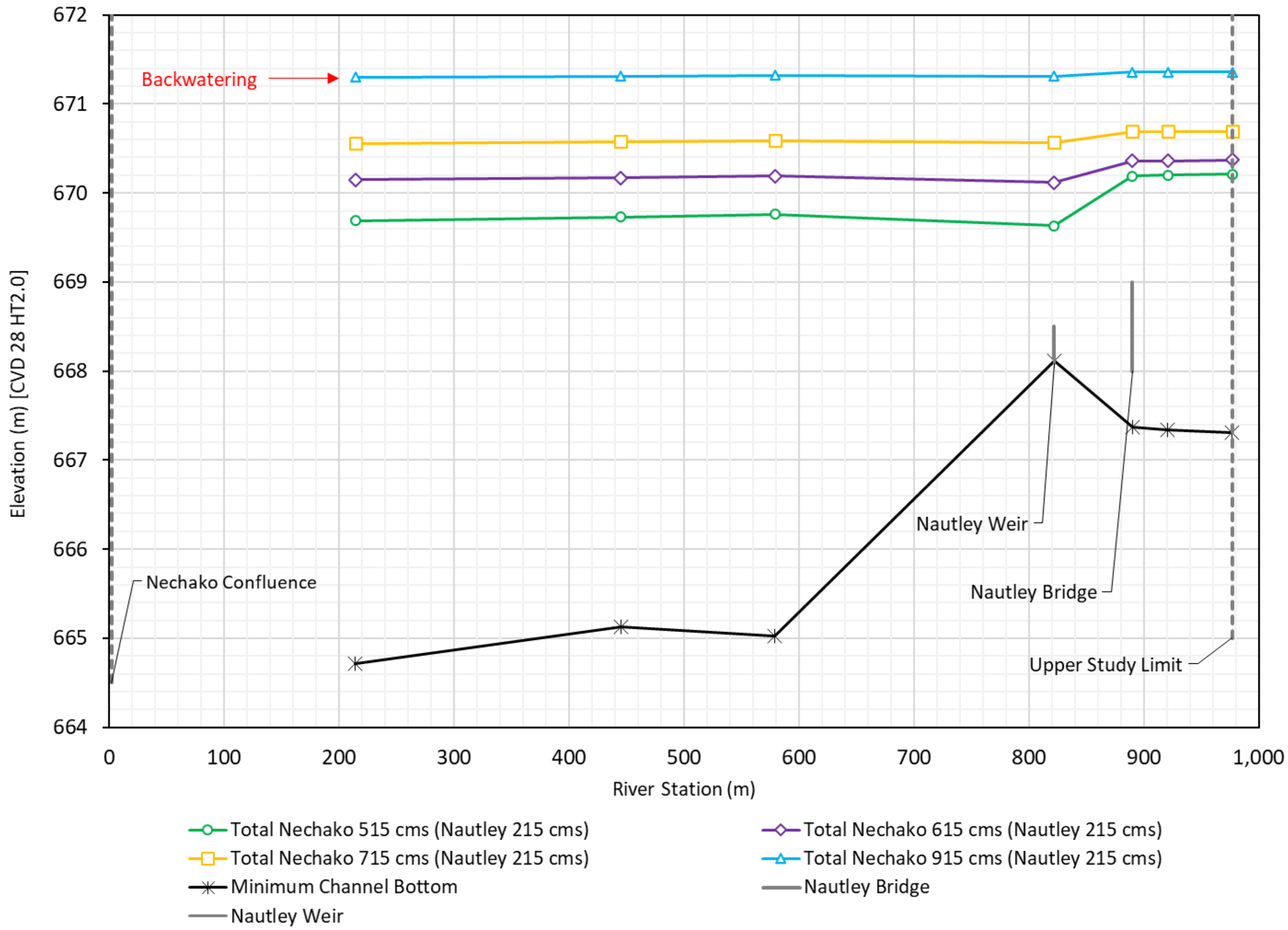



**Figure 6.10 Simulated water surface profiles for the high-flow scenario on the Nautley River (215 m³/s). Nechako River inflows are varied, from 300 m³/s to 700 m³/s.**

# 7 FLOODING ON FRASER LAKE

Backwatering of the Nautley River reduces the hydraulic gradient between the outflow of Fraser Lake and the Nechako River, thereby reducing the rate at which water flows out of Fraser Lake. Once backwatering reaches the Nautley River bridge, it is assumed that the water level at the outflow of Fraser Lake, and hence the flow rate, is largely controlled by the water level of the Nechako River. Reducing the rate at which water flows out of Fraser Lake can lead to flooding, particularly when lake inflows are high (e.g., during spring snowmelt or large rainstorms in the summer and fall).

