Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: (604) 980-6011
www.nhcweb.com

NHC Reference 3006322
October 31, 2022

Regional District of Kootenay Boundary
#202- 843 Rossland Avenue
Trail, BC, V1R 4S8 **Attention:** **Kristina Anderson, Watershed Planner**

Via email: watershedplanner@rdkb.com

Re: **Floodplain Mapping for Boundary Region – Grand Forks to Cascade Falls Hydrological Assessment – Final**

Dear Ms. Anderson:

1 Introduction

This document describes the hydrological analysis for the Kettle River from the eastern border of the City of Grand Forks to Cascade Falls, BC. Flood maps are to be created for these river reaches as part of the greater *Flood Mapping for Boundary Region* project for the Regional District of Kootenay Boundary (RDKB). Further details of the project are provided in the main report: *Regional District of Kootenay Boundary – Floodplain Mapping for Boundary Region – Kettle River – Grand Forks to Cascade Falls* (NHC, 2022).

2 Study Area

The hydrological study reach begins at the Canada-US border near Carson Townsite and ends at Cascade Falls (Figure 2.1). The area of the Kettle River watershed to the downstream model boundary is approximately 9,311 km^2. The Granby River flows into the Kettle River at Grand Forks and has an area of 2,061 km^2. The Kettle and Granby Rivers have a snowmelt-dominated regime with spring freshet occurring around late May or June. The annual hydrologic regime for both these rivers is presented in Figure 2.2 and Figure 2.3. The most extreme floods are typically rain-on-snow events during the spring. The period between September and March typically consists of low flows.

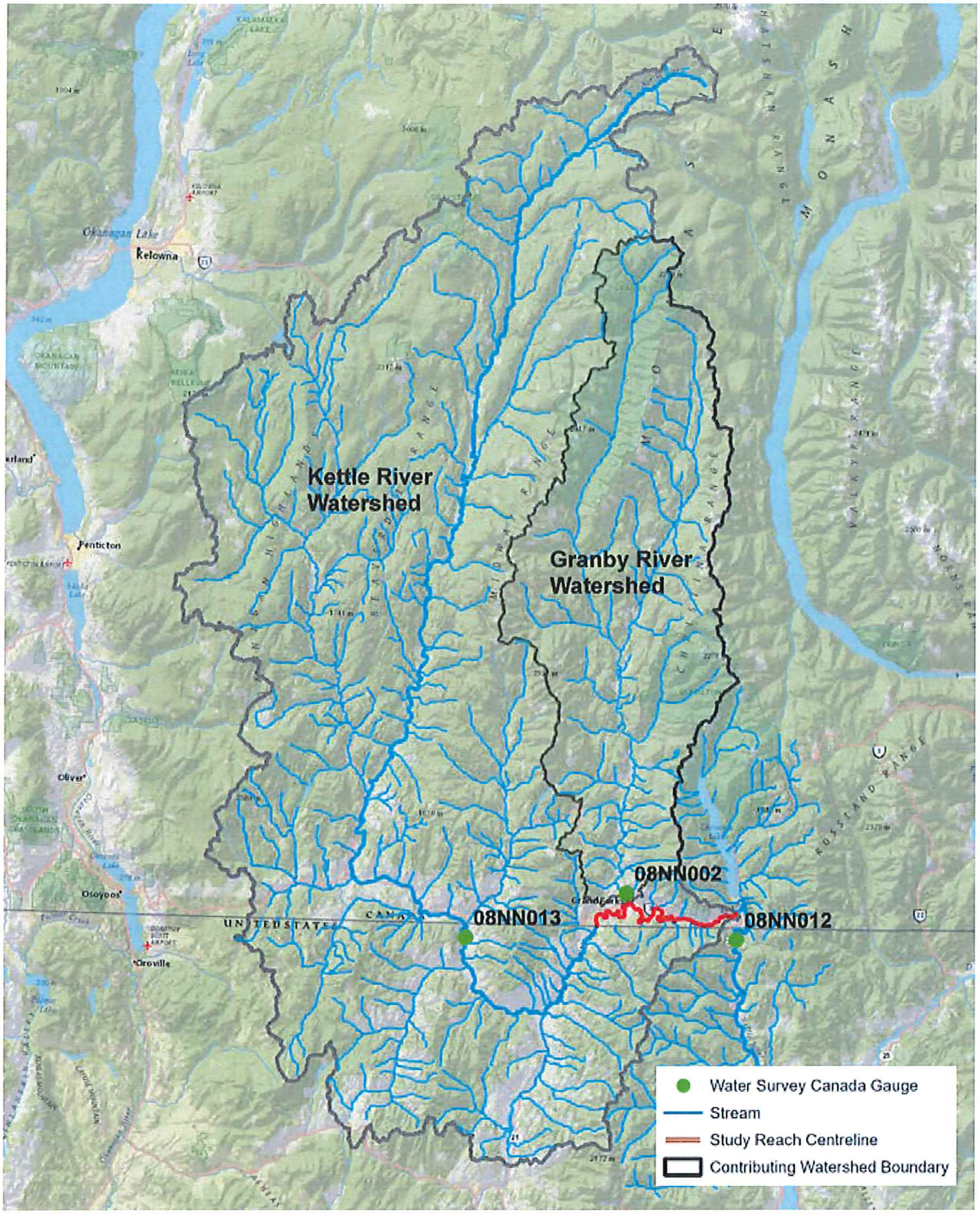

Figure 2.1 Overview of Kettle River and Granby River watersheds, study reach and key hydrometric gauges.

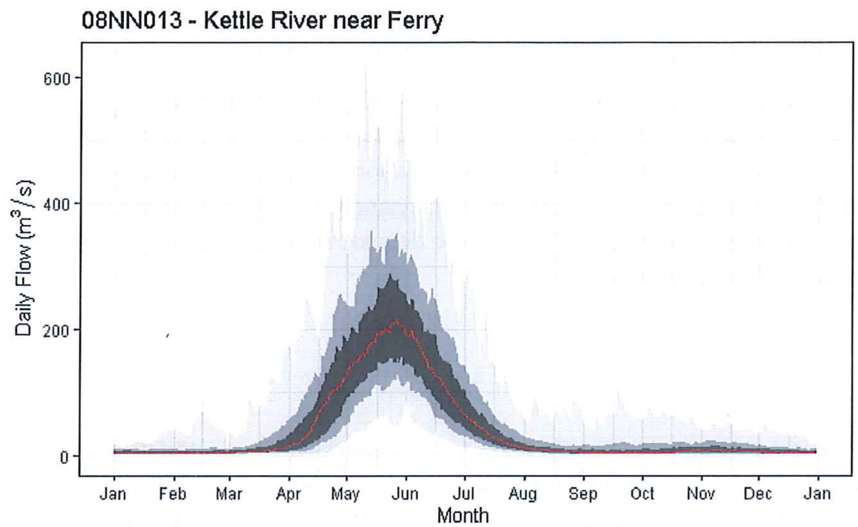

Figure 2.2 Hydrologic regime of the Kettle River at Ferry (08NN013). Red line represents the median flow (1929-2018), grey bands represent the 25th-75th percentile, 10th-90th percentile and maximum/minimum, respectively according to receding shade.

