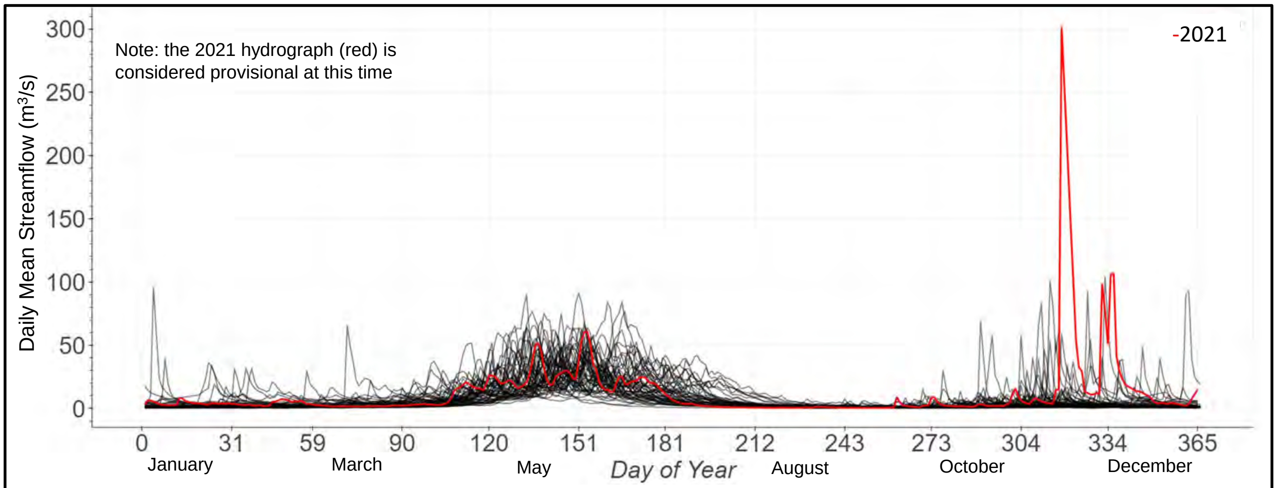


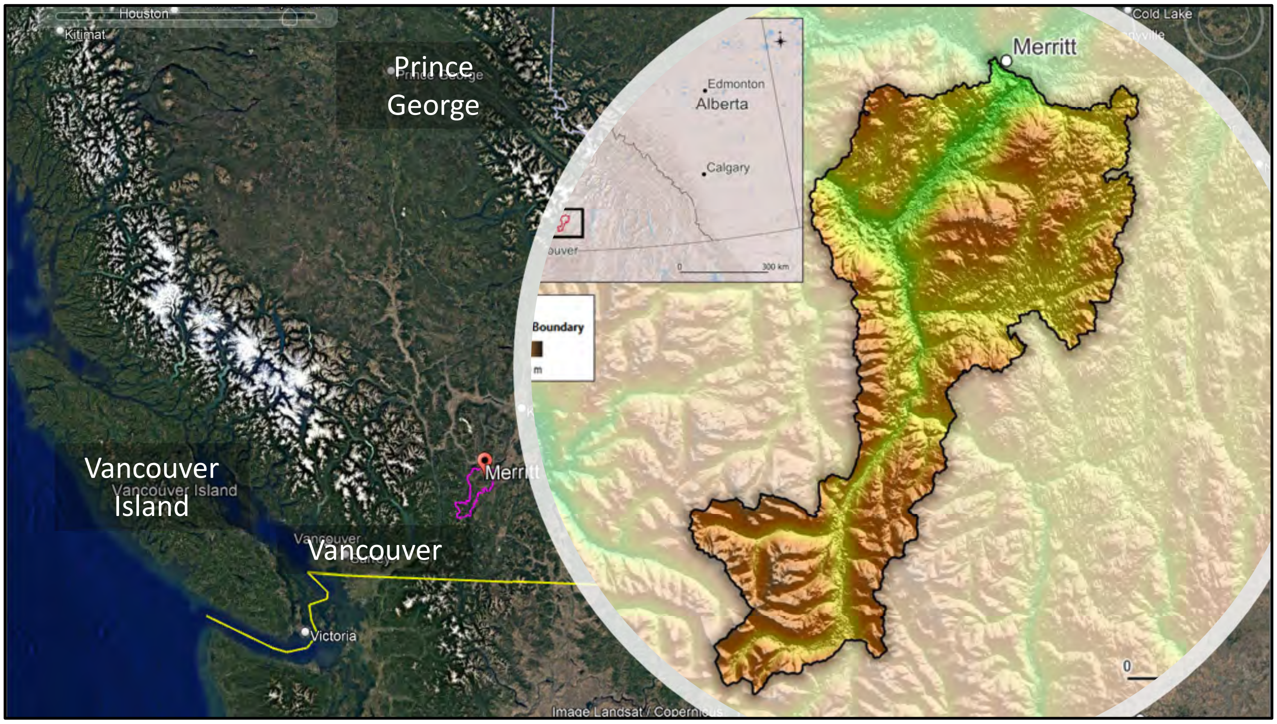
Flood Frequency-Magnitude Relationship for the Coldwater River

Presented by: **Melissa Hairabedian, M.Sc., P.Geo. , Dr. Kenneth Lockwood, E.I.T., and Dr. Vincenzo Coia**

Date: **June 20, 2022**

BGC

To set the stage for the presentation, I want to talk a bit about the figure you see you the introductory slide. What you see on the screen is the daily mean streamflow time series recorded at the Coldwater River at Brookmere (08LG048) over the 1965 to 2021 period. The 2021 time series is highlighted in red. The hydrologic regime for the Coldwater River watershed is nival-pluvial where the annual peak typically occurs in response to springmelt in May and June but on occasion, an AR-driven peak will exceed it in the fall/winter.


Houston
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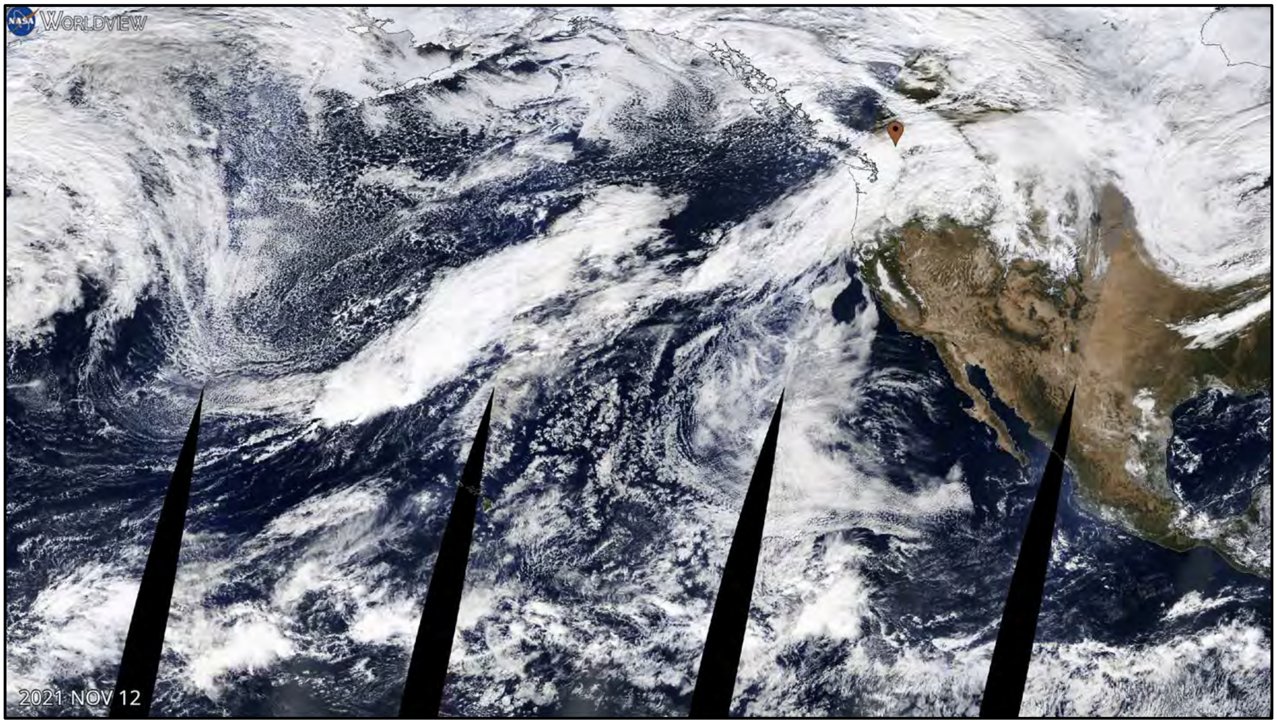


The atmospheric river (AR) that brought two days of intense rainfall to southwestern British Columbia (BC) on November 14, 2021 is shown on this seqnece of images. What you see here is a sequence of satellite images from Nov. 12 to 16 in the Pacific Northwest. The label marks the location of Merritt, BC at the mouth of the Coldwater River where it flows into the Nicola River.