Hydraulic modelling conducted by NHC (Section 6.4) demonstrates that various flow conditions can cause backwatering of the Nautley River; in general, backwatering appears to occur when low to moderate flows on the Nautley occur concurrently with moderate to high flows on the Nechako River. The weir on the Nautley does not directly influence backwatering.

The model extent does not include Fraser Lake, so knowledge of critical water levels impacting the lake are limited at this time. Regardless, the model results provide a useful indication as to when the level of Fraser Lake may be impacted by backwatering and may be used to inform operational strategies to mitigate flooding. Additional analyses and recommendations related to flooding on Fraser Lake are provided in Section 9.

# 8 DISCUSSION

This section provides a summary of the main findings, highlights of key considerations related to backwatering of the Nautley River, and an overview of some of the limitations of the analysis.

## 8.1 Summary of Results

The main findings of the study related to headcutting and the Nautley River weir and backwatering of the Nautley River are summarized below in Section 8.1.1 and Section 8.1.2, respectively.

### 8.1.1 Headcutting and the Nautley Weir

The following points list the key findings related to headcutting erosion on the Nautley River and stability of the Nautley weir:

1. Headcutting erosion on the Nautley River likely required relatively high flows on the river, combined with low Nechako River flows. It is therefore likely that headcutting erosion began in the spring of 1953, when the amount of flow conveyed by the Nechako River at the confluence would have been exceptionally low due to infilling of the Nechako Reservoir (1952 to 1956).
2. The rock weir was subsequently constructed in 1953 to mitigate the headcutting erosion.

3. The rock weir eroded by up to 2 feet (60 cm) between 1953 and 1965, reportedly lowering the level of Fraser Lake[7]. The weir was then repaired in October 1965.
4. A gradual decrease in Fraser Lake water levels and a concurrent drop in Nautley River flows occurred between 1967 and 1972, as the hydraulic control at the weir eroded by up to 0.4 feet (12 cm) over this period.
5. Repeated surveys confirmed that the weir remained relatively stable from 1993 to 2017 with no notable erosion.
6. An updated analysis of discharge measurements from the Nautley River near Fort Fraser (08JB003; 1988 to present) conducted as part of this study indicates that the weir has remained relatively stable since 1988, although minor erosion and lowering of the water levels, on the order of -0.03 to -0.05 m, may have occurred over the last 35 years. Despite this apparent, minor lowering, the data suggest that the headcut has not continued to advance upstream in any appreciable way, and the overall geometry of the channel and weir appears to have remained relatively stable in recent years. It does not appear that headcutting erosion is currently impacting the function of the weir or upstream water levels.

### 8.1.2 Backwatering of the Nautley River

Following are summaries of NHC's key findings related to Nautley River backwatering:

1. Station notes and records on water level and discharge from the WSC Nautley River near Fort Fraser (08JB003) gauge indicate that there have been three known backwatering events over the period of record (1972 to 2022); these events occurred in June 2007, October 2011, and June 2015.
2. Local residents reported observations in May or June of some years (unspecified) when "several homes/farms adjacent to the Nautley River have their access road/driveway submerged" and standing water was impacting properties throughout area (Kurtz, 2020).
3. Stage and discharge records from WSC hydrometric stations show that the water level (stage) of the Nautley River increased by approximately 53 cm, 51 cm, and 35 cm during the 2007, 2011, and 2015 backwatering events, respectively.
4. The flows during the three backwatering events (2007, 2011, 2015) do not necessarily correspond to the highest flows on the Nechako or Nautley rivers in recent history; for all three events, the discharge at the Nechako River below Cheslatta Falls (08JA017) gauge was over 450 $m^3$/s, while the discharge of the Nautley River was 165 $m^3$/s or less.
5. Nechako River flows in the 300 to 400 $m^3$/s range at the Nechako River below Cheslatta Falls (08JA017) gauge did not appear to cause notable backwatering of the Nautley River in 2018 and 2022, when the Nautley River discharge was 40 to 100 $m^3$/s. High flows on the Nautley River in 1997, reaching 265 $m^3$/s, also did not appear to cause notable backwatering.
6. Results from the 1-D HEC-RAS hydraulic model showed that, under low-flow conditions in the Nautley River (33 $m^3$/s), backwatering began to occur once Nechako River flows exceeded approximately 350 to 400 $m^3$/s upstream of the river confluence. During moderate flows on the Nautley River (100 $m^3$/s), backwatering began once Nechako River flows exceeded