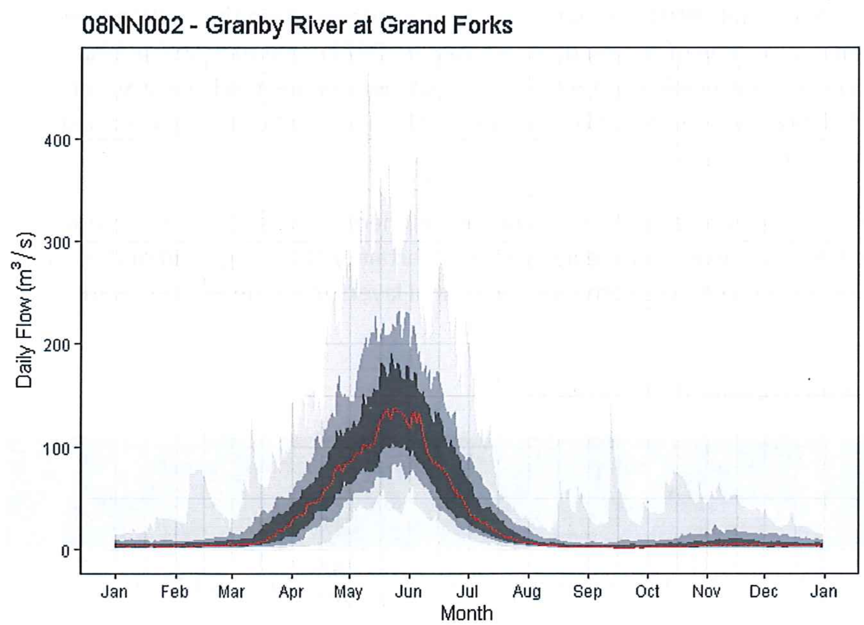

Figure 2.3 Hydrologic regime of the Granby River at Grand Forks (08NN002). Red line represents the median flow (1927-1930, 1967-2019), grey bands represent the 25th-75th percentile, 10th-90th percentile and maximum/minimum, respectively according to receding shade.

3 Study Approach

To simulate various flood modelling scenarios for the Grand Forks to Cascade Falls study reach, inflow points and associated drainage areas were defined for the Kettle River and Granby River watersheds. Water Survey of Canada (WSC) gauges were reviewed to determine appropriate gauges to inform flood frequency analysis. A climate change factor was applied to frequency analysis estimates which were then transferred to model inflow points. Inflow hydrographs were developed for various calibration and design scenarios using hydrograph shapes from past events.

4 Source Data

Design flows were based on three gauges as shown in Table 4.1. The gauges were selected based upon the inflow requirements of the hydraulic model. The Kettle River near Ferry and Granby River gauges were used to develop inflows for the hydraulic model. Data from the Kettle River near Laurier was used only for estimation of the historic 1894 flood on the Kettle River, as some pre-gauge information is available from the USGS. This analysis is described in Section 4.1.

The Kettle River near Ferry and Kettle River near Laurier stations are operated by the USGS. WSC pulls data from the USGS website for the USGS Ferry and Laurier gauges and publishes it on their website under WSC gauge number 08NN013 and 08NN012. Data records were accessed via the Environment Canada Data Explorer (version 2.1.8) HYDAT (version date October 19, 2021). Due to a WSC publication backlog, data from 2018-2021 was unavailable from HYDAT. This data was requested from WSC for the Granby gauge and downloaded directly from the USGS website for the Ferry and Laurier gauges. Flow and stage records were approved data grades.

Data records were assessed for completeness and years with instantaneous peaks (QPI) and maximum daily peaks (QPD) were noted. Rating curves were reviewed for uncertainty at the high end of the curve. Drainage areas were reviewed using Esri ArcGIS software and spatial layers from the BC Freshwater Atlas.

Table 4.1 Hydrometric stations used for design inflows.

River	WSC gauge	USGS gauge	Record	Regulated	QPI Record	QPD Record	Basin Area (km^2)
Kettle River near Ferry	08NN013	12401500	1928-present	N	1929-2020	1929-2020	5700
Granby River at Grand Forks	08NN002	n/a	1914-1915, 1927-1930, 1967-present	N	2005-present	1914-1915, 1927-1930, 1967-present	2060
Kettle River near Laurier	08NN012	12404500	1930-present	N	1932-2020	1930-2020	9930

4.1 Record Extension

The QPI record for the Kettle River near Ferry and Granby River gauges was extended by calculating a peaking factor using rank-rank linear regression. The linear models for both gauges are shown in Figure 4.1. The linear models for both the Kettle River and Grand Forks gauge indicate a consistent relationship between QPD and QPI flows. The peaking factors were used to extend the QPI record to the same length as the QPD record for peak flow analysis.

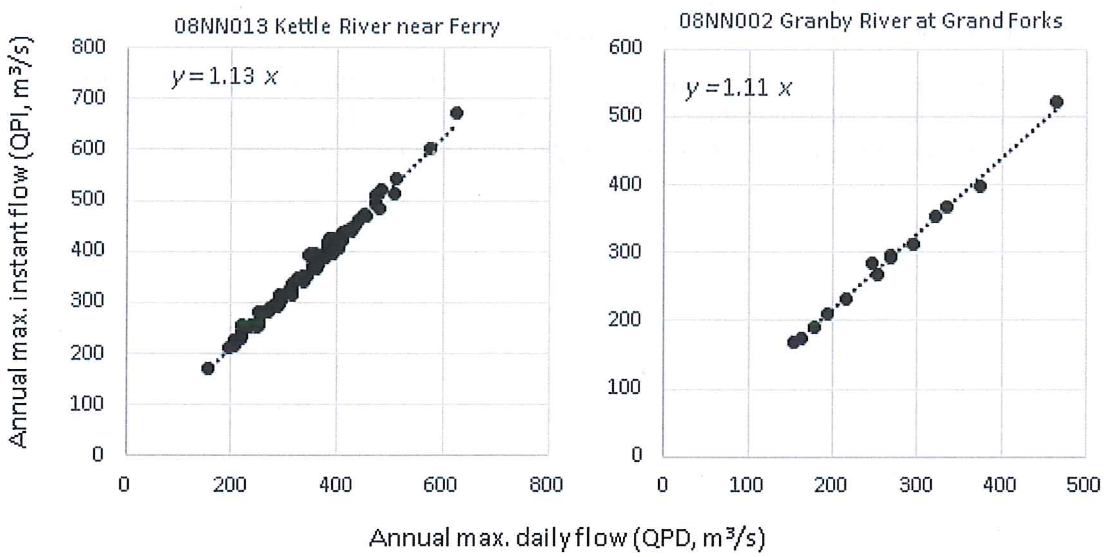

Figure 4.1 Rank-rank linear models for infilling instantaneous peaks on WSC gauges 08NN013 Kettle River near Ferry and 08NN002 Granby River at Grand Forks.

Historic (pre-gauging) flooding along the Kettle River was also investigated. Septer (2007) describes the 1894 flooding in Southern British Columbia, which caused extensive damage in BC's Fraser Valley, and is the flood of record for the Fraser River at Hope, BC. According to the report, extensive damage also occurred on the Thompson, Columbia, Kettle, and White Rivers. Septer states that "All bridges on the Kettle River were lost", indicating an extreme flood that occurred outside of the historical record (beginning in 1928 for the Kettle River).