ARs are long, conveyor belts of warm, moist air that occur typically during the late fall and early winter. The AR orientation on Nov. 14, 2021 was aligned with the orientation of the Fraser River valley, facilitating the inland penetration of the rainfall. This alignment induced an orographic uplift from Vancouver, BC, to Merritt, BC, to Hope, BC, after which the rainfall was funneled down to more localized watersheds, like the Coldwater River.

Flooding extending at least 600 m (⊥) from the Coldwater River reaching the edge of the parking lot of the Home Hardware in Merritt.

This rainfall resulted in extreme streamflow on November 15, 2021 with the peak occurring towards the end of the day. AR-related floods are typically larger than non-AR-related floods in coastal watersheds in BC. During the November 14, 2021 AR, the streamflow generated by rainfall (80%) was augmented by melting snow (20%), associated with a rapid rise in temperature.

Here is a picture taken from a video filmed by Marcel Irnie at approximately 4:30pm November 15, 2021. Mr. Irnie is standing in the parking lot of the home hardware located 600 m NE from the edge of the Coldwater River.

Link to Mr. Marcel Irnie’s video here:
https://www.youtube.com/watch?v=gwUMPs6ULtI

Flooding extending 900 m (⊥) from the Coldwater River reaching the intersection of Houston and Granite Streets

Here is another picture taken from the same video a bit later at the intersection of Granite Street and Houston Street. This intersection is located approximately 900 m from the Coldwater River.

Link to Mr. Marcel Irnie’s video here: https://www.youtube.com/watch?v=gwUMPs6ULtI

Extreme streamflow ensued concurrent with extensive river planform changes in watersheds across numerous rivers in the lower Fraser River watershed, including the Coldwater River at Merritt. Numerous infrastructures, notably roads and bridges were destroyed or inoperable. This destruction led to a near complete isolation of the Lower Mainland from road and rail access.

This picture shows some houses that were destroyed in the avulsion down Pine Street in Merritt, BC. This picture was taken on the emergency dike that was constructed.

In support of ongoing programs and recovery from November 15, 2021 flood, BGC Engineering Inc. (BGC) was retained by several interested parties to complete hydrotechnical hazard and risk assessments and flood hazard mapping in the Coldwater River.

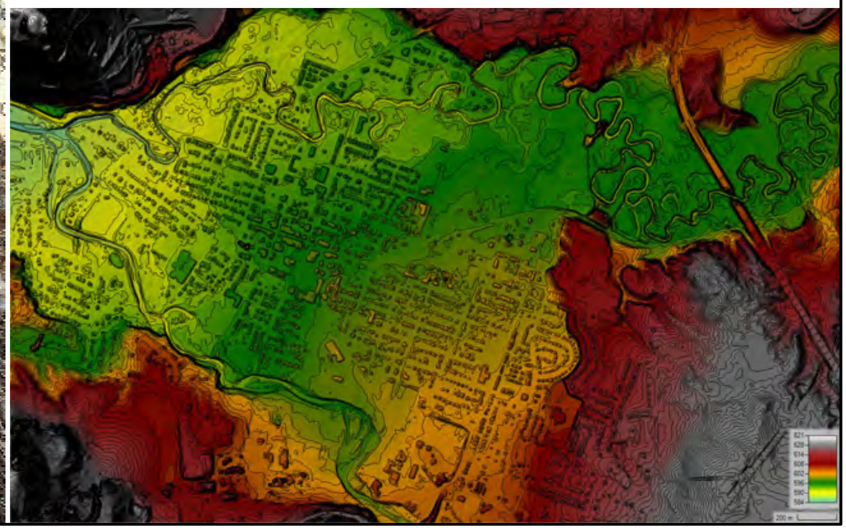
Estimating November 2021 Event: Approach

- Why couldn’t we just use WSC gauges?
  - Deemed unreliable during event
  - WSC working on their own estimate
- Alternate approach?
  - Made use of HECRAS model developed for 2021 flood mapping of Merritt
  - We have terrain, inundation extents, and Manning’s n, solve for flow

Calibration to May 16 2018 Event

Determined a Manning's n of 0.025 for the main channel

Estimating November 2021 Event: Data

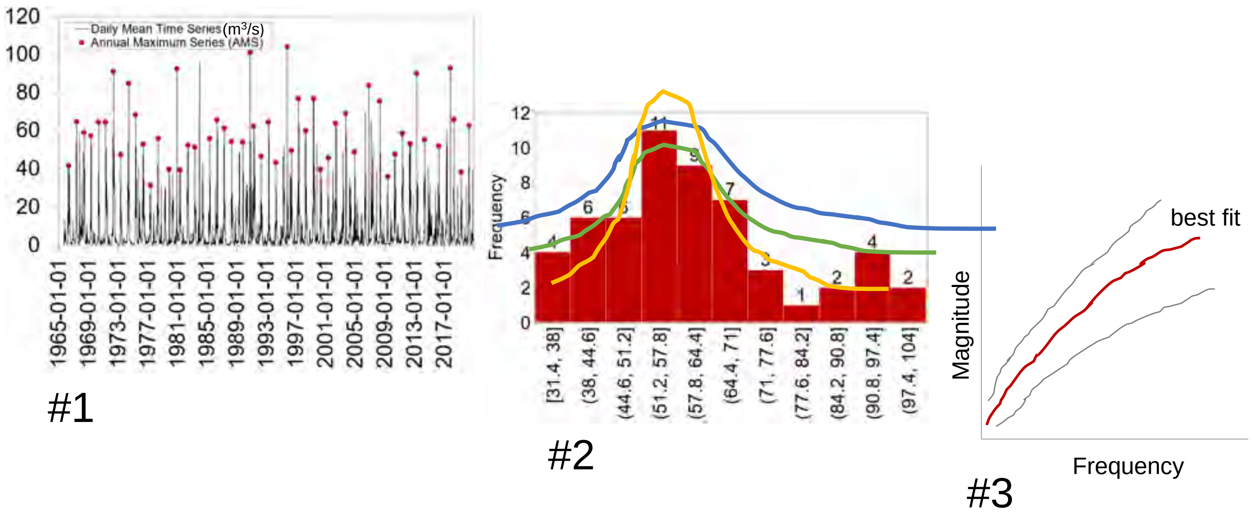


Estimating November 2021 Event: Results

Estimating November 2021 Event: Results

Scenario Discharge (m^3/s)	Mean Difference in WSE (m)	Normalized Root Mean Squared Error
400	0.02	0.13
300	0.20	0.15
250	0.31	0.18
200	0.41	0.24

The standard practice to flood frequency analysis is adequate for watersheds where peak flows are caused by one hydrological process



Using this instantaneous value of 400 m3/s, BGC developed a post-flood frequency-magnitude relationship for the Coldwater River at Merritt.

A frequency analysis is a statistical method to describe the frequency-magnitude relationship of a natural phenomena. The standard practice to estimate the frequency-magnitude relationship is based on the annual maxima series (AMS) to which a statistical distribution is fit.

A standard frequency analysis is completed in three steps.

1. First you extract the annual maximum from the daily or sub-daily time series. What you see in the first panel is a time series of the daily mean streamflow at the Coldwater River at Brookmere (08LG048) hydrometric station. The black line is the daily time series and the red circles show the annual maximum value.

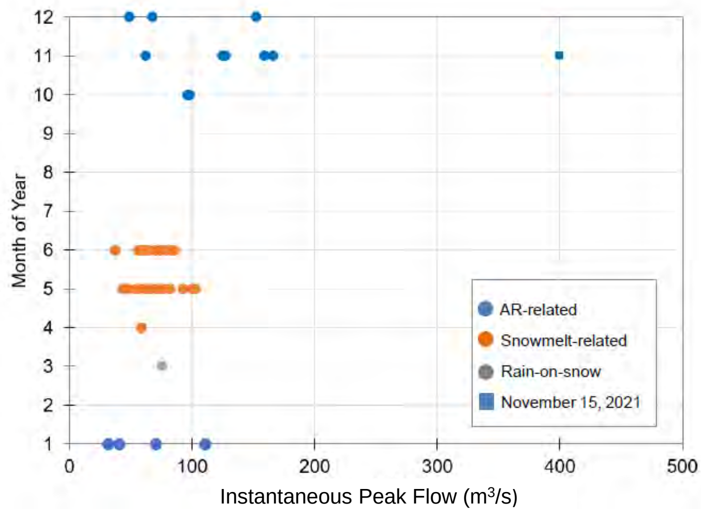
2. Then you plot a histogram and try to fit different statistical models to the empirical data as shown by the coloured lines, like the GEV, the Log Pearson

Type III, and others.

3. Once you are satisfied with the model fit, you plot your frequency-magnitude relationship. Sometimes it's based on one distribution or sometimes it's hard to tell so you can take an ensemble of distributions.

The standard approach to frequency analysis is adequate for watersheds where peak flows are driven by a single process like snowmelt.