[7] Stage data from WSC gauge Fraser Lake at Lejac (08JB005) show no evidence of reduced lake levels during this period.

approximately 500 to 600 $m^3/s$ upstream of the river confluence. Under high-flow conditions in the Nautley River (215 $m^3/s$), backwatering only occurred once while Nechako River flows exceeded approximately 900 $m^3/s$ upstream of the river confluence. These results are summarized in Table 8.1.

7. The model shows that backwatering could occur when very high flows occur concurrently on the Nechako and Nautley rivers; however, this would likely require an extremely large flood for the post-regulation period (e.g., Nechako flows over 800 $m^3/s$ upstream of the confluence).
8. When the Nautley River is backwatered to the Nautley bridge, the Nechako River water level primarily controls the water level at the outlet of Fraser Lake. It is possible that flooding around Fraser Lake could occur as a result of backwatering caused by very high flows on the Nechako River.

**Table 8.1 Summary of 1-D HEC-RAS model results showing the simulated flow conditions that produce a backwatering effect on the Nautley River.**

| Modelled Scenario | Nautley Flow ($m^3/s$) | Total Nechako Flow Downstream of Confluence ($m^3/s$) | Backwatering |
|---|---|---|---|
| Low-flow scenario | 33 | 333 | No |
| | | 433 | **Yes** |
| | | 533 | **Yes** |
| | | 733 | **Yes** |
| Moderate-flow scenario | 100 | 400 | No |
| | | 500 | No |
| | | 600 | **Yes** |
| | | 800 | **Yes** |
| High-flow scenario | 215 | 515 | No |
| | | 615 | No |
| | | 715 | No |
| | | 915 | **Yes** |

## 8.2 Key Considerations

It is NHC's understanding that backwatering of the Nautley River occurred prior to flow regulation, and not as a result of flow regulation on the Nechako River. Flow regulation has likely reduced backwatering events caused by very large floods in the Nechako River, given that reservoir operations have eliminated the occurrence of large, pre-regulation floods (e.g., over 1,000 $m^3/s$). However, dissimilarities in the present-day hydrographs and contrasting flow conditions between the Nechako and Nautley rivers created by reservoir operations may exacerbate backwatering during certain periods of the year while Nautley River flows are typically low.

The frequency and magnitude of backwatering events on the Nautley River can potentially be reduced or managed through reservoir operations. The Fraser Lake and surrounding communities are impacted by flooding related to backwater, which supports further investigation into mitigation options. Reservoir operations may be informed by additional modelling or by real-time monitoring, as further discussed in Section 9. In the interim, NHC cross-referenced results from the 1-D HEC-RAS model (Table 8.1) w with observed flow conditions during the 2007, 2011, and 2015 backwatering events (Table 6.1) to produce Figure 6.7, which provides initial guidance on which flow conditions may be expected to produce backwatering in the Nautley River.

## 8.3 Limitations of Analysis

The analysis, interpretation, and results presented herein are based on available data and are commensurate with the current project scope. Limitations of the study include:

1. Limited information and data are available for the initial period of headcutting erosion on the Nautley River in 1953. Knowing the exact timing of when headcutting initiated would be helpful to better understand the processes driving the subsequent erosion
2. Limited information is available regarding potential headcutting erosion on the Nechako River; NHC will explore this limitation further as part of the Geomorphic Atlas of the Nechako River (NHC, In Prep.)
3. A limited number of flow measurements are available at the Nautley River near Fort Fraser (08JB003) gauge; additional measurements during different flow conditions would help refine backwatering thresholds
4. Uncertainty remains regarding operational scenarios and how they can affect Fraser Lake water levels and water storage
5. Uncertainty remains about the critical water levels that impact the community of Fraser Lake
6. There was a lack of detailed bathymetric data in Fraser Lake for the numerical model
7. Limited calibration data were available for the numerical model.