The only numerical information about the 1894 flood on the Kettle River is at the USGS/WSC gauge on the Kettle River at Laurier (08NN012). Gauge notes indicate a peak stage of 22 feet in 1894. This is the highest peak stage recorded, with the second highest at 18.38 feet in 2018. However, no associated discharge is available. Thus, while we can conclude that 1894 was indeed a large flood on the Kettle River at Laurier, a precise peak flow is unknown at Laurier, and has even greater uncertainty upstream at the Kettle River at Ferry gauge.

To incorporate 1894 flood information for the Kettle River at Ferry the following steps were completed:

1. Extend the provided rating curve equation[1] from the USGS for the Laurier gauge to 22 feet, giving an estimated flow of 71000 ft^3/s or 2000 m^3/s for 1894.
2. Fit a linear regression model between peak flows on the Kettle River at Laurier and Kettle River at Ferry. This linear regression estimates an 1894 peak of 1094 m^3/s for the Kettle River at Ferry gauge. However, testing showed that the regression may over-predict for extreme flows. For example, the 2018 flood was over-predicted by 13% using this method.
3. Our understanding of the 1894 flood indicated unprecedented snowmelt over a wide spatial scale along with heavy rainfall (Septer, 2007). For these large-scale flood events, the synchronized melt may become less important as the watershed size decreases. Thus, direct scaling of the 1894 flood at Laurier to Ferry is likely inappropriate. Instead, we assumed that the 1894 flood was at least as large as the 2018 flood, and up to double the size of 2018.

While we can feel reasonably confident to incorporate 1894 flood information for the Kettle River at Ferry gauge, we are less confident in this on the Granby River gauge (08NN002). Thus, the historic estimate was only used for extending the record for the Kettle River at Ferry gauge.

[1] https://waterdata.usgs.gov/nwisweb/get_ratings?site_no=12404500&file_type=exsa

5 Frequency Analysis

Frequency analysis was performed on both the Kettle River at Ferry and Granby River gauges using the USGS "expected moments algorithm" (EMA) to fit the Log-Pearson Type III distribution. The EMA approach allows a hydrologist to input less precise information about floods outside of the standard period of record to help improve a flood frequency analysis (Cohn et al., 1997; England Jr et al., 2019). In practice with EMA, the assumption that has influence on the frequency analysis is the lower bound, that 1894 was at least as big as 2018. As is advised in the USGS bulletin 17C, the multiple Grubbs-Beck test was used to screen low outliers from the gauge data (Cohn et al., 2013).

Frequency curve fits are shown for the Granby River in Figure 5.1 and the Kettle River at Ferry in Figure 5.2. For the Granby gauge, the 2018 flood is flagged as a high outlier, though not removed from the fit. For the 08NN013 gauge, the 1894 flood is shown as a range rather than a single observation (described in Section 4.1).

The log pearson type III distribution is a three-parameter distribution; that is, three parameters describe the shape of the curves in Figure 5.1 and Figure 5.2. The mean is the first parameter and describes the vertical position of the black line in these figures. The variance (or in some cases standard deviation) describes the slope of the line. The third parameter, skew, describes the curvature of the line. A distribution with skew of 0 would appear as a straight line on the supplied scale and be equivalent to a lognormal distribution. A negative skew is curved downwards, and a positive skew is curved upwards. The skew value has large implications for estimates at high return periods. With a positive skew, the difference between a 500-year and 100-year flow estimate would be much larger than for a distribution with a negative skew.

The skew parameter has been found to have regional organization. For the Bulletin 17B flood frequency guidelines (USGS, 1982), the USGS provided regional skew maps which recommend a skew adjustment for gauges with short periods of record. In the updated bulletin 17C, the USGS provided adjustment recommendation methods by region; they recommended a region wide skew adjustment for the entire Pacific Northwest of the United States of -0.07 (Mastin et al., 2016).

In general, in BC, NHC has found a tendency towards positively skewed distributions nearer the coast, where rain-on-snow and midwinter flooding is possible. In more arid interior BC watersheds, where flooding most often occurs in the spring, the skew value tends to be closer to 0 or slightly negative (NHC, 2021). In these results, the skew value for 08NN002 was -0.15 and for 08NN013 it was -0.08.

Results at select return periods are shown in Table 5.1. In this table, the 1000- and 5000-year return period results are also shown as they were used for model sensitivity testing. However, the reader should interpret these values with caution, as the uncertainty between magnitude and average recurrence interval rapidly increases for evaluation of more extreme events. There is considerably higher uncertainty in these extrapolations than even a 100- or 200-year flow estimate, which already have substantial uncertainty (shown in grey bands in frequency analysis figures).

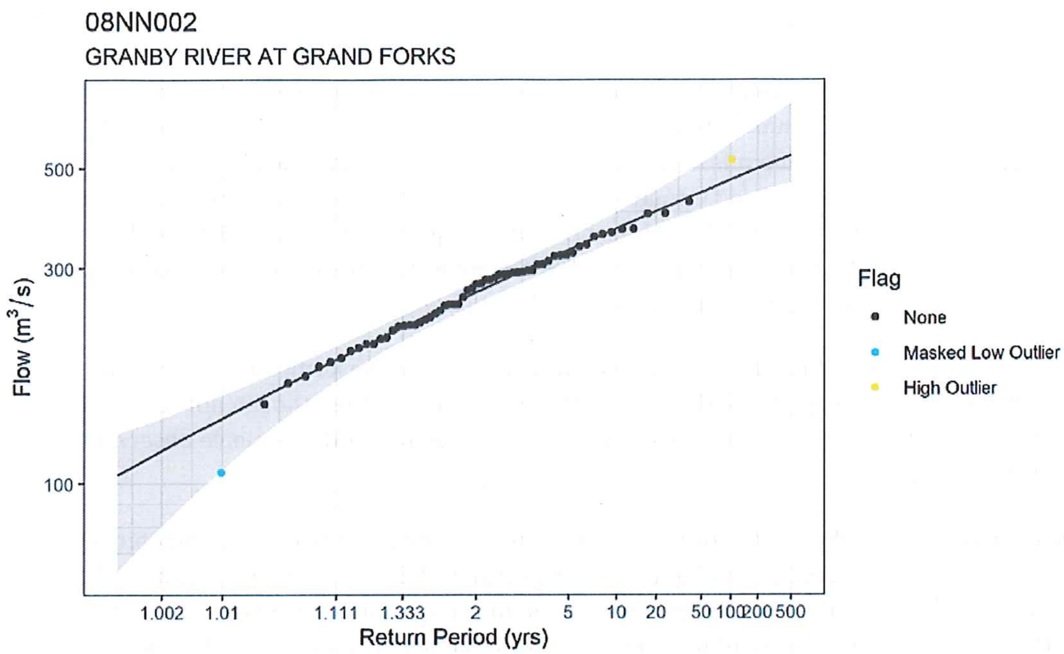

Figure 5.1 Log-Pearson type III frequency analysis for WSC gauge 08NN002 – Granby River at Grand Forks.

