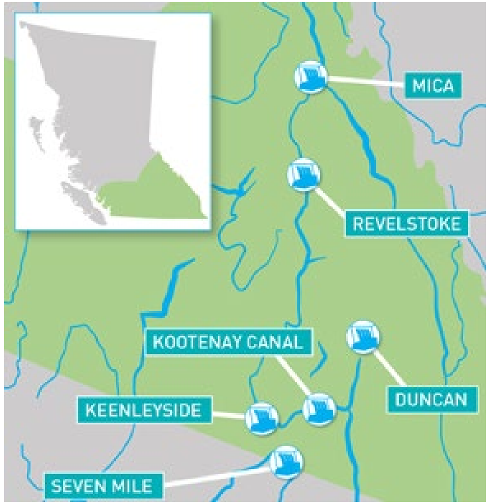
Lessons learned in development of extreme flood calibrations for BC Hydro

Leanna King, Ph.D., P.Eng.

Introduction

- BC Hydro operates 41 dams across the province of BC
- These range from very small, low consequence dams to very large, extreme consequence dams.



Introduction

- In 2022, a fleet-wide investigation was initiated to update the “Safety Evaluation Floods” (SEFs) for our dams – the Safety Evaluation Flood Update Project (SEFUP)

- The Safety Evaluation Flood (SEF) is the uppermost extreme flood used to evaluate whether the dam has adequate discharge capacity.

- This is a BC Hydro term that differs from the frequently used term “Inflow Design Flood” which is the flood a dam was initially designed or has been upgraded to.

Introduction

- SEF's are set equal to the Flood Hazard Target Levels proposed within the Canadian Dam Association Guidelines – from a 1 in 100-year recurrence interval flood and up to the Probable Maximum Flood.

Dam Consequence Classification	Annual Exceedance Probability Floods
Low	1/100
Significant	Between 1/100 and 1/1000
High	1/3 between 1/1000 and PMF
Very High	2/3 between 1/1000 and PMF
Extreme	PMF

CDA ACB

SEFUP Program

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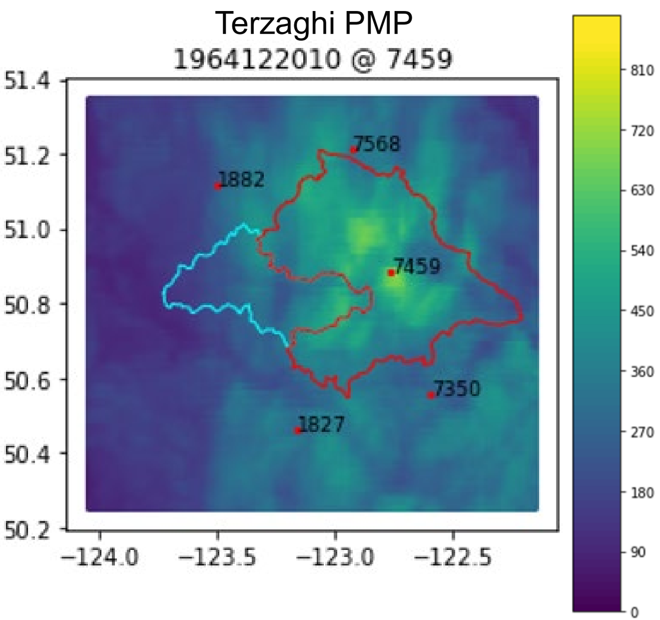
    1. The BC MetPortal – regional Probable Maximum Precipitation (PMP) analysis results, as well as point precipitation frequency estimates (BC MetPortal, 2021)



