Exploring Hydrologic Extremes in the Nicola River Watershed: Weaving Science and Traditional Knowledge Together

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ABSTRACT

Floods and droughts can adversely impact ecosystems and communities and are projected to intensify under climate change. The Nicola River watershed in British Columbia has experienced historic and recent hydrologic extremes, notably in November 2021. However, the limited understanding of the local weather and climatic drivers of past events has hindered understanding the future of the region.

Floods and droughts have occurred since time immemorial. However, western science is limited by written observations of weather and hydrometrics. To address this issue, we connected with local Indigenous communities to listen to and learn community stories to extend the spatial and temporal extent of the observation record.

These stories fed into quantitative analyses, for which we first developed a conceptual model comprising several drivers and modulators of floods and droughts. Drivers are the weather and climate processes that trigger floods or droughts (e.g., heavy rainfall). Modulators are the local watershed characteristics that can affect or amplify these conditions (e.g., watershed physical characteristics, land use changes, etc.). Then, we identified the main drivers using statistical methods. Results suggest the Nicola River watershed encompasses various hydrologic regimes.

We used the findings of this statistical analysis in a climate change assessment to evaluate projected changes for different drivers at 1.5°C and 4°C global warming levels. The main drivers of hydrologic extremes relate to snow and temperature processes. Rainfall is another important driver depending on the hydrologic regime. These main drivers could undergo considerable changes in a warming world. Our findings can support decision makers to better understand risks from floods and droughts under the changing climate to inform adaptation actions.

KEYWORDS: Flood, Drought, Hazard drivers and modulators, Correlation analysis, Climate change, Traditional Knowledge, Place-based knowledge

1 INTRODUCTION

Floods and droughts profoundly impact sectors such as water, ecosystems, and infrastructure. These events arise from complex interactions between hydrology, meteorology, and land surface features. Floods are often triggered by heavy rainfall, snowmelt, and/or high antecedent soil moisture, while droughts are linked to prolonged periods of low precipitation (Rezvani et al., 2023).

Flooding is Canada's most costly natural hazard. The Nicola River Watershed (NRW) in British Columbia is particularly susceptible to both floods and droughts. This area is home to the Scw̓ʼéxmx (People of the Creeks). Historically, the watershed has experienced freshet, as well as flooding in fall, and winter. A recent, devastating flood followed an atmospheric river in November 2021 (City of Merritt, 2024). The region is also prone to drought, such as the event in 2019 caused by low snowpack and a dry summer (McCleary, 2019).

A limited understanding of the local drivers of past events hinders preparation for future extremes. Climate change is expected to intensify the hydrologic cycle, making this understanding crucial. To address this, we examine the *drivers* and *modulators* of these events (Jiang et al., 2024). Drivers are the weather and climate processes that trigger floods or droughts. Modulators are the local watershed characteristics that can affect or amplify these conditions (e.g., watershed physical characteristics, land use changes, etc.).

Conventional quantitative analyses are limited by short observational records, typically 50-70 years. This makes evaluating rare, extreme events difficult. Furthermore, sparse data collection fails to capture the physical and environmental diversity across the NRW. To address these limitations, we incorporate place-based knowledge, from Indigenous communities. These narratives extend the historical record and provide a nuanced, hyper-local understanding of past events.

This project integrates place-based knowledge with quantitative methods. Our objective is to identify the dominant drivers of floods and droughts in the NRW. We then use these findings to assess how climate change may influence future conditions in the watershed. This combined approach provides a more comprehensive understanding of hydroclimatic extremes.

The structure of this paper is as follows: Section 2 introduces the study area and the datasets used, followed by a summary of the methods and limitations in Section 3. Results are presented and discussed in Section 4, and the study conclusions and recommendations are provided in Section 5.

2 STUDY AREA AND DATA

2.1 Study Area

The Nicola River watershed covers approximately 7,183 km² on the southwestern edge of BC's Interior Plateau (Figure 1). Its landscape includes rolling hills, pine forests, the Cascade Mountains, and four large lakes. The area is composed primarily of forest (75%) and grassland (11%) (Agriculture and Agri-food Canada, 2023).