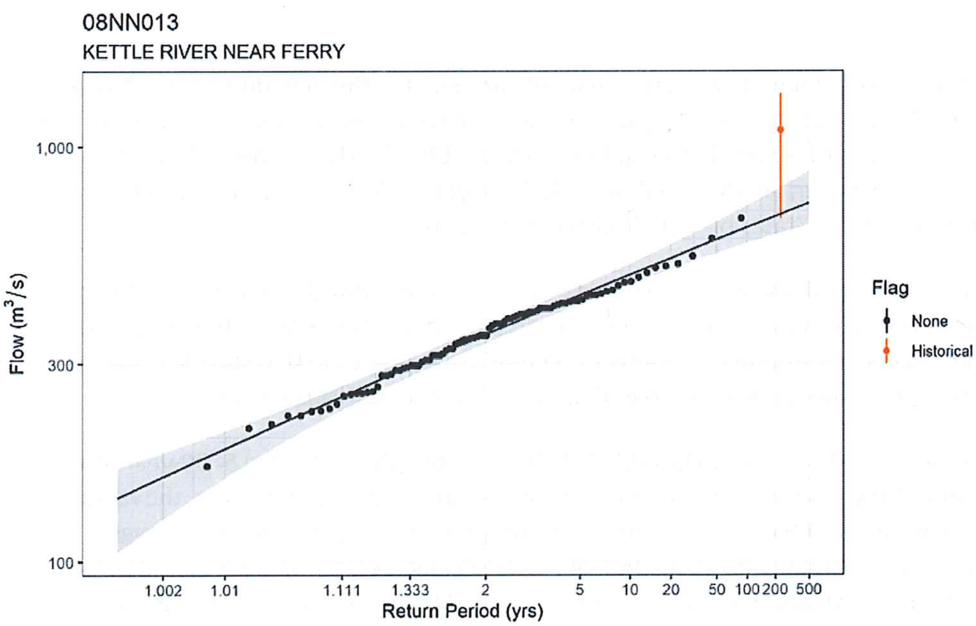

Figure 5.2 Log-Pearson type III flood frequency analysis for WSC gauge 08NN013 – Kettle River near Ferry. The USGS expected moments algorithm was used to incorporate information about the 1894 flood on the Kettle River (orange).

Table 5.1 Instantaneous design flow estimates (QPI, m^3/s) for the present day for WSC gauges 08NN002-Granby River at Grand Forks and 08NN013 – Kettle River near Ferry. The 2018 flood peak flow is shown for comparison.

Return Period/Event	08NN002	08NN013
2-year	266	353
5-year	330	439
10-year	368	491
20-year	401	539
50-year	442	597
100-year	471	638
200-year	499	678
500-year	534	730
1,000-year	560	769
5,000-year	618	856
May 10 2018	521	671

6 Future Peak Flows and Climate Change

Peak flows on the Kettle River are dominated by the spring snowmelt, with the most extreme flows augmented by spring rainfall. Existing regional studies and data were reviewed to understand the projected impacts to temperature and precipitation within the region:

- A study of the Kootenay/Boundary Region within British Columbia (PCIC, 2013) using 30 global climate model projections indicates that temperature is expected to increase throughout all seasons, with the greatest increase during summer months. The annual precipitation is expected to increase by about 5% by 2050, with a greater increase (8%) in the winter and a decrease (-6%) in the summer months. The increase in temperature results in a decrease in snowfall of 5% in the winter months and 48% in the spring months. However, colder, and high elevation regions may see an increase in snowpack due to the increase in precipitation. More intense precipitation extremes including rain-on-snow events are expected. Projections for the end of century include greater warming and a greater overall precipitation increase of 15%.
- The IDF-CC Tool, provides climate change projections to intensity duration frequency (IDF) curves at Environment Canada climate stations using an ensemble of global climate models (UWO, 2022). For the end of century, the 24-hour precipitation at Grand Forks is expected to increase by 10% under both the RCP 4.5 and 8.5 scenarios.

The expected changes to temperature and precipitation in the region, will impact the peak flow regime of the Kettle River. In general, the combination of warmer temperatures and greater precipitation mean that peak flows may shift earlier in the year, with a decrease in the amount of snowmelt generated peak flows. There is also the potential for more rain-on-snow events in the spring and rain driven peaks in the fall and winter.

It is uncertain how the competing factors will tip the total balance of peak flows. Lower winter snowfall may result in smaller peak flows, but potential for more intense rainfall and mid-winter warming periods may result in larger peak flows. Hydrologic modelling is the best approach to disentangle these numerous processes, and a number of modelling studies have been carried out on the Kettle River to assess the hydrologic impacts of climate change on the river.

A hydrologic modelling study of the Kettle River (from the headwaters through Grand Forks) was carried out by Associated Engineering (AE) (2021) which extended a model developed in the Raven hydrologic modelling platform (Craig et al., 2020) for the entire Kettle River watershed (Chernos et al., 2020). The extended model used the BCCAQv2 - PNWNAmet Bias-corrected Downscaled Global Climate Model Dataset[2] from the PCIC to make model projections from 1949 to 2099 for the Kettle and Granby Rivers using both the six different climate models and two different carbon pathways (RCP 4.5 and 8.5). Associated Engineering granted the use of the model outputs from the 2021 study for analysis in this work.

In addition to the AE Raven modelling, modelled streamflow data under 12 climate scenarios is available from PCIC (PCIC, 2020) for the Kettle River near Ferry and the Granby River at Grand Forks. NHC analyzed the PCIC VIC model data in a similar manner and found very similar results to the AE Raven study. As such, only the AE Raven results are presented here.

6.1 Climate Model Analysis

We first extracted annual peak flows from the AE Raven model results for each of the 12 different climate model runs. As the model ran on a daily time step, the annual peak flows represent mean daily values (QPD); however, the relationship between QPD and QPI appears quite stable for these watersheds (Figure 4.1).

We extracted QPD values for the Kettle River near Ferry (Figure 6.1). This figure shows two-dimensional histograms of QPD values; binned in 5-year increments. As colors trend from blue to yellow, the frequency of occurrence increases. Additionally, a loess smoothed line shows the general trend for of mean annual flood for the subbasins. The modelled trend of QPD values appears to be moving generally downward; that is modelled peak flows appear to be gradually decreasing over time. This result makes physical sense for a snow dominant watershed such as the Kettle River; as winter snow accumulation decreases, we would expect a smaller spring freshet.

[2] https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios

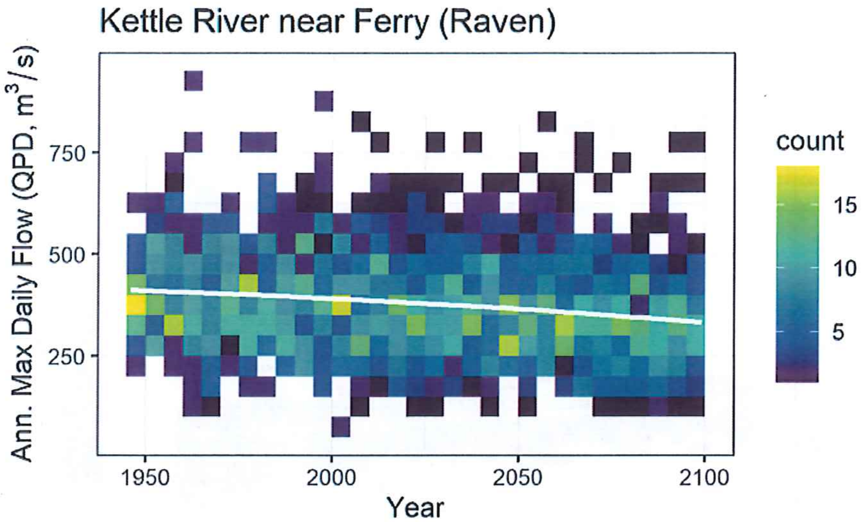

Figure 6.1 Change in annual peak flow (daily average flow) over time from the Raven hydrologic model developed in AE (2021) for the Kettle River near Ferry shown as a two dimensional histogram. Lighter colors indicate more frequent occurrence. The white line is the smoothed median value.