# 9 PERFORMANCE METRICS

During the WEI's broad-based engagement activities and Technical Working Group meetings, concerns were raised regarding the potential effects of Rio Tinto operations on backwatering of the Nautley River and associated flooding on Fraser Lake. While this issue is important to some community members and has social significance, the sensitivity to Rio Tinto operations is unknown. This technical report was prepared to better understand the history of headcutting erosion on the Nautley River, evaluate the stability of the weir in recent years, and investigate what flow conditions drive backwater propagation on the Nautley River.

This section presents a discussion of the potential objectives of performance metrics on backwatering of the Nautley River and Fraser Lake and provides recommendations for next steps.

## 9.1 Objectives

The primary objectives of these performance metrics include:

1. Limit inundation and potential damage to property caused by backwatering of the Nautley River
2. Limit or manage the effect of backwatering on Fraser Lake water levels
3. Develop tools to inform reservoir operations related to backwatering of the Nautley River.

## 9.2 Recommendations

The frequency and magnitude of backwatering in the Nautley River may be monitored and managed (i.e., reduced) through reservoir operations. NHC recommends that reservoir operations consider limiting flow releases on the Nechako River during periods when the Nautley River flows are comparatively low to prevent backwatering (Figure 6.7). However, we also acknowledge that limiting flow releases may conflict with existing operational strategies (e.g., STMP). At present, the line in Figure 6.7 could be used as an initial performance criterium to assess how often backwatering of the Nautley River might be occurring.

To improve confidence in the delineation of the line separating backwatering from non-backwatering conditions (Figure 6.7), NHC recommends modelling additional flow scenarios close to the threshold conditions. Our team modelled the Nautley weir based on the T&T Surveys Ltd. survey profile in 2017 (Swiftwater Consulting, 2017); additional surveying may be conducted to update and refine the weir geometry in the model. Additionally, the existing hydraulic model does not include the Nautley bridge, located at the outlet of the lake, which could be included in the model to better simulate lake outflows. The model may also be extended to include Fraser Lake to better evaluate flood levels around the lake; this model extension would likely require bathymetric surveys within the lake. Finally, the model may be updated to include a precipitation runoff module to simulate lake inflows. Once backwatering occurs, outflows from Fraser Lake are delayed and flooding duration is increased. Additional modelling of the entire lake and inflows to the lake would be required to quantitatively evaluate the impact of backwatering on flooding around the lake.

NHC also recommends establishing a monitoring program to more accurately define the flow thresholds that lead to backwatering and to record the magnitudes of future backwatering events. For example, an index velocity sensor combined with a stable reference could provide a relative measure of backwatering on the Nautley River for real-time monitoring purposes, which could be used to inform reservoir operations. Alternatively, a mass-balance approach of basin inflows and outflows from Fraser Lake could provide a similar index of backwatering, albeit to a coarser degree.

Finally, the 1D HEC-RAS model could be used to forecast the impact of Nechako River flows on the Nautley River; however, it should be noted that the current 1D HEC-RAS model does not extend upstream of the Nautley Bridge, nor does it include water storage in Fraser Lake and its interaction with Nautley River backwatering.