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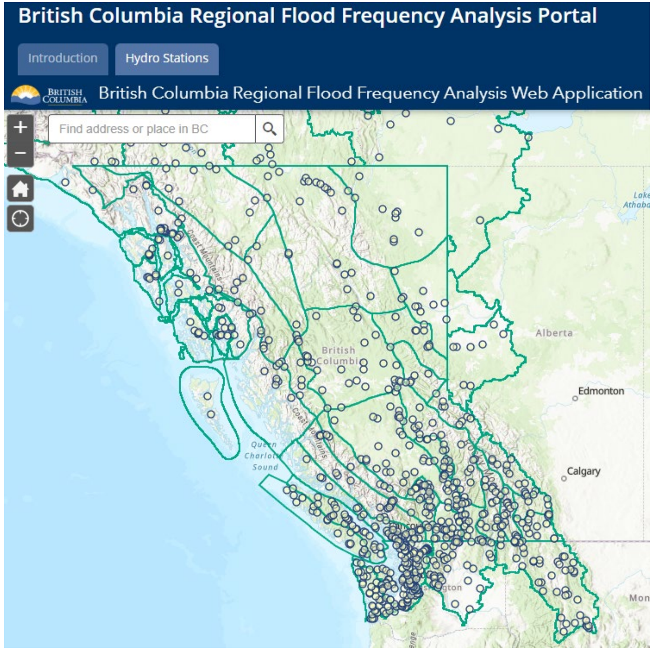
    1. The BC MetPortal – regional Probable Maximum Precipitation (PMP) analysis results, as well as point precipitation frequency estimates (BC MetPortal, 2021)
    2. Regional flood frequency analysis (Northwest Hydraulic Consultants, 2021)



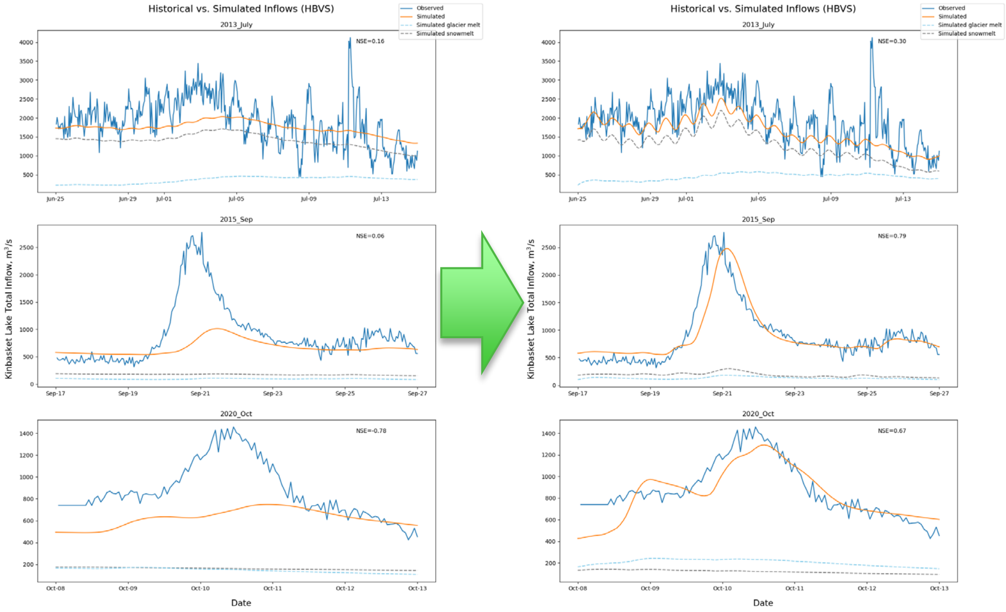
SEFUP Program

- Most of the completed SEFUP studies to date involve the use of hydrological simulation to evaluate the PMF or flood frequency curve.

- A brief history of hydrological models used for dam hydrologic loading assessments at BC Hydro:
  - 1980s – most early PMF studies applied the SSARR model at a six-hourly time-step.
  - 2003-2004 – Mica Dam PMF study → detailed comparison between WATFLOOD and UBC Watershed Model.
  - 2005-2013 – UBC Watershed Model adopted and used in forecasting and flood studies across all basins.
  - 2013-2025 – BC Hydro's Hydrology team "translated" original UBC calibrations into Raven. The latest versions of these UBC/Raven models applied in the recent flood studies.
  - 2024-2025 – A new effort was initiated by the Hydrology team in 2024 to update model discretization and test a variety of model structures. A new model setup called "HBVS" was provided and adapted for use in the new Mica PMF study, to be compared alongside the older, lumped UBC/Raven model.