Along with checking the change in magnitude of the annual peak flow, we investigated the change in the date of peak flow over time, again for the 12 combinations of climate model and carbon pathway for 1949 to 2099. These results are shown in Figure 6.2. As one might expect, the peak flow for the year gradually occurs earlier over time, trending from ~125 (mid May) to 100 (mid April).

Though this was expected, the more concerning model result is the occurrence of peak flows outside of the normal freshet period (~DOY 300 or later). These are the outlier purple occurrences; they represent mid-winter rain or rain-on-snow events. This type of mid winter melt event has thus far not occurred on the Kettle River; however, the model results indicate that it may become possible (though still unlikely) in the future.

Figure 6.1 shows that even if the timing of the peak flows become drastically different, the magnitude is not expected to increase. However, there are still concerns with moving into a regime with the potential for mid-winter peak flow events.

First, it is unlikely that the AE Raven model is particularly adept at modelling the magnitude of rain-on-snow melt on the Kettle River. The snowpack energy balance of rain-on-snow melt is substantially different than that of a typical spring freshet (Marks et al., 1998; Trubilowicz and Moore, 2017), and there has never been a winter rain-on-snow event on the Kettle River to calibrate against. Thus, we should not trust in the accuracy of the winter flood magnitude predicted by the AE Raven model.

Second, even if the AE Raven model predicts the mid-winter flood magnitudes accurately, there are practical implications for peak flows occurring at different times of year than what is typically expected. Flood preparations focus around the spring freshet event; forecasting is focused on the spring melt, and preparations for the public (e.g. sandbag availability) is set for reaction in the spring in the region. A flood that occurs at a different time would potentially catch the public and governments off-guard.

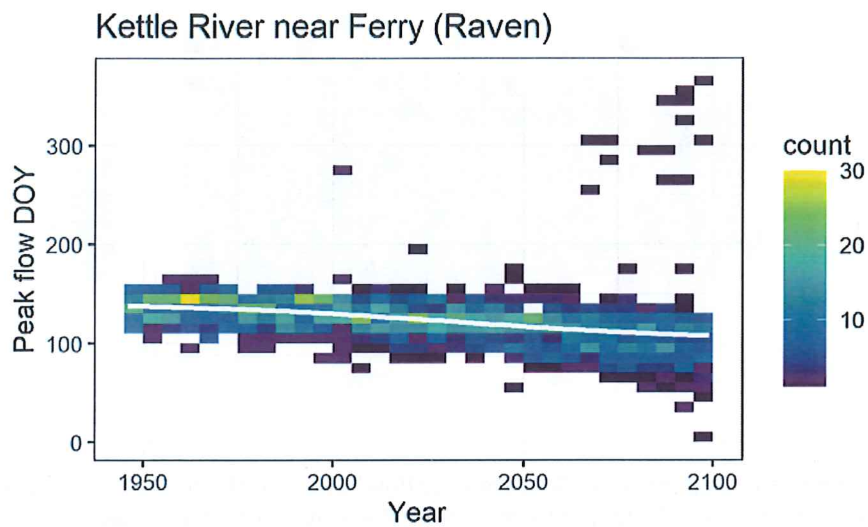

Figure 6.2 Change in day of year of peak flow over time from the Raven hydrologic model developed in AE (2021) for the Kettle River near Ferry shown as a two dimensional histogram. Lighter colors indicate more frequent occurrence. The white line is the smoothed median value.

6.2 Skew Adjustment

As described in Section 5, watersheds that can experience peak flows in both winter and during the spring freshet tend to have higher skew values than more arid interior BC watersheds. Additionally, NHC (2021) found that the most extreme floods in BC tended to be winter rain-on-snow floods, a result that agrees with the understanding of different types of flooding in hydrology research (McCabe et al., 2007).

Though climate model results do not show an increase in the mean annual flood for the Kettle River, the shift towards a possibility of winter peak flows means that an adjustment in skew for future conditions is the most appropriate climate change adjustment to the design flows. In practice, adjusting skew rather than adjusting by a constant percentage will result in smaller changes to lower return periods (e.g. 5- 10- 20- year) and larger changes to the higher return periods. This result is most appropriate considering the modelling results, spring peak flows may decrease, while very extreme winter peak flows may become possible.

We re-investigated the skew results from NHC (2021) to determine an appropriate skew adjustment to account for future conditions. We selected watersheds from the study with:

- A similar size (between 100 and 1000 km^2) as the 08NN002 and 08NN013 gauges

- A similar ratio of winter to spring peak flows (15 to 25%) as the future projections (from 2050-2100) for the Kettle and Granby River

From this subset of results, we found a (rounded) median skew value of 0.5 for the 1-day peak flow distributions. We then replaced the log pearson type III distribution with a skew value forced to 0.5 for both the Granby and Kettle Rivers. Results of these skew adjusted frequency analysis fits are shown in Figure 6.3 and Figure 6.4.

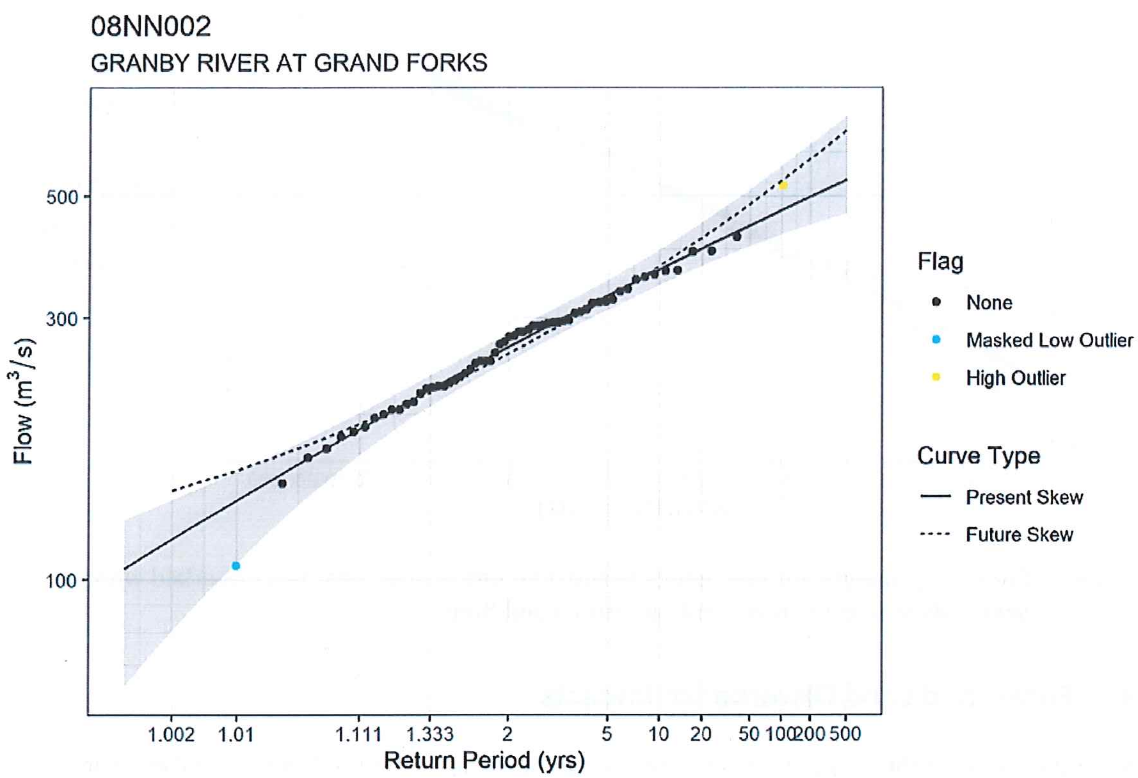

Figure 6.3 Frequency analysis for WSC gauge 08NN002 – Granby River at Grand Forks overlaid with the skew-adjusted curve representing future conditions.