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# APPENDIX A

## HISTORICAL AIR PHOTOS AND PHOTOGRAPHS

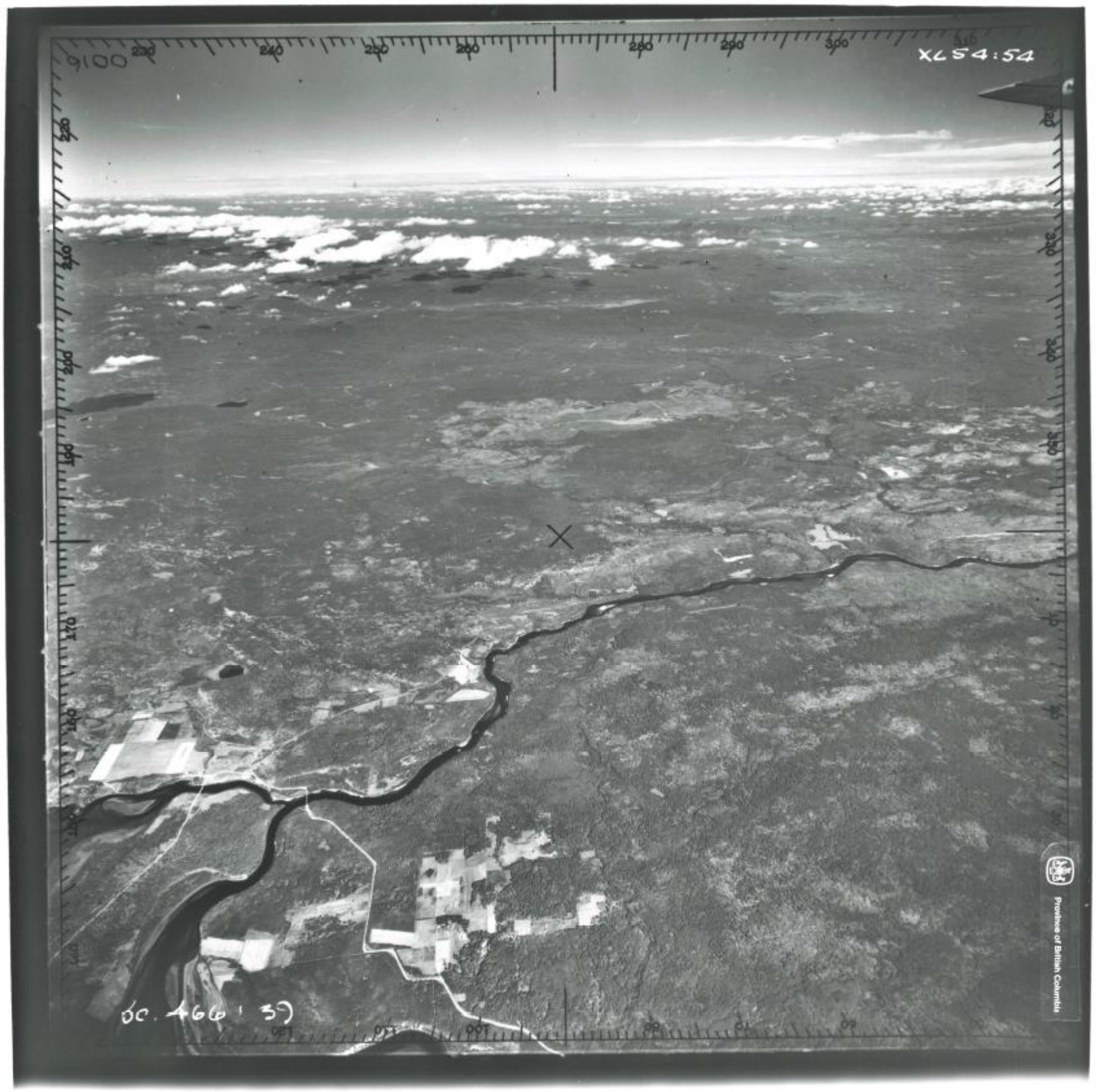
**Photo A.1 1928 A732.25 air photo of the Nautley River flowing from Fraser Lake to the Nechako River.**

**Source:** Photographs provided by UBC.

**Photo A.2 1928 A732.25 air photo of the Nechako River and Nautley River confluence. The Nautley is the smaller waterway seen in the centre of the photograph.**


**Source:** Photographs provided by UBC

**Photo A.3 1947 XL54.52 air photo of Fraser Lake and its outlet, Nautley River. The Nechako River and Nautley River confluence can also be seen in the bottom right of the photograph.**




**Source:** Photographs provided by UBC

**Photo A.4 1947 XL54.52 air photo of Fraser Lake and its outlet, the Nautley River. The Nechako River and Nautley River confluence, and the constriction on the Nechako downstream of the Nautley confluence can be seen.**


**Source:** Photographs provided by UBC

**Photo A.5 1950 BC1046.34 air photo of the outlet of Fraser Lake, the Nautley River.**


**Photo A.6 BC 1046_357 historical aerial photograph of the Nechako River and Nautley confluence shown in the top right of the photograph (1950).**


**Photo A.7 BC 1046_36 historical aerial photograph of the Nechako River and the Nautley confluence shown in the top left corner of the photograph (1950).**

Figure 2 Salmon weir on the Nautley River in 1909 (5).

**Photo source:** Frank Swannel

**Photo A.8 Exploration, Nechako River: 1909 to 1910.**