The climate is arid, a result of the watershed's high altitude and its position in a rain shadow (Nicola WUMP Multi-Stakeholder Committee & Compass Resource Management, 2010). This leads to hot summers and cold winters. Average mean temperatures range from -3.9°C in January to 18.9°C in July. April is the driest month (15 mm), while December is the wettest (38 mm).

Streams in the watershed exhibit nival and mixed hydrological regimes (Figure 1). Nival regimes have low winter flows followed by a high spring freshet. In contrast, mixed regimes experience spring freshet in addition to high flows from fall and winter rainfall (Figure 2).

2.2 Data

We obtained historical data for precipitation, air temperature, Snow Water Equivalent (SWE), streamflow, land cover, land use, and land disturbance (wildfire) from various government agencies (Figure 1). The datasets varied in temporal coverage and completeness. We conducted a quality assessment, retaining stations with at least 30 years of complete records over the 1969–2010 period. Years with fewer than 10 missing days were considered complete. Due to data gaps, records from two climate stations outside the watershed were also included (Kamloops and Kelowna as shown in Figure 1).

Future hydroclimatic projections were obtained from the Pacific Climate Impacts Consortium (PCIC). This dataset included an ensemble of six downscaled and bias-adjusted (using the Bias Correction/Constructed Analogues and Quantile mapping technique) Global Climate Models (GCMs) from the 5th Phase of the Coupled Model Intercomparison Project (CMIP5). Each GCM was paired with two radiative forcing scenarios: RCP4.5 and RCP8.5. We also used hydrologic simulations from the Variable Infiltration Capacity (VIC) model, which was forced with the GCM ensemble to project future SWE, and streamflow.