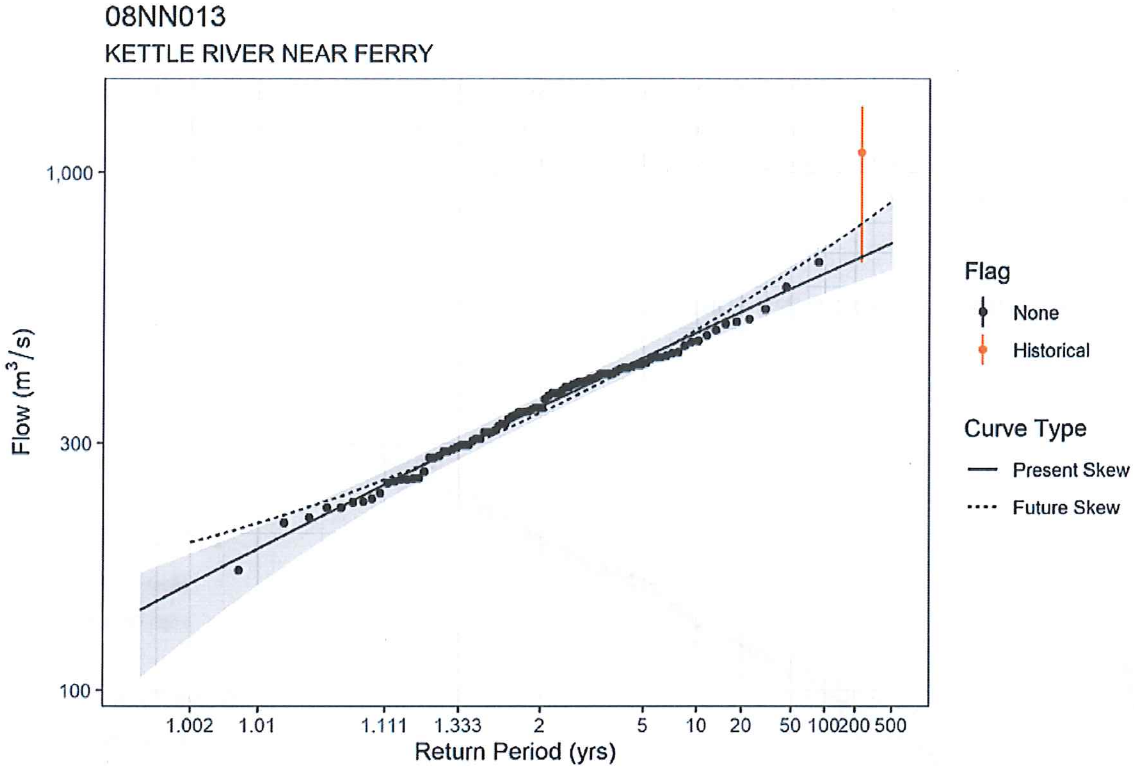

Figure 6.4 Frequency analysis for WSC gauge 08NN013 – Kettle River near Ferry overlaid with the skew-adjusted curve representing future conditions.

6.3 Forest and Land Disturbance Impacts

Climate change is not the only potential future change impacting the Kettle River watershed. Forest harvesting and disturbance (due to wildfires, insect infestation, etc.) has the potential to impact the hydrology of these watersheds in the next century. These potential changes have been investigated through hydrologic modelling by Chernos et al. (2020). They found an increase of 3-6% for the 100-year peak flows within the Kettle River watershed. As we recommend the EGBC (2018) minimum increase of 10% to peak flow adjustments, no further increase adjustment is necessary.

6.4 Future Design Flows with Climate Change

The recommended design flow adjustments for gauges 08NN002 and 08NN013 are shown in Table 6.1. Skew adjustments that resulted in changes less than 10% were capped at a 10% minimum, as recommended by EGBC (2018).

Table 6.1 Climate change adjustments to the design flow estimates (QPI, m³/s) for the present day for WSC gauges 08NN002-Granby River at Grand Forks and 08NN013 – Kettle River near Ferry. Peak flow increases of less than 10% from the skew adjustment were left at 10%, the minimum increase recommended by EGBC.

Return Period	08NN002		08NN013	
	% Increase	Design flow	% Increase	Design flow
2-year	10	293	10	388
5-year	10	363	10	483
10-year	10	404	10	541
20-year	10	442	10	592
50-year	10	487	10	656
100-year	13	533	12	713
200-year	17	585	15	783
500-year	23	658	21	880

7 Scaling Peak Flows to Model Reach

Previous NHC work explored regionalization of flood frequency analysis for hydrologic regions in BC (NHC, 2021). The results of this work found that the Kettle River watershed resides in a hydrologically heterogenous region and does not support area-based scaling well. For this reason, the WSC Kettle River at Ferry gauge was not scaled to the upstream extent of the study reach to inform model inflows. Alternatively, a watershed balance was completed to inform the approach for transferring frequency analysis results to model points of inflow.

7.1 Watershed balance

The Kettle River at Ferry gauge is approximately 42 km upstream of the model upper boundary. Tributaries between the Kettle River at Ferry gauge and the upper model boundary include Toroda Creek, Curlew Creek and several small tributaries (Figure 7.1). The Kettle River at Laurier gauge is approximately 8 km downstream of the model extent and encompasses inflows from the Granby River and Christine Lake watershed. Watershed areas for tributaries is presented in Table 7.1.

A watershed balance examined whether the sum of the Kettle River at Ferry (08NN013) and Granby River (08NN002) gauges represented flows at the downstream Kettle River near Laurier gauge (08NN012). Table 7.2 presents a subset of the watershed balance for five historic large floods. The summation of the flows for 08NN013 and 08NN002 is both higher and lower then flows at the 08NN012 for various years. This may be due to uncertainty associated with rating curve extrapolation, lack of coincidence of flood peaks and flow contributions from the Christina Lake watershed.

A review of the flood hydrographs for the Grandy River and Kettle River at Ferry WSC gauges confirmed that the timing of flood flows on these two systems do not coincide. The Granby River typically peaks prior to flows on the Kettle River as seen during the May 2018 flood event (Figure 7.2). Furthermore, the hydraulic model was used to estimate routing of flood flows from the Kettle River at Ferry WSC gauge to the confluence of the Granby and Kettle Rivers. Results showed that, at the confluence, the Kettle River may peak up to 9 hours after the Granby River (Figure 7.3). This is reflective of routing characteristics for smaller (Granby) versus larger (Kettle) watershed drainage areas. We also assumed that inflows of Toroda Creek, Curlew Creek and smaller tributaries will not coincide with timing of peak Kettle River flows.