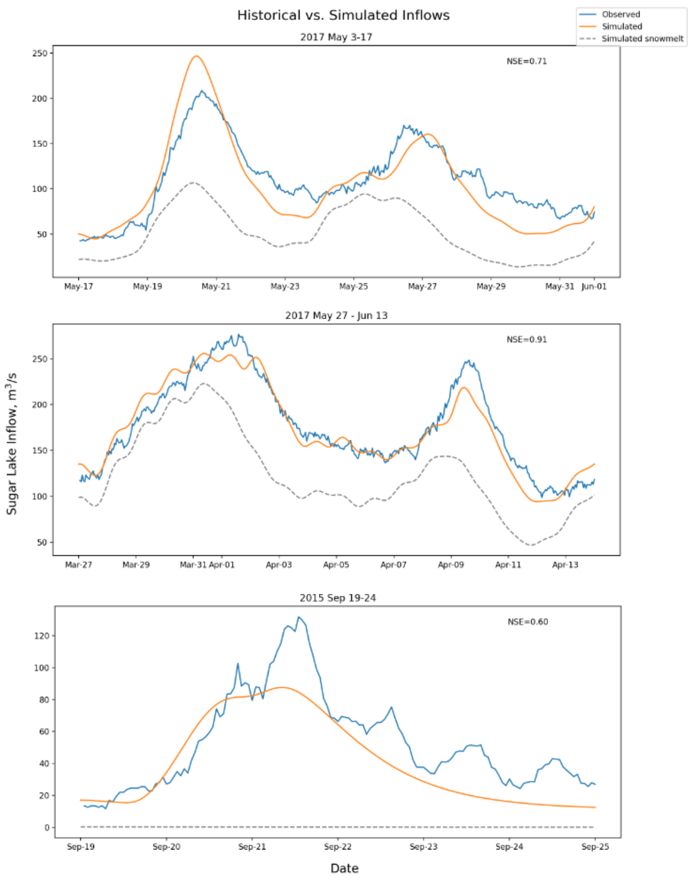
Extreme Flood Calibrations

- Forecasting model is a starting point. Model adaptation and re-calibration carried out to move from a general-purpose forecasting model to a flood-specific calibration.
- The goal is to develop an hourly storm calibration that best emulates watershed response during the largest floods of record.
- This improves confidence in extrapolation to extreme floods well beyond those in the historical record.



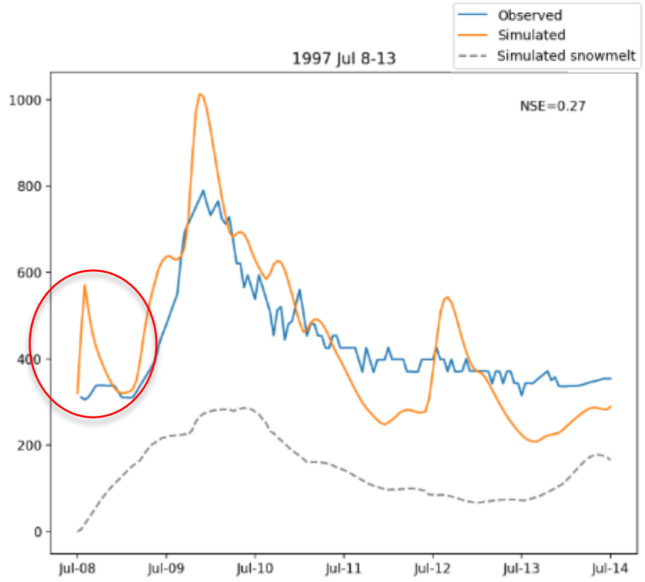
Extreme Flood Calibrations

- Important to develop hourly storm calibrations to a variety of flood producing events to ensure a robust calibration where model parameters are not compensating for one another:
  - Rain on snow
  - Snowmelt only
  - Rain only
- This has been particularly important for some interior / transition basins where early calibrations focused only on rain/rain on snow events – can be easy to get the right results for the wrong reasons (eg. By dialing up snowmelt)



Extreme Flood Calibrations

- Model “spinup” is necessary to develop initial conditions .rvc files for hourly calibrations and