AR-, Snowmelt- and Rain-on-Snow-related floods form their own data populations. Should there be a different type of analysis?



However, the standard approach can be inappropriate for watersheds where peak flows are caused by more than one process, like snowmelt and ARs, that may form a separate data population thus violating the rules of data homogeneity in statistical analysis.

What you see here is the timing of the annual maximum (y-axis) as well as the magnitude (x-axis). Different hydrological processes are driving the annual maximum peak flows. Peak flows are driven by snowmelt, ARs, and rain-on-snow events. The largest floods in the Annual Maximum Series occur in November and December coinciding with AR storms. In this case, the AMS seems inadequate for use in frequency analysis given the multiple floods populations.

Consequently, a statistical model for the annual maxima was built for the Coldwater River combining models for both snowmelt- and AR-related floods. This method of combining different populations of peak flows is not new in the field of statistical hydrology. In fact, this method was published as recently as 1982 (Waylen and Woo 1982). I think the reason we don’t hear a lot about it is in part because most watersheds in Canada are driven by a single process.

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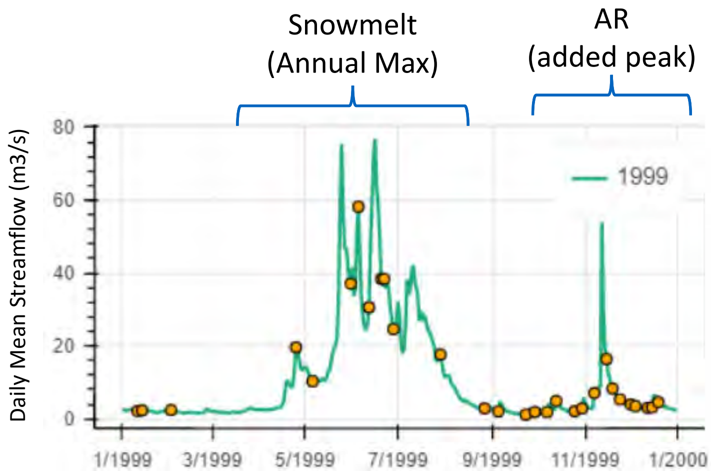
Rain-on-snow events are present in the AMS in the spring. However, the role of ARs on snowmelt in the spring contributing to rain-on-snow events was not considered explicitly in the statistical model because:

1. only a few of those events are present in the dataset,
2. the peak flow magnitude is in between snowmelt-related and AR-related peak flows, and
3. the AR frequency seems to be the lowest in the spring, at least historically (Sharma & Déry, 2019).

The AR-related peak flow dataset was extended by extracting additional peaks from the daily time series using timing and historical AR events



AR database:
SIO-R1 Catalog
Gershunov et al., (2017)

In the AMS for the Coldwater River at Brookmere, we have about 10 floods related to AR storms and 41 related to snowmelt. The peak flow dataset for each flood-generating process was extended by extracting additional peaks from the daily time series using timing for snow and historical AR events to generate a Dual Maximum Series (DMS).

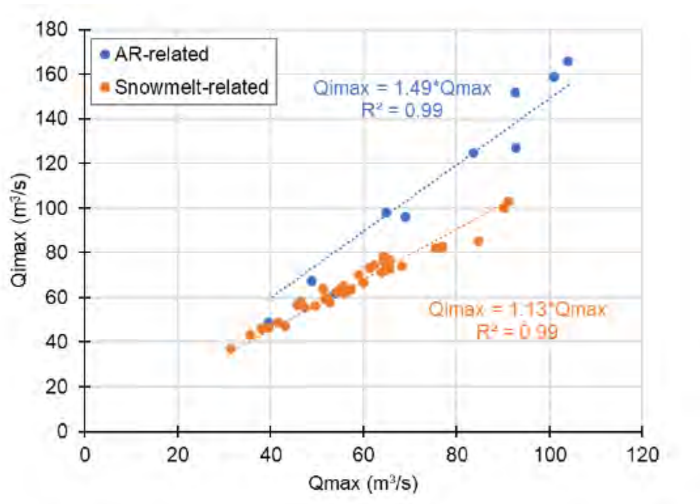
For example, snowmelt-related peak flows were extracted for every freshet over the record period from April to June.

The AR-related peak flow dataset was extended by extracting additional peaks from the daily time series using timing and using a database of historical AR events that was published in 2017. To associate an AR with a peak flow, all ARs within the Coldwater River watershed were identified from September to March from 47.5o to 50o N using the SIO-R1 Catalog (Gershunov et al., 2017).

These AR events were cross-referenced with the daily mean streamflow recorded at the Coldwater River at Brookmere (08LG048) hydrometric station.

An AR event was associated with a daily mean peak flow if the hydrological response occurred on or up to 6 days after the AR event. The daily mean peak flow is considered AR-related if the IVT field exceeds the 250 kg/m/s threshold value within at least one of those 7 days.

Instantaneous peak flow value was estimated using a regression forced through zero built using pairs from the AMS



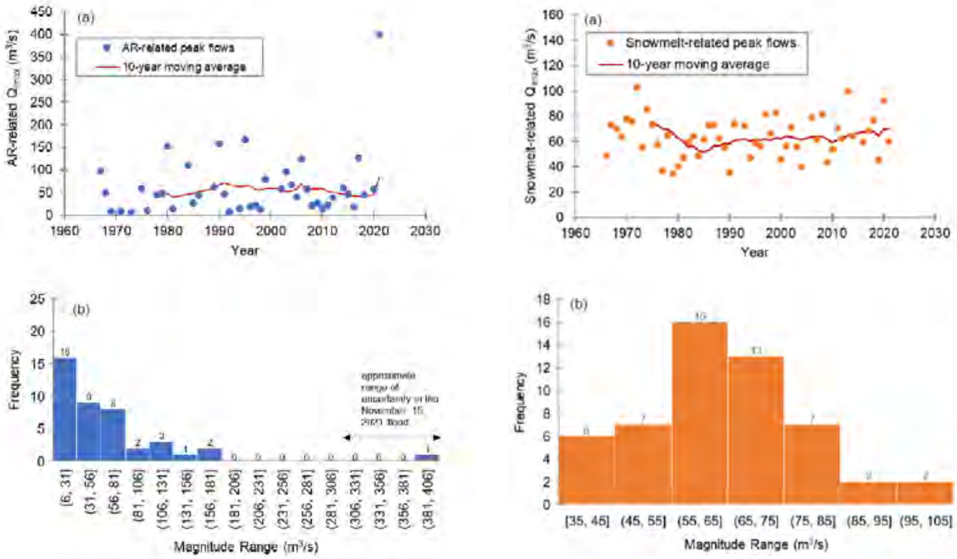
For the peaks extracted from the daily mean time series, we estimated the instantaneous value using a regression built using the peaks from the Annual Maximum Series where both Qa and Qi were published.

A regression was built for both AR and snowmelt-related peaks

The regression model was forced through zero.

For context, the Nov. 15, 2021 event plots where the red star is. I'm being silly but luckily, the regression is used to estimate the instantaneous peak flow within the range shown in this figure only.

AR-related and Snowmelt-related peak flows have different statistical distributions

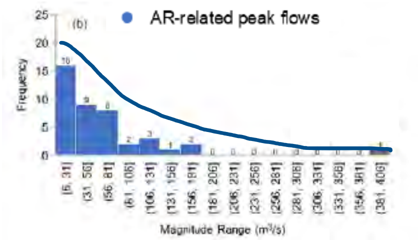


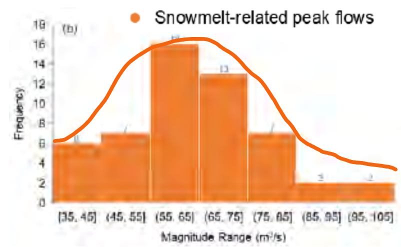
AR-related and Snowmelt-related peak flows have different statistical distributions. On the left, you have the AR-related peak flows and on the right you have the snowmelt-related peak flows. The top panels show the time series and the bottom panel shows the corresponding histogram.

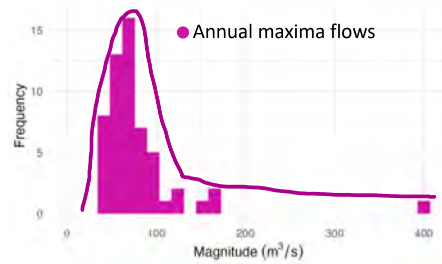
The magnitude of AR-related annual maximum peak flows has not changed between 1967 and 2021 in the Coldwater River watershed. The Sen's slope is slightly positive 0.45 with and 0.34 without the November 15, 2021 flood. The trend is not significant with (p-value = 0.26) or without (p-value=0.49) the November 15, 2021 flood. The record peak flow is the November 15, 2021 flood with an estimated value of 400 m3/s. The next largest peak flow was recorded in 1995 with a value of 166 m3/s in response to an AR event at the end of November. The AR-related peak flows range from 6 to 400 m3/s, with a median value of 47 m3/s. The AR-related peak flows are skewed to the right and characterized by a heavy right tail with the presence of a few large events.