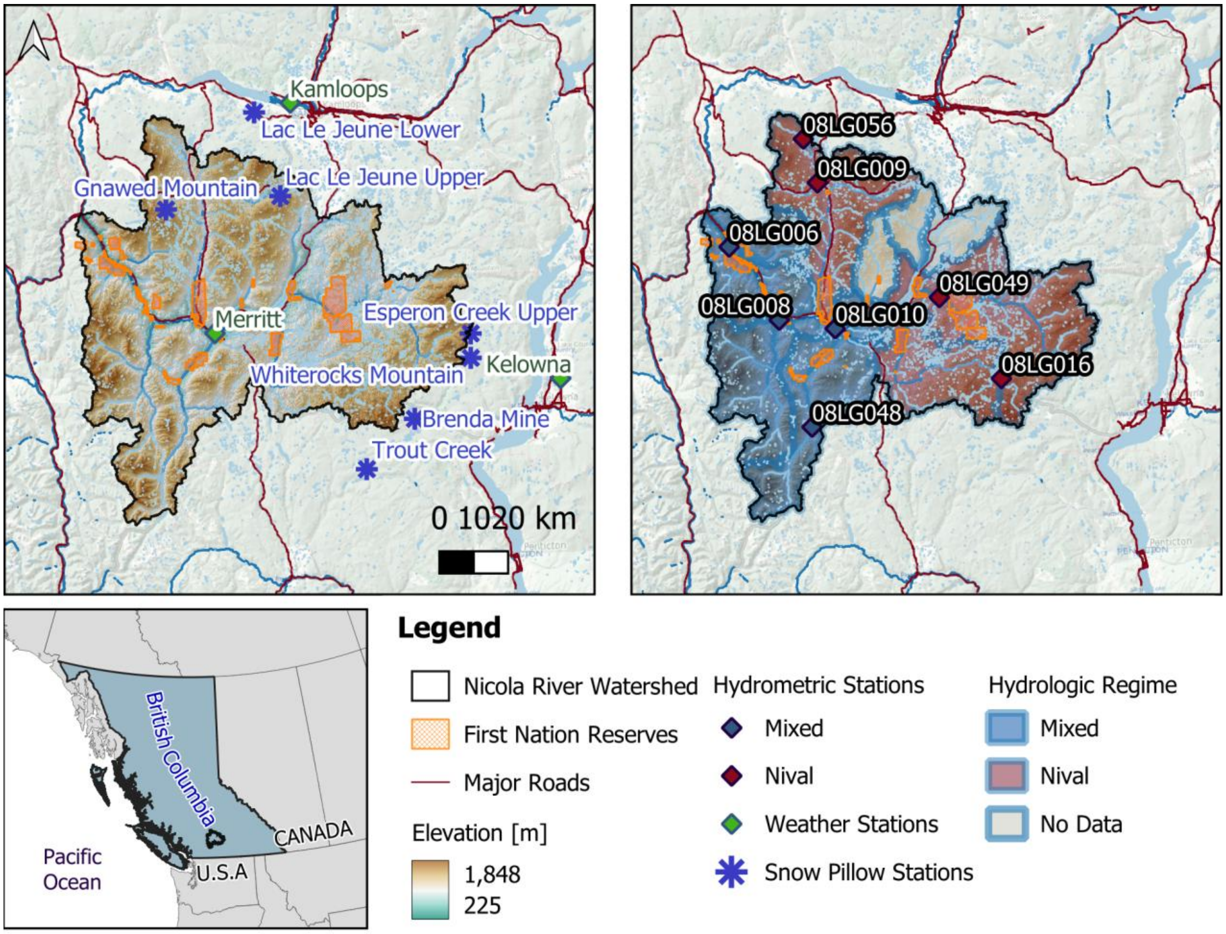

Figure 1: Location map of the Nicola River watershed, weather and hydrometric stations, and various hydrologic regimes in the watershed.

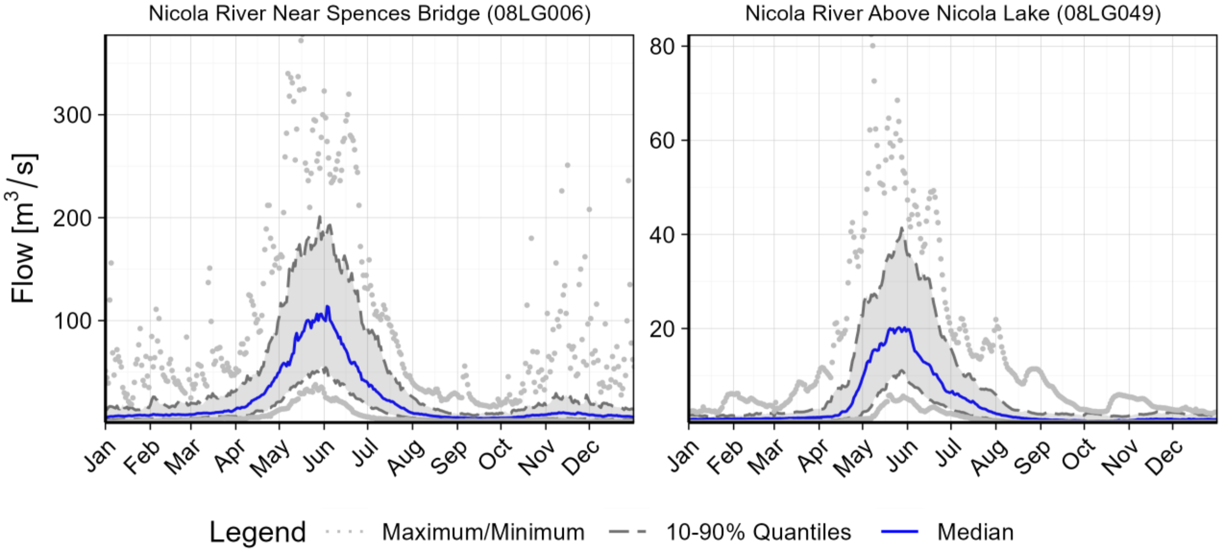

Figure 2: Example hydrographs of the creeks and rivers with mixed (left) and nival (right) hydrologic regimes in the Nicola River watershed (1969–2010).

3 METHODOLOGY

3.1 Identifying the Main Drivers of High and Low Flows

To identify the drivers of high and low flows, we conducted a correlation analysis similar to Curry and Zwiers (2018). This analysis assessed the relationship between seasonal high and low flow events and a set of hydroclimatic indices.

First, we defined seasonal flow events. Due to the watershed's seasonal hydrologic variability, we extracted the single highest and lowest streamflow for two six-month periods each water year: the *cold season* (October–March) and the *warm season* (April–September). This approach separates events generated by different processes, such as spring freshet and fall rainfall. These seasonal maxima and minima are distinct from hydrological floods or droughts, which are defined by sustained periods above or below a threshold.

Next, we defined several climatic indices to represent the hydroclimatic processes relevant to flood and drought generation (Table 1). The selection of these indices was informed by previous research and our understanding of the local hydroclimate.