Basin characteristics of Toroda Creek, Curlew Creek and smaller tributaries upstream of the model boundary were reviewed to determined potential flow contributions for model input. No historic gauge data is available for Toroda Creek, Curlew Creek and the smaller tributaries. Toroda Creek and Curlew Creek watersheds lie within the rain shadow of the Cascade Mountains. This area of northern Washington, east of the Cascades, encompasses the Okanagan Highland ecoregion. The Okanagan Highland ecoregion is one of the hottest and driest in Canada. The Toroda Creek and Curlew Creek watersheds lie within the Okanagan Highland ecoregion and have semi-arid climates.

In previous work, (NHC, 2022a) NHC found that Myers and Rock Creek contribute approximately between 1-3 percent of the flow to the Kettle River at Ferry gauge. Rock Creek and Myers Creek are immediately adjacent drainages to Toroda Creek and Curlew Creek, also fall in the Okanagan Highland ecoregion, and serve as representative proxy watersheds (Figure 7.1). Mean annual precipitation values for select tributaries is presented in Table 7.1. Due to similar physiographic processes, drainage areas, and mean annual precipitation, it is assumed that Toroda Creek, Curlew Creek and smaller tributaries will also have small contributions to the Kettle River flow (less then 5 percent). Even though the cumulative watershed area of Toroda Creek, Curlew Creek and smaller tributaries is approximately 14 percent of the Kettle River study basin, watershed area is not always representative of flow contribution in this ecoregion. Tributaries on the south side of the Kettle River in the Okanagan Highlands have relatively low flow contributions compared to tributaries on the north side such as the Granby River due to differences in physiographic characteristics. The Granby River watershed receives twice the annual precipitation compared to that of Curlew, Toroda, Rock and Myers Creek.

In summary, inflows from Toroda Creek, Curlew Creek and smaller tributaries were not added to the Kettle River at Ferry gauge to estimate inflows at the upstream model boundary based upon the following rationale:

- These watersheds potentially provide a relatively small contribution of flow to the Kettle River due to their different physiographic process. They are in the Okanagan Highland ecoregion and have semi-arid climates.
- Routing analysis of the Kettle River system supports the assumption that smaller tributary inflows do not coincide with the flood peak on the Kettle River. It may be overly conservative to add tributary inflows to the flood hydrograph at the upstream model boundary.

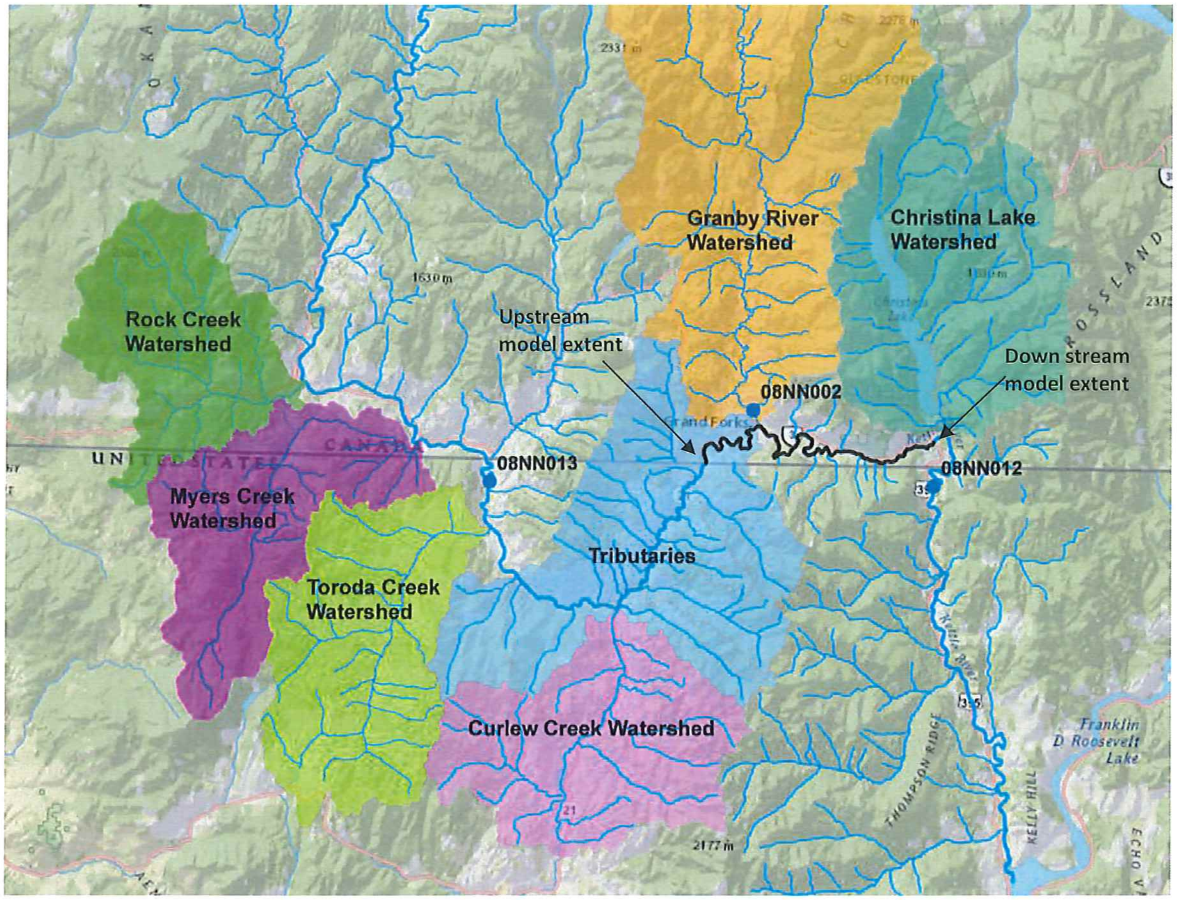

Figure 7.1 Grand Forks to Cascade Falls study reach and relevant tributaries.

Table 7.1 Summary of watershed areas and mean annual precipitations (MAP) for contributing reaches in the study area.

	Kettle River study basin	Rock Creek watershed	Myers Creek watershed	Toroda Creek watershed	Curlew Creek watershed	Unnamed tributaries	Granby River watershed	Christina Lake watershed
Area (km^2)	9,311	303	328	421	400	512	2,061	523
MAP (mm)	-	453	380	-	373	-	736	778

Table 7.2 Instantaneous discharge (m^3/s) for WSC gauges during the five large floods.