The magnitude of snowmelt-related annual maximum peak flows does not have a statistically significant upwards or downwards trend over the 1967 to 2021 period (p-value = 0.84). The largest snowmelt-related peak flow was recorded in 1972 with a value of 103 m3/s recorded at the end of May. The snowmelt-related peak flows range from 35 to 103 m3/s, with a median value of 63 m3/s. The snowmelt-related peak flows are slightly skewed to the right and characterized by a short right tail with the presence of several large events.

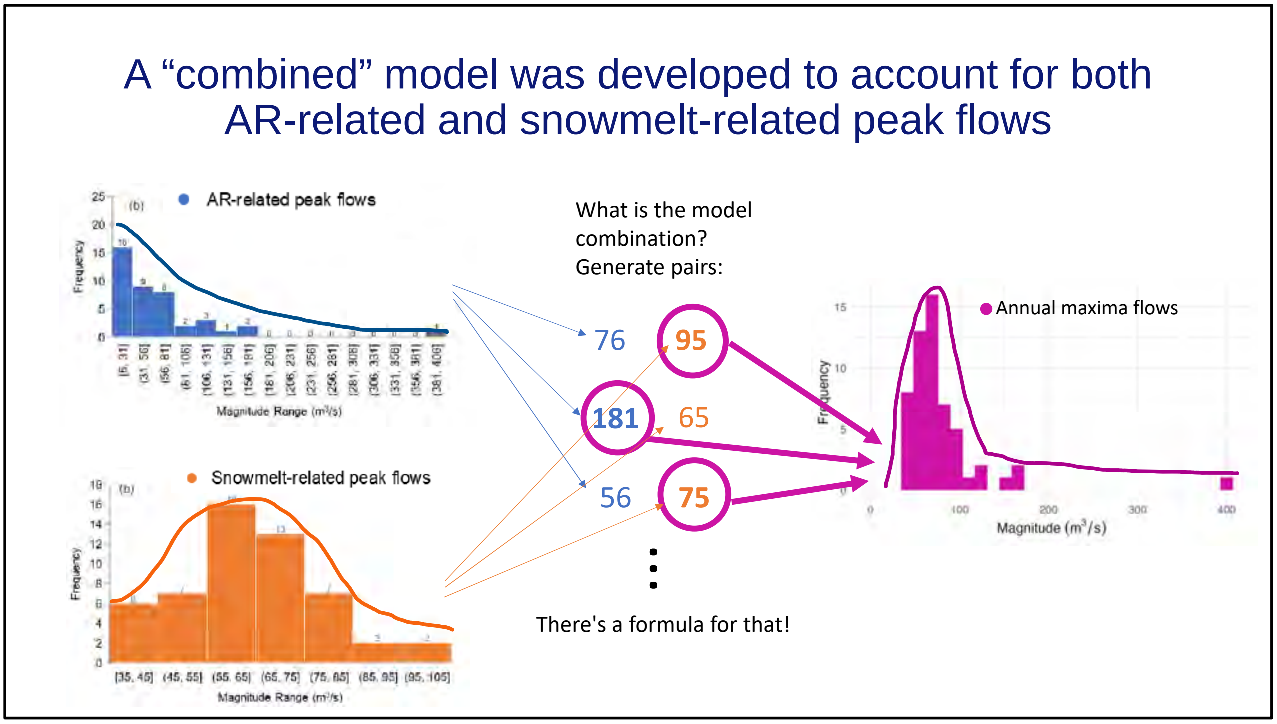
A “combined” model was developed to account for both AR-related and snowmelt-related peak flows







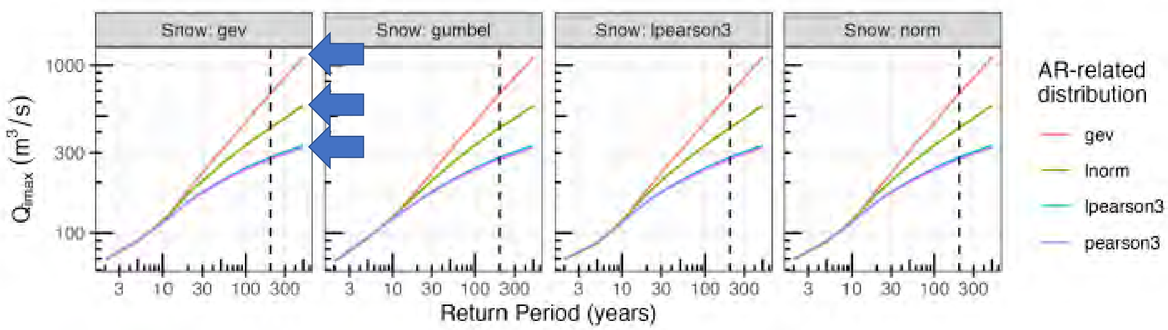
Waylen, Peter & Woo, Ming-ko. (1982). Prediction of annual floods generated by mixed processes. Water Resources Research. 18(4):1283-1286.



You can think about the combined model in terms of random draws from both the AR-related and snowmelt-related distributions: it's the collection of maxima of randomly drawn pairs.

Although this sounds like the standard AMS-based approach, it's different because we're combining models, not data. Just as the AMS can be produced from the DMS, a model for the AMS can be produced from models of the DMS. This standard AMS-based model is less flexible than the DMS-based model, because one curve is being fit to the AMS, compared to a combination of two curves.

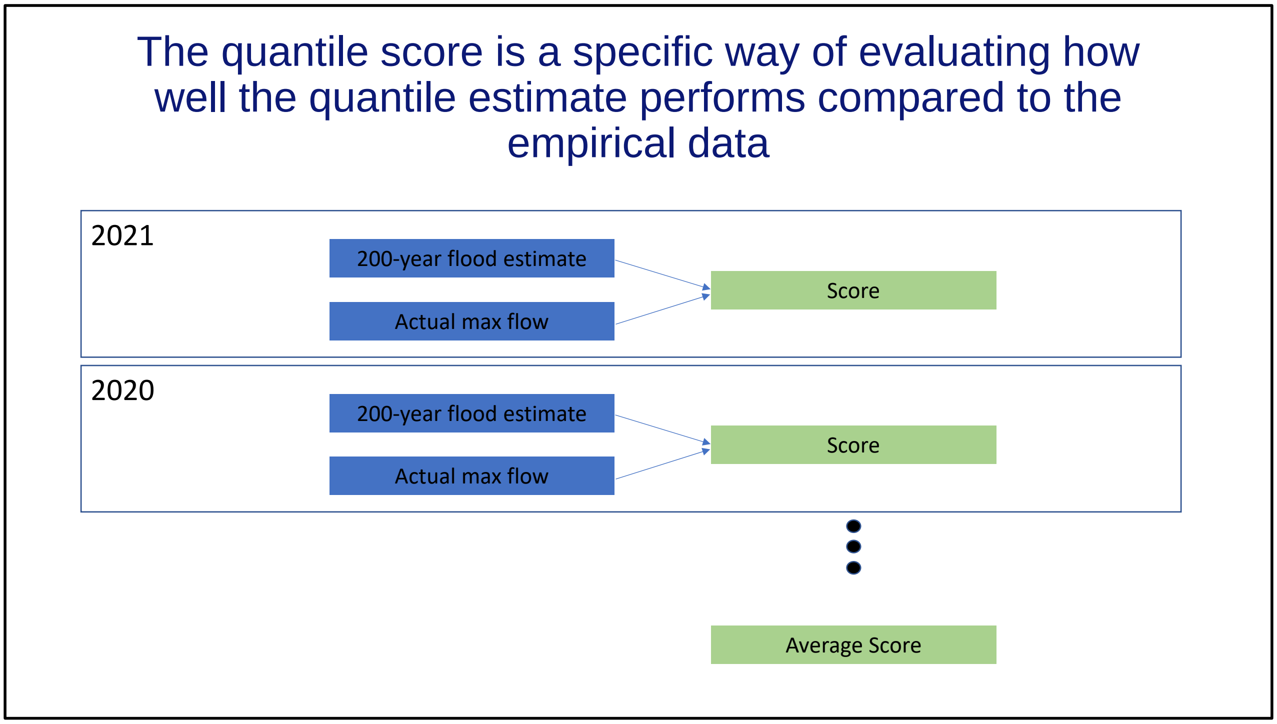
An ensemble of three distributions was used to characterize the AR-related peak flows to account for the range in distribution tail behaviours



A suite of statistical distributions were considered to characterize the tail of the empirical distributions. The frequency-magnitude relationships show that the influence of the snowmelt-related peak flow distribution is not strong, as shown by the similarity in the frequency-magnitude relationship for any given AR-related peak flow distribution (all 4 panels are nearly identical). However, the influence of the AR-related peak flow distribution is prominent as shown by the differences in the frequency-magnitude relationship for any given snowmelt-related peak flow distribution (the coloured lines).