Finally, we paired the seasonal high and low flows with each climatic index and used the nonparametric Spearman rank correlation to assess the relationship. The correlation coefficient indicates the strength and direction of this relationship. We tested these correlations for statistical significance at the 5% level, and only significant results are presented.

We classify the strength of correlations based on the coefficient value. Coefficients between 0 and ±0.2 are considered very weak. Values ranging from ±0.2 to ±0.4 are classified as weak. Correlations are moderate for values between ±0.4 and ±0.6. They are considered strong between ±0.6 and ±0.8. Finally, values from ±0.8 to ±1.0 indicate a very strong correlation.

Table 1: Climatic indices used to assess the importance of different driver groups on high and low flows in the Nicola River watershed.

Index	Description	Reference
Seasonal average temperature	Average of maximum daily temperatures over the season (warm or cold)	Dierauer et al. (2018)
Peak/Low Flow (PLF) rainfall	Total rainfall from X days before the seasonal peak/low flow to Y days after seasonal peak/low flow (see descriptions below)	Curry & Zwiers (2018)
Annual maximum snow	Annual maximum SWE	Curry & Zwiers (2018); Dibike et al. (2021); Jenicek et al. (2016)

3.2 Future Projections

We selected monthly values of air temperature, precipitation, and snowpack for analysis. This choice was informed by the correlation analysis that identified the key drivers of high and low flows in the watershed.

We report projected changes for these indicators at two Global Warming Levels (GWLs) of +1.5°C and +4°C, relative to the preindustrial era. We also use a 31-year baseline period of 1970–2000 as a reference for comparing past and future conditions. To ensure a consistent assessment, each GWL is defined for every model in our ensemble. A GWL is the centre of the first 31-year period during which the global mean temperature exceeds the target warming level. The timing for reaching each GWL varies between climate models and emission scenarios and is based on the ranges reported in Rezvani et al. (2023).

3.3 Traditional and Place-Based Knowledge

In this project, we applied the concept of knowledge weaving to combine the various knowledge systems (Henri et al., 2021; Indigenous Climate Hub, 2024). This approach has been applied to previous work of a similar nature in *Syilx* Territory (Ebbwater Consulting Inc. and Okanagan Nation Alliance, 2019). This integration ensures that management decisions are environmentally sustainable, culturally relevant, and socially acceptable to local communities (Berkes, 2017; Nicola Watershed Governance Partnership & POLIS Water Sustainability Project, 2024; Robinson et al., 2019).

3.4 Limitations

The datasets used and the methodology applied have several limitations. The climate and hydrologic models used (GCMs and VIC) are incomplete representations of reality and have known uncertainties. For example, our analysis indicates the VIC model tends to underestimate the magnitude of high flow events. Therefore, projections should be interpreted in terms of their direction and relative change rather than their absolute values. Furthermore, the daily timestep of the model does not fully capture sub-daily processes, meaning changes to instantaneous peak flows are likely greater than what is reported here.

The statistical methodology also has constraints. The correlation analysis used seasonal high and low flow values, which are not necessarily synonymous with hydrological flood or drought events. This approach was necessary to overcome methodological limitations but means the identified links are associative, not necessarily causative.

4 RESULTS AND DISCUSSION

4.1 Results

Figure 3 shows the correlation of the seasonal high/low flows in the NRW with annual maximum SWE, average of maximum temperature, and PLF rain.

The analysis shows that warm season high flows are strongly correlated with the annual maximum SWE. A moderate positive correlation also exists between SWE and warm season low flows (Figure 3). These findings mean a larger snowpack is associated with larger streamflows in the warm season. In contrast, SWE is negatively correlated with both high and low flows in the cold season. This may be because higher SWE indicates more water being stored as snow, resulting in less runoff during winter.

Warmer seasonal temperatures are negatively correlated with both high and low flows in the warm season (Figure 3). This means that warmer temperatures are associated with smaller streamflows during this period. The relationship is particularly strong for warm season low flows and is statistically significant at all assessed locations.

The results show a moderate positive correlation between short-term rainfall and cold season high flows in rivers with mixed regimes (Figure 3). This suggests that rainfall is a driver for high flows during this period. We also found a positive correlation between rainfall and cold season low flows. This indicates that larger rain events can lead to higher baseflows in winter.