Date	Data	08NN013 Kettle River near Ferry	08NN002 Granby River at Grand Forks	Sum of 08NN013 + 08NN002	08NN012 Kettle River at Laurier
June 1, 2020	QPI	521	352	873	878
May 10/11, 2018	QPI	671	521	1192	1373
May 6/7, 2017	QPI	544	366	910	934
May 21, 2006	QPI	510	396	906	858
May 16/17, 1997	QPI	496	397	893	872

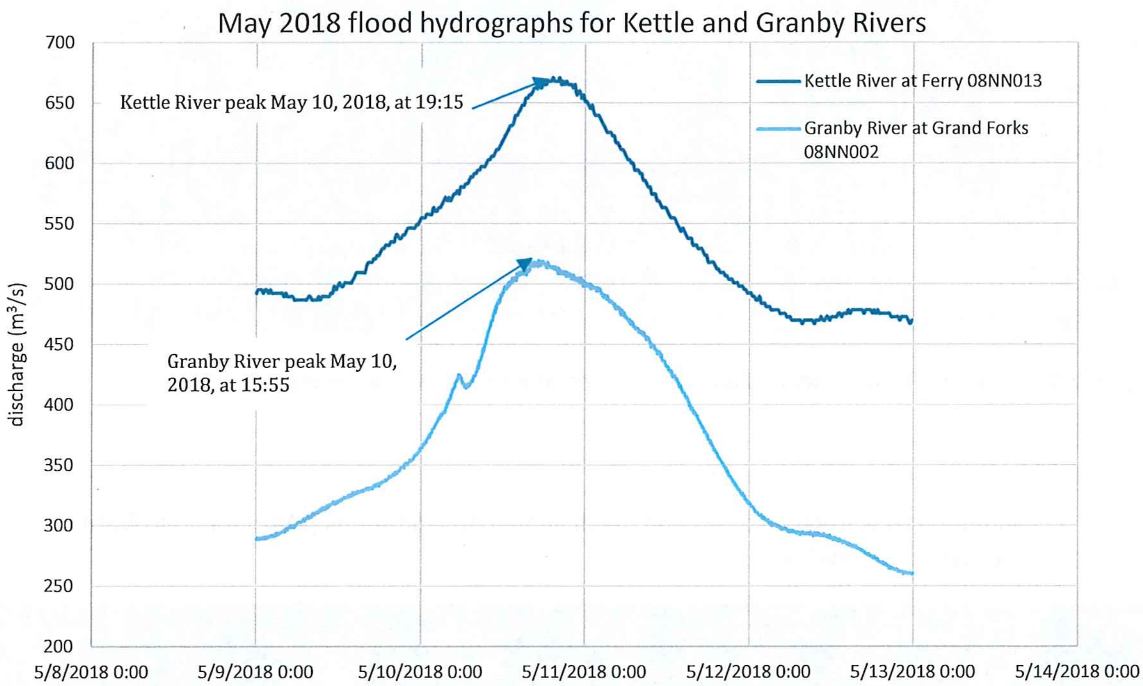

Figure 7.2 Comparison of flood hydrographs for the Kettle and Granby River WSC gauges for the May 2018 flood event.

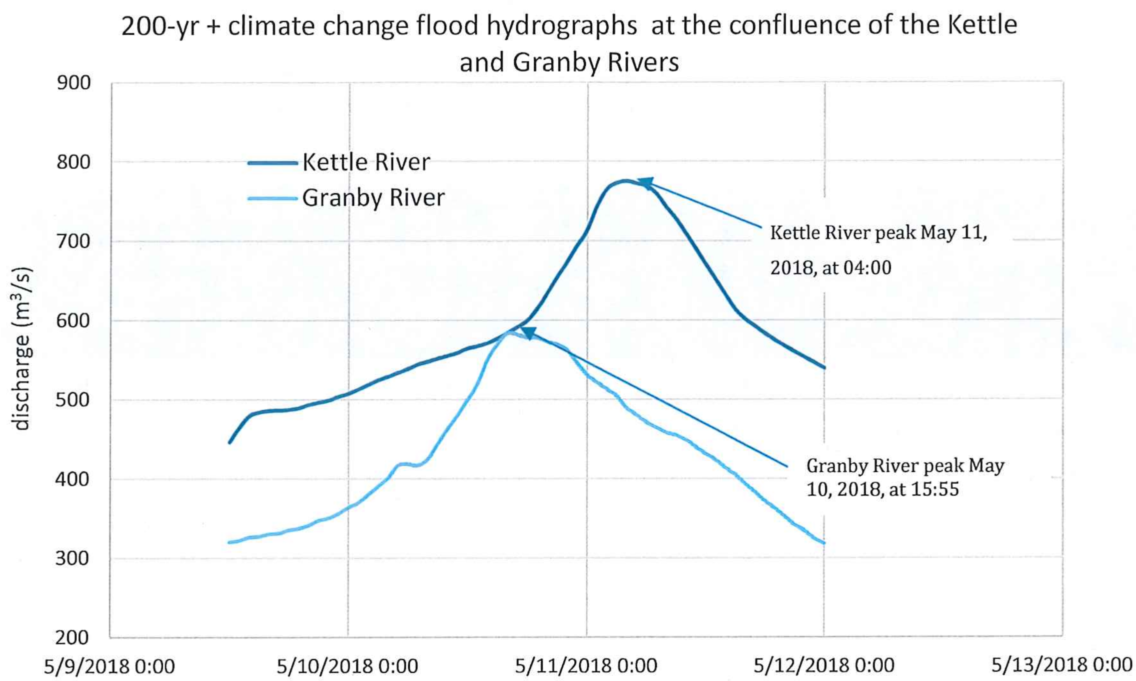

Figure 7.3 Comparison of flood hydrographs for the Kettle and Granby Rivers for the 200-yr + climate change flood event. Flood hydrographs represent timing of flood flows at the confluence of the Granby and Kettle Rivers.

7.2 Model Inflows

Results from the watershed balance identified that the Kettle River at Ferry gauge was most representative of the flows at the upstream model boundary. Frequency analysis results for the Kettle River at Ferry gauge were transferred directly to the model point of inflow. Frequency analysis results for the Granby River gauge were input as a change in flow in the modelling platform. For model simulations of design scenarios, synthetic flood hydrographs were developed with the assumption that the flood hydrograph shape follows that of a recorded WSC hydrograph shape. The May 2018 flood hydrograph was scaled for the 200-year design flow event. The 2018 flood hydrograph was selected as it represents a larger flood event for the watershed and the hydrograph shape is that of a single peak (versus double peak hydrograph).

The hydraulic model was used to estimate routing of flood flows from the Kettle River at Ferry WSC gauge to the model upstream boundary. Results showed that, under flood conditions, it takes approximately 7 hours for flows to travel from 08NN013 to the upstream boundary. Kettle River inflow hydrographs were based upon the May 2018 WSC hydrograph for 08NN013, however the hydrograph timing was adjusted to represent inflows at the model boundary rather than that of the WSC gauge. Adopted design flows for model input are presented in Table 7.3.

Table 7.3 Adopted design flows for model input for the Grand Forks to Cascade Falls study reach. Peak flow increases of less than 10% from the skew adjustment were left at 10%, the minimum increase recommended by EGBC.

	Kettle River			Granby River		
Return Period/Event	Present Day	Climate Change		Present Day	Climate Change	
	Discharge (m^3/s)	Discharge (m^3/s)	% Increase	Discharge (m^3/s)	Discharge (m^3/s)	% Increase
20-year	539	592	10	401	442	10
200-year	678	783	15	499	585	17
May 10, 2018	671			521		

DISCLAIMER

This report has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of **Regional District of Kootenay Boundary** for specific application to the **hydrologic analysis to support the flood mapping for Kettle River between Grand Forks and Cascade Falls.** 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 engineering and geoscience practices.

Despite these efforts, actual flood levels and extents may vary from those reported. Northwest Hydraulic Consultants Ltd. and Regional District of Kootenay Boundary deny any liability whatsoever to other parties who obtain access to this report, for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents.

Report prepared by:

Joel Trubilowicz, PhD, P.Eng.
Environmental Data Scientist

Faye Hirshfield, PhD, P.Ag.
Hydrologist

Report reviewed by:

Dale Muir, M.Eng., P.Eng.
Principal

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