Given this similarity, the GEV distribution was chosen for snowmelt-related peak flows because of its flexibility when extrapolating to longer return periods (lower % AEPs)

To account for a range of tail behaviours, an ensemble of three distributions was used for the AR-related peak flow distribution when building a final model: the GEV, Log Normal, and Pearson Type III.



The score you get for producing a flow quantile *q* when the actual annual maximum for a year is *y* is basically just the difference between the two, scaled by either *p* or *1-p*.

if 200-year return period, 1- p = 0.995
y-q is the difference between the observation and the estimated flow quantile

Specific example to illustrate :

Say the max flow in 1960 is 120 m3/s. The difference is 445-120 = 325 m3/s (although we ignore the units in the scoring function). Because we're evaluating how well we've estimated the 200-year flood, p = 1 - 1/200 = 0.995. And because what materialized (120 m3/s) is smaller than the Q200 estimate (445 m3/s), the difference gets scaled by (1-p) = 0.005, for a score for the year 1960 being 0.005*325 = 1.625.

Now, move on to 1961, where the max flow is (say) 455 m3/s. The difference between our Q200 estimate (445) and what materialized (455) is 10, and because what materialized is *bigger* than the Q200, this difference of 10 gets scaled by p = 0.995, for a score for the year 1961 being 0.995*10 = 9.95.

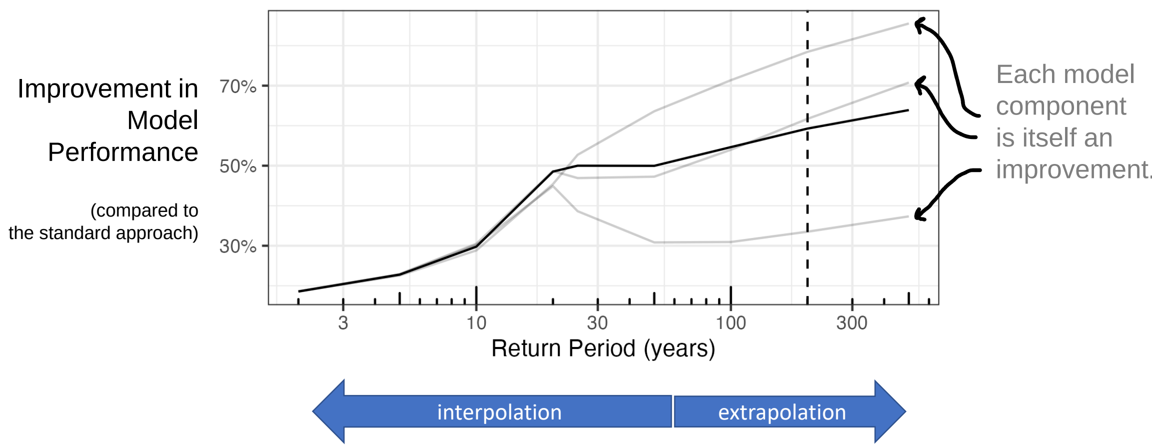
Notice that the score (best thought of as a penalty?) for 1961 is far more severe than 1960: even though the observed difference in 1961 was 10 m3/s -- much smaller than the 325 m3/s saw in 1960 -- those 10 units were *above* the Q200, which should almost never happen, hence the large penalty.

Once you've produced a score for each year on record, just average the score to see how well your model does for that specific return period.

Run the same procedure for a different model (say, the standard AMS-based model), and you'll get a different average score. The one with the smaller score "wins" because they received an overall lower penalty.

Note that quantile score can't be compared between return periods because the scale changes as the return period changes. So, a penalty of 9.95 for the Q200 is different than for the Q2. The scores do get smaller for longer return periods.

The quantile score for the proposed combined model is better than the standard practice model, and improves with higher return periods (% AEP)



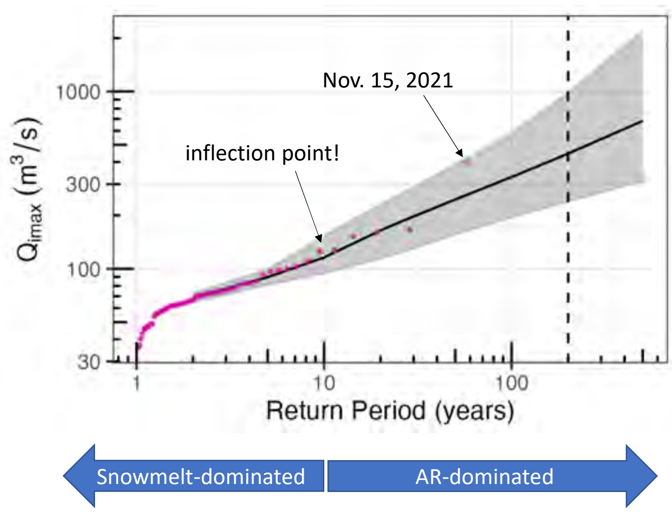
One of the questions we pose now is which model performs better? The standard approach or the combined approach.

To answer this questions, we ran a “leave one out” cross-validation based on the quantile score. The quantile score is a specific way of evaluating how well our quantile estimate compares to the annual maximum peak flow recorded at the hydrometric station over all years on record with a penalty depending on whether our quantile estimate is above or below. The overall quantile score was obtained by averaging each year’s quantile score. This process was done for all return periods and for both AMS and DMS models.

Note that quantile score can’t be compared between return periods because the scale changes as the return period changes. For example, the penalty for the Q200 is different than for the Q2. The scores do get smaller for longer return periods.

Based on this approach, it looks like the Combined Approach is better across all return periods.

The inflection point marks the transition between snowmelt- and AR-related peak flows in the frequency-magnitude relationship



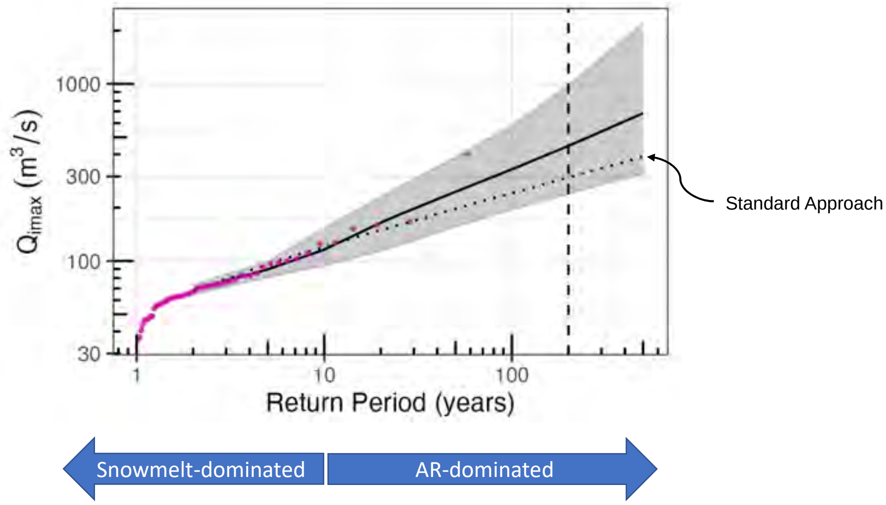
The frequency-magnitude relationship was established by combining models for AR-related and snowmelt-related peak flows. The frequency analysis was based on the maximum value for each of the snowmelt- and AR-related peak flows by splitting the year (January to December) in two forming the Dual Maximum Series (DMS) – one peak flow in the spring in response to snowmelt and one peak in the fall/winter in response to an AR event, if any.

The frequency-magnitude relationship can be obtained by noting that the peak flow in any given year is the maximum of the snowmelt-related peak flow and the AR-related peak flow. Such a distribution can be obtained in terms of its probability of non-exceedance (1 - AEP) of a given peak flow value, which can be obtained by multiplying the respective non-exceedance probabilities of the snowmelt-related and AR-related peak flows (Waylen & Woo, 1982).

The computation involved with this type of model combination was done through the distplyr R package (Coia et al., 2022).

An infection point emerges in the combined model around the 10-year flood which identifies the transition between snowmelt-related and AR-related peak flows.

The combined approach allows the more extreme process to be expressed, resulting in higher quantiles for higher return periods



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The computation involved with this type of model combination was done through the distplyr R package (Coia et al., 2022).

An infection point emerges in the combined model around the 10-year flood which identifies the transition between snowmelt-related and AR-related peak flows.