The main drivers identified in the correlation analysis are projected to change in a warming climate (Figure 4).

Projections indicate seasonal changes in precipitation. Spring, fall, and winter are projected to become wetter, while summers are projected to be drier (Figure 4). Further, the precipitation regime is likely to shift from snowfall to rainfall, particularly between September and May (Figure 4).

Progressive decreases in SWE are projected across the watershed. This is due to reduced snowfall and increased snowmelt (Figure 4). The timing of peak SWE is projected to shift one month earlier, from March to February. Similarly, peak snowmelt is expected to shift from April to March. Consequently, snow-free periods may become longer by approximately one month.

These projected changes could impact the hydrologic regime (Figure 5). The annual peak flow, which occurs in May-June in the base period, is expected to shift to April-May, aligning with earlier snowmelt. The magnitude of this peak is projected to increase at the higher warming level (+4°C). Furthermore, extreme flows are projected to increase, with substantial changes in the fall (Figure 5). For example, at the +4°C warming level, the most extreme fall daily flow could increase from approximately 50 m³/s to 190 m³/s. This could indicate a greater likelihood of rain-on-snow events.

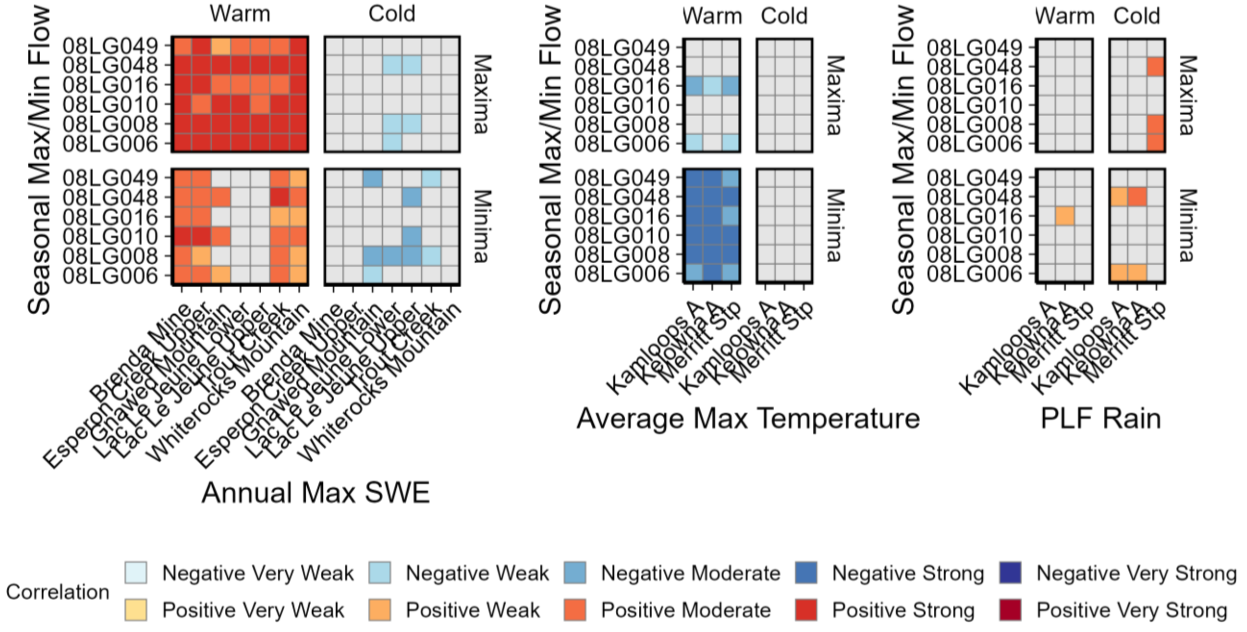

Figure 3: Correlation between snowpack (left), air temperature (middle), and rainfall (right) and seasonal high- and low-flow events (1969–2010). Squares are colored according to the correlation coefficient, with grey squares indicating correlations that are not statistically significant at the 5% level (p-value > 0.05).