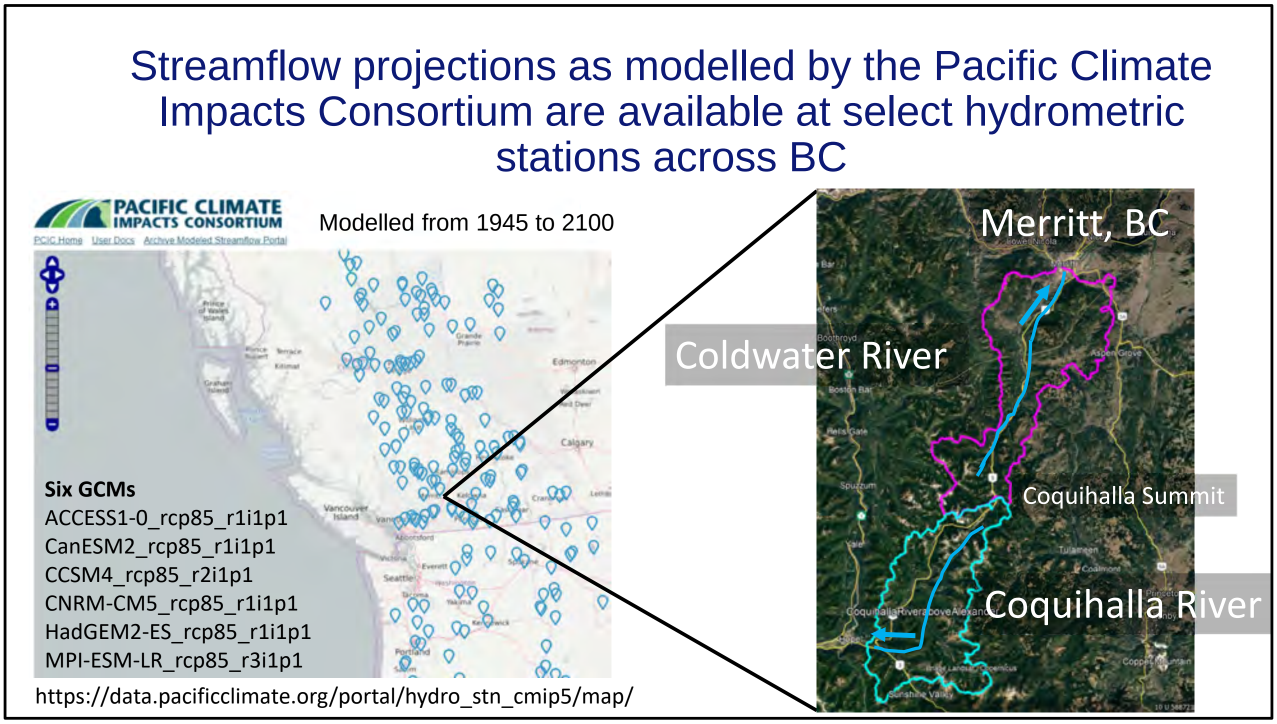
Let's take a breath and recap…

- The 200-year (0.5% AEP) event in the Coldwater River at Merritt in absence of climate change is estimated to be **445 m^3/s** (90% confidence interval 240 m^3/s to 980 m^3/s) based on a combined approach
- A combined approach to frequency analysis should be considered when **more than 1 process** is driving peak flows, especially when the distribution of those peaks are different.
- The 200-year (0.5% AEP) event based on the standard approach is **295 m^3/s** (160 m^3/s to 550 m^3/s).
- Failing to account for both hydrologic processes separately could result in an **underestimation** of the design flood and compromise long-term flood protection

We built a statistical model that combines snowmelt-related and AR-related peak flows in the Coldwater River. Using this combined model, the 200-year (0.5% AEP) event in the Coldwater River at Merritt in absence of climate change is estimated to be 445 m3/s.

Last week we saw how the distribution of snowmelt-related and AR-related peak flow differ in their shape and range of peak flows. A combined approach to frequency analysis should be considered when more than 1 process is driving peak flows. This point is especially important if the distribution of those peak flows are different.

In comparing the results of a standard approach to frequency analysis where the annual maximum is used to fit a statistical distribution irrespective of the process driving it, we see that the 200-year (0.5% AEP) is 35% smaller in this case. Failing to account for both hydrologic processes separately could result in an underestimation of the design flood and compromise long-term flood protection.

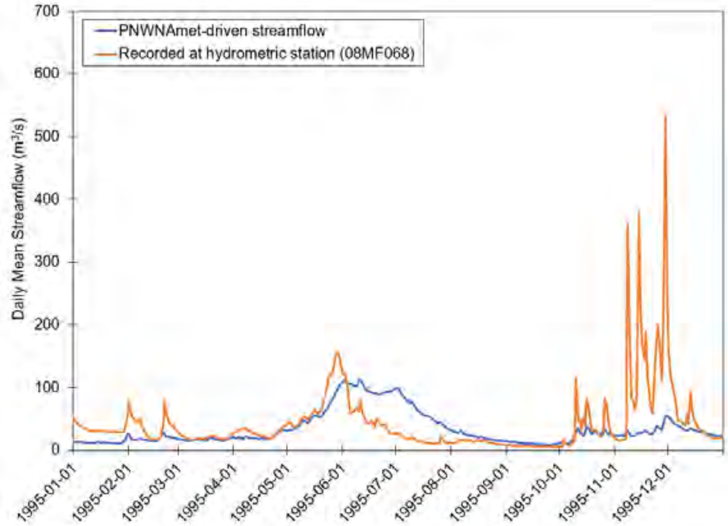


Streamflow projections as modelled by the Pacific Climate Impacts Consortium are available at select hydrometric stations across BC.

Daily mean streamflow at the *Coquihalla River above Alexander* (08MF068) hydrometric station are modelled from 1945 to 2100 under naturalized streamflow conditions and driven with using 6 GCM models assuming representative carbon pathway 8.5. by the end of the century. The daily mean streamflow is simulated using runoff and baseflow generated with an upgraded version of the Variable Infiltration Capacity (VIC-GL) model that is coupled to a glacier model (Schnorbus, in prep) and routed with RVIC (Lohmann et al., 1998, 1996; Hamman et al., 2016).

The Coquihalla River watershed is located on the other side of the North Cascade mountains relative to the Coldwater River watershed. Before we contemplated using these projections to inform changes in the Coldwater River watershed, we wanted to check whether we could use the peak flow projections for frequency analysis of AR and snowmelt-related peak flows in the Coquihalla River itself.

The capability of the VIC-GL model to simulate the magnitude of snowmelt peaks varies from its ability to simulate the magnitude of AR-related peaks in the **Coquihalla River watershed**



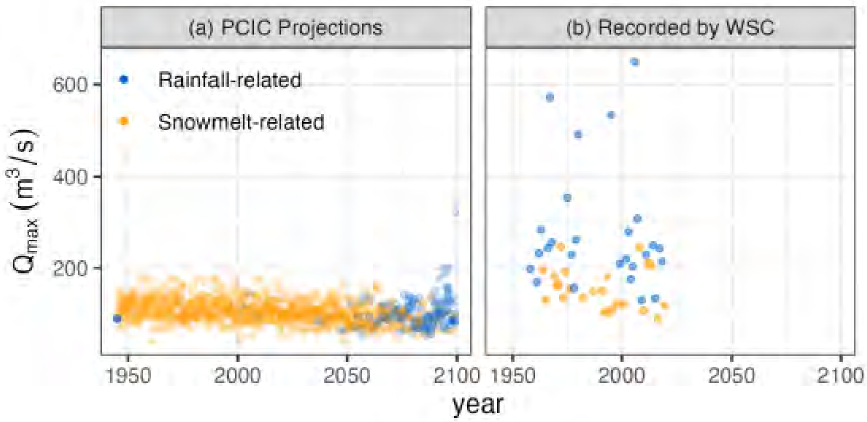
The short answer is no.

What you see here is a time series for 1995 with the blue line showing the modeled daily mean flows and the orange line shows the streamflow recorded at the hydrometric station in the Coquihalla River above Alexander hydrometric station..

The capability of the VIC-GL model, as driven by the PNWNAmet gridded dataset, to simulate the magnitude of snowmelt peaks varies from its ability to simulate the magnitude of AR-related peaks. While both flood types are captured by the VIC-GL model, its ability to simulate the magnitude of snowmelt-related peak flows is much better compared to AR-related peak flows.

The climate models suggest that AR-related peaks emerge in the AMS towards the end of the century, whereas the historical data show that such peaks are already prominent in the **Coquihalla River**.

Coquihalla River above Alexander Creek (08MF068)



The discrepancy in the magnitude between the simulated peak flows and those recorded at the hydrometric station is playing out in the projected trend.

Projected rainfall-related peak flows don't emerge in the Annual Maximum Series from the PCIC projections until the end of the century as shown by the blue dots in the left panel.

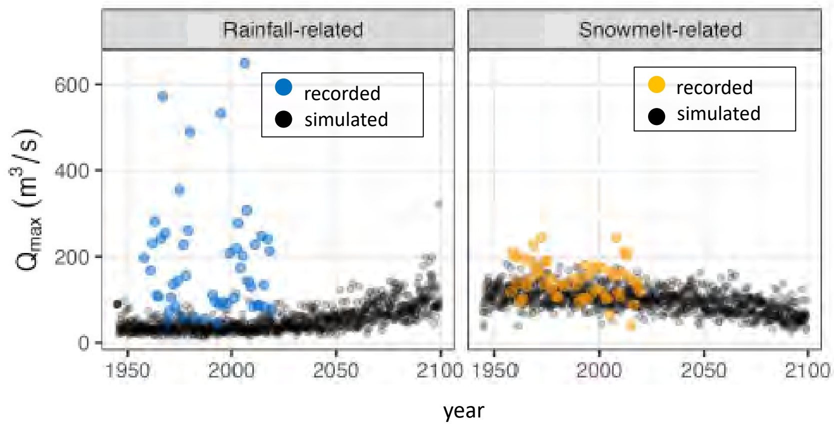
This late emergence is not consistent with what we see recorded at the hydrometric station historically as shown in the right panel. A total of 50% of the peak flows in the historical AMS are AR-related over the 1958 to 2020 period. The AR-related peak flows are shown in blue while the snowmelt-related peak flows are shown in yellow.

The absence of AR-related peak flows in the simulated historical AMS shows that this simulated time series is not representative of the flood types that have occurred historically in this watershed. Moral of the story is that it's not realistic to characterize the trend in the simulated peak flows using the AMS for the

Coquihalla River watershed.

The question now is, can we still use these simulations to characterise the future trend in rainfall-related peak flows?

Constructing the DMS series reveals different trends in the rainfall-related and snowmelt-related peak flows.



The answer is yes.

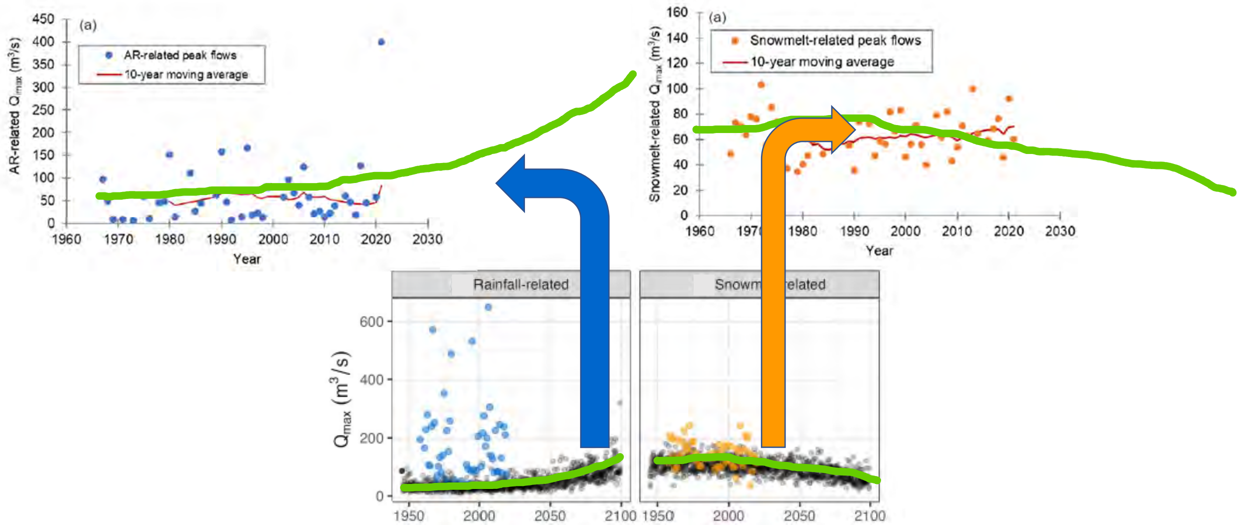
We teased apart the simulated daily mean streamflow by assuming the maximum peak flow that occurs in the fall/winter (September to March) period is rainfall-related (AR and non-AR), and the maximum peak flow that occurs over the spring period (April to August) is snowmelt-related. The 6 GCM run VIC-GL peak flow simulations are shown in black while the peak flows recorded at the hydrometric station are shown in blue for rainfall and orange for snowmelt.

By doing that, we see that the rainfall-related (AR and non-AR) peak flows are projected to increase significantly over time as shown in the left panel.

The snowmelt-related peak flows, on the other hand, are projected to decrease significantly over time as shown in the right panel.

The question now is can we trust the trend if the model does not adequately capture the magnitude? We said yes because the simulations emulate the historical trend at Coquihalla River above Alexander Creek (08MF068) hydrometric station. The simulations over the recorded period (1965 to 2021) show a stationary trend in line with the trend in the AR-related peak flows.

Trends in the index floods are assumed to translate to the Coldwater River data, resulting in two approaches for obtaining future annual peak flow distributions.

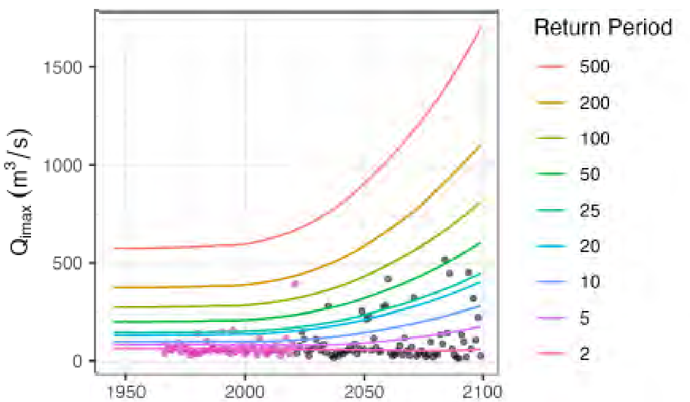


The next question is, how do we transfer the information from the Coquihalla River to the Coldwater River?

Curves were fit to these three separate time series using a LOESS regression, representing the geometric mean across time of the pooled simulations from the six GCMs. The scales were removed from each curve by dividing out the current 2022 value of the curve to capture how many time greater each future year's geometric mean is compared to the geometric mean in 2022. The dimensionless scaling factors were transferred to the Coldwater River.

Results show that the 200-year (0.5% AEP) is projected to be approximately 65% greater in the next 75 years due to the positive and increasing trend.

Return Period (% AEP) projections based on the dimensionless scaling factors from the DMS see an immediate and rapid increase



Return Period (% AEP) projections based on the dimensionless scaling factors from the AMS see minor change over time compared to an immediate and rapid positive increase from the DMS reflecting the trend in the rainfall-related peak flows (AR and non-AR).

The AMS series show an overall decrease consistent with the snowmelt-related peak flows and a sporadic increase by the end of the century reflecting the projected emergence of the AR-related peak flows.

In a non-stationary context, the frequency-magnitude relationship requires explicit definition because the exceedance probability associated with a flood magnitude changes with each consecutive year. The climate-adjusted frequency-magnitude relationship can be defined in several ways with specific probability implications in a changing climate.

We came up with three definitions:

1. Maximum Peak Flow

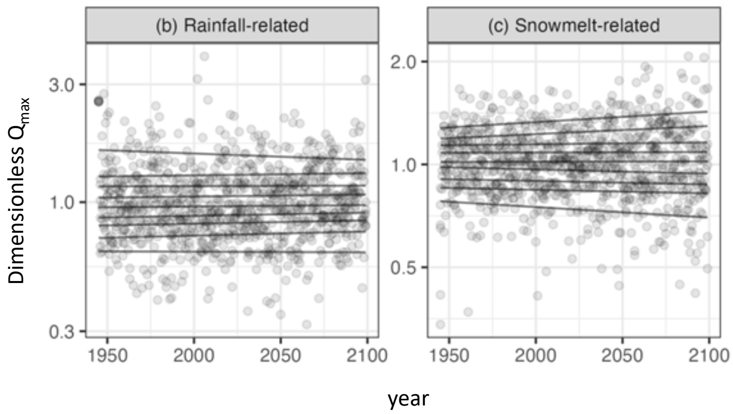
   1. This definition results in the peak flow value defined by the orange line by the end of the century (1,075 m3/s) on the figure above. This definition results in the highest Q200 because of the projected increasing trend in AR-related peak flows. This estimate may be too high given the uncertainty in peak flow projections by the end of the century.

The other two definitions include:

1. Matching the number of exceedances
   1. The peak flow associated with 0.375 number of exceedances over the next 75 years. This definition results in a peak flow value with an arithmetic mean of 0.5% AEP.
2. Matching the probability of exceedances.
   1. The peak flow associated with a 31% chance of being exceeded at least once in 75 years

The second definition (matching the number of exceedances) was used to obtain the climate- adjusted frequency-magnitude relationship because it (along with the third definition matching the probability of exceedance) is a translation of the stationary definition of the 200-year (0.5% AEP) peak flow.

The residuals appear to be stationary over time for the rainfall-related peaks, justifying the use of scaling factors for at least the PCIC projections, so presumably also for the historical flows.



From the previous slide, you'll know that we used the mean to scale the projections in the Coquihalla River to the Coldwater River. You could argue that climate change impacts different quantiles in different ways. For example, the Q2 will not necessarily shift in the same way the Q200 will over time.

The reliability of the scaling assumption based on the mean was verified by observing the residuals of the simulated maxima about the fitted geometric mean curves.