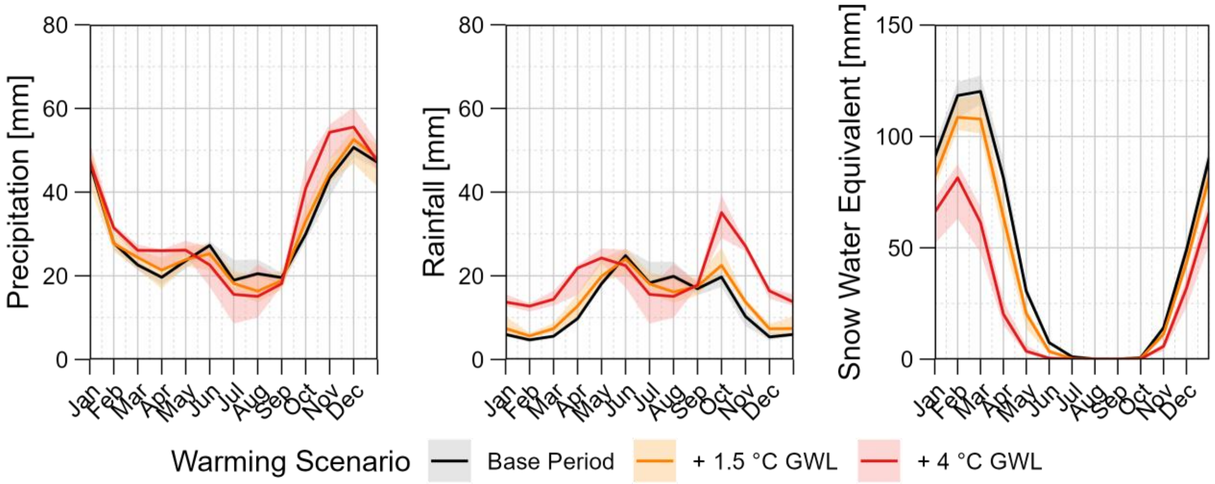

Figure 4: Monthly total precipitation (left), rainfall (middle), and Snow Water Equivalent (right) over the Nicola River watershed for the base period and future warming periods. Lines show the multi-model ensemble median, and the shading represents the ensemble's 80% confidence interval (ensemble's 10th - 90th percentiles range).

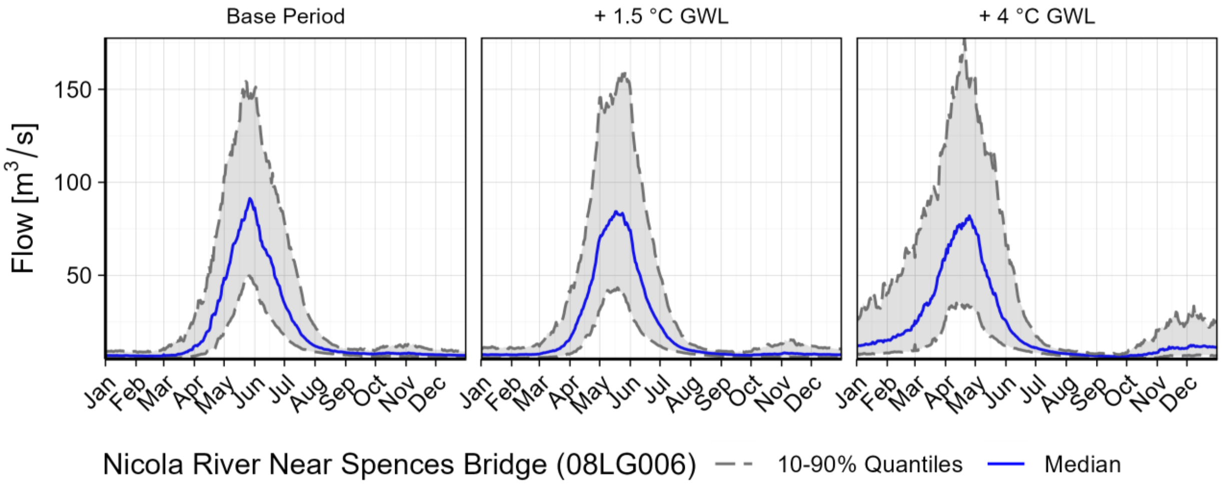

Figure 5: Projected daily hydrographs under warming scenarios at the Nicola River near Spencer Bridge hydrometric station based on daily simulations of the Variable Infiltration Capacity hydrologic model. For each day of the year, the multi-model ensemble's median and 80% confidence interval are presented.

Data gathering from place-based knowledge holders generally reflected the findings of the quantitative analysis. However, the qualitative research identified additional strong drivers of flood and drought, for which there was not adequate observed data to show a statistically significant correlation. Specifically, qualitative research identified the importance of land cover and land disturbance from anthropogenic activities (recreation, mining, etc.) and natural events (wildfire and mountain pine beetle infestations) as key drivers of change in hydrologic extremes.

4.2 Discussion

Our analysis shows that warmer summer temperatures are strongly correlated with lower summer flows. This suggests that cooler summers result in less evapotranspiration, which helps sustain streamflow. Precipitation patterns are also key drivers, with cold season rainfall linked to high flows and higher low flows. However, the strongest relationship identified is between annual maximum SWE and warm season flows. A larger snowpack results in both larger high flows during the spring freshet and more sustained low flows throughout the summer. Qualitative results, which are not repeatable with quantitative datasets due to sparse availability, highlight the importance of land disturbance as a key driver of meteorologic extremes.

Looking forward, climate projections indicate considerable changes for these drivers. Air temperature is projected to increase in all seasons, with the watershed warming at a higher rate than the global average. This warming will alter precipitation patterns, making fall, winter, and spring wetter while summers become drier. Further, a shift from snowfall to rainfall is also projected. This combination of wetter winters and existing snowpack increases the potential for rain-on-snow events, which can generate large floods. Despite increased winter precipitation, overall SWE is projected to decrease, especially at lower elevations.

These projected changes to temperature, precipitation, and snowpack will alter future streamflow patterns. The spring freshet peak is projected to shift approximately one month earlier. Increased fall rainfall will likely increase fall flows, shifting the river's hydrologic regime from nivo-pluvial to pluvio-nival. While the overall reduction in snowpack means that flood potential from snowmelt alone is likely to decrease in an average year, the risk of extreme floods will increase. The shift to rainfall, especially during years with high snowpack, heightens the risk of severe floods from rain-on-snow events.

Recognizing that climate change is largely outside the control of the communities in the NRW, the research identifies the importance of watershed stewardship to heal the land, and limit future land disturbance as a key tool to mitigate meteorologic extremes in the area.

5 CONCLUSION

The Nicola River watershed is vulnerable to floods and droughts. These hazards are expected to intensify with climate change. However, a limited understanding of the local drivers of past events hinders future preparedness. Therefore, this project used a two-pronged approach by weaving place-based knowledge with quantitative analyses to understand the historic, present, and future drivers of these hydroclimatic extremes. Our goal was to provide a local-level understanding of what climate change will mean for the region.

The technical analysis identified snowpack, temperature, and rainfall as the dominant local drivers of seasonal flows. The strongest relationship observed was between the annual maximum snowpack and warm season high and low flows. These key drivers are projected to undergo changes in a warming climate. Projections indicate a shift from snow to rain, a reduced overall snowpack, an earlier spring freshet, and more frequent rainfall-induced flooding in fall and winter. The qualitative analysis identified the importance of land cover and land disturbance as a key driver of meteorological extremes. Long-term watershed stewardship is identified as a pathway to mitigate this driver.

While the analyses are subject to data and methodological limitations, these findings provide a foundational understanding of future hydroclimatic conditions in the Nicola River watershed. The insights provide a basis for decisions that will support climate adaptation. Further work is required to build upon this analysis and continue to enhance the understanding of floods and droughts in the watershed.

6 ACKNOWLEDGEMENTS

The authors respectfully acknowledge the First Nations that have communities within the Nicola River watershed. These are the Coldwater Indian Band, the Lower Nicola Indian Band (LNIB), the Upper Nicola Band, the Nooaitch Indian Band, and the Shackan Indian Band.

The funding support for this project came from the Scw'exmx Tribal Council (STC), Indigenous Services Canada (ISC), and First Nation Adapt (FNA). The authors wish to thank the STC project manager, Neil Todd, who provided support throughout. Additionally, the authors wish to acknowledge the effort and resources provided by the steering committee including Robin Fenn, Susan Anderson Behn, Tom Duncan, Dylan Forrest, Brent Baron, Muhammad Naveed Khaliq, Sarah Simon, and Jeptha Ball.

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