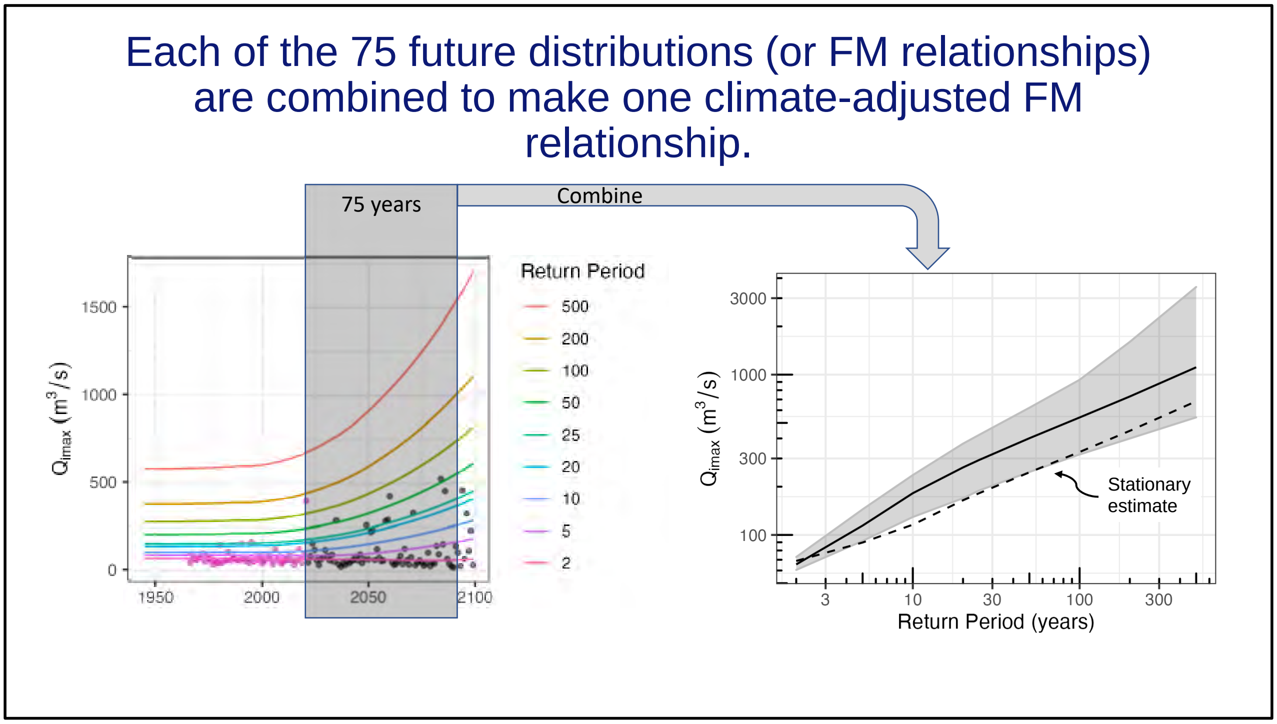
The residuals were defined as the ratio of simulated peak flows to the LOESS geometric mean for each future year.

If the distribution of the residuals appears to be constant over time, the scaling assumption was deemed reasonable, suggesting that the dimensionless scaling factors capture the key changes in the peak flow distribution based on the six GCMs.

The residuals for the AMS and snowmelt-related peak flows show a significant flaring out of the nine decile lines. This significant flaring indicates that the scaling assumption for these processes may not be appropriate.

The residuals appear to be stationary over time for the rainfall-related (AR- and non-AR) peak flows suggesting that the distribution is not changing due to climate change aside from this scaling factor.

Because the rainfall-related (AR and non-AR) distribution becomes increasingly dominant in the future, the potentially poor assumption in the AMS and snowmelt-related cases is considered negligible for higher return period (% AEP) events.



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In a non-stationary context, the frequency-magnitude relationship requires explicit definition because the exceedance probability associated with a flood magnitude changes with each consecutive year. The climate-adjusted frequency-magnitude relationship can be defined in several ways with specific probability implications in a changing climate.

We came up with three definitions:

1. Maximum Peak Flow

    1. This definition results in the peak flow value defined by the orange line by the end of the century (1,075 m3/s) on the figure above. This definition results in the highest Q200 because of the projected increasing trend in AR-related peak flows. This estimate may be too high given the uncertainty in peak flow projections by the end of the century.

The other two definitions include:

1. Matching the number of exceedances
    1. The peak flow associated with 0.375 number of exceedances over the next 75 years. This definition results in a peak flow value with an arithmetic mean of 0.5% AEP.
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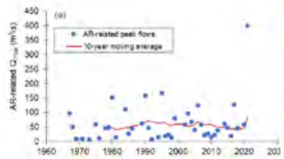
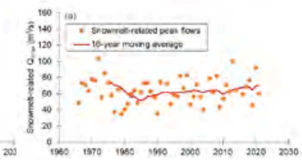
    1. The peak flow associated with a 31% chance of being exceeded at least once in 75 years

The second definition (matching the number of exceedances) was used to obtain the climate- adjusted frequency-magnitude relationship because it (along with the third definition matching the probability of exceedance) is a translation of the stationary definition of the 200-year (0.5% AEP) peak flow.

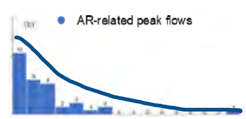
Summary of Steps: Stationary Analysis

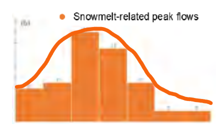
1. Make a Dual Maxima Series (DMS) from gauge data.



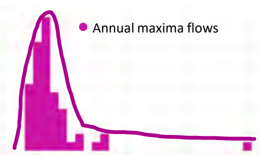


2. Fit a distribution to each series (snowmelt-related and rainfall-related).





- If stopping at a stationary analysis, combine the two distributions.



Summary of Steps: Climate-Adjusted

3. Make a DMS from VIC-GL projections of daily mean discharge.

4. Fit a curve through each series (snowmelt-related and rainfall-related).

5. Translate the curve to the two stationary distributions.

7. Combine ("maximize") the two distributions for each year.

8. Combine annual models over the next (say) 75 years.

Results

- The 200-year (0.5% AEP) event in the Coldwater River at Merritt in absence of climate change, assuming a Nov. 15, 2021 event of 400 m^3/s, is estimated to be:

Combined approach: **445 m^3/s** (90% confidence interval: 240 to 980 m^3/s).

Standard approach: **295 m^3/s** (90% confidence interval: 160 to 550 m^3/s).

- Accounting for climate change, projected over the next 75 years, the 200-year (0.5% AEP) event is approximately 65% larger: **730 m^3/s**

We built a statistical model that combines snowmelt-related and AR-related peak flows in the Coldwater River. Using this combined model, the 200-year (0.5% AEP) event in the Coldwater River at Merritt in absence of climate change is estimated to be 445 m3/s raging from 240 m^3/s to 980 m^3/s (90% bootstrap CIs).

In comparing the results of a standard approach to frequency analysis where the annual maximum is used to fit a statistical distribution irrespective of the process driving it, we see that the 200-year (0.5% AEP) is 35% smaller in this case. Failing to account for both hydrologic processes separately could result in an underestimation of the design flood and compromise long-term flood protection

Failing to account for both hydrologic processes separately could result in an underestimation of the design flood and compromise long-term flood protection.

If we want to be consistent about how we do frequency analysis, we need to consider the following

Things to Consider	Decision Made	Reasoning
1. AMS or DMS (Timing / Process) ?	DMS	Capture AR-related and snowmelt-related peak flows
2. Distribution Selection?	Ensemble	Capture uncertainty in the tail behaviour
3. Stationary or Climate-adjusted?	Climate-adjusted	Design should work towards that estimate (or better yet be risk-based). If it’s not possible because it’s too expensive, a higher level of risk has to be accepted.
4. Include or not include the Nov. 15, 2021 event.	?	This point has generated opposing views. Some suggest including it because it’s physically based. Some say to exclude it because we don’t know the actual return period. Discretion remains to the professional.

Limitations and next steps…

- Is 730 m^3/s physically possible in the Coldwater River water?
- Can we translate the trend from the Coquihalla River to the Coldwater River? A regional trend analysis can be done.
- Rainfall-related trend, is it realistic for the trend to remain positive and aggressive or is there a physical limit?

There are limitations in the way we thought about the frequency analysis.

→ Is 730 m^3/s physically possible in the Coldwater River water? We don't know but we can find out using a physically-based hydrological model. BGC is working to build a hydrological model in the Coldwater River focussing on the peak flows to help answer this question.

→ Can we translate the trend from the Coquihalla River to the Coldwater River? We did but perhaps a regional trend analysis can improve the transfer.

→ Is the rainfall-related trend realistic to remain positive or is there a physical limit ? That one is tricky and we don't have the answer right now.

Questions? Comments?

Cartoon guide to statistics by Gomick and Smith

For folks that have follow up questions, please feel free to contact myself at kholm@bgcengineering.ca

The details behind this estimate can be found in the following report:
Here is the link: https://www.fraserbasin.bc.ca/_Library/TR_Flood/tr_frequency-magnitude-coldwater_draft_may_2022_web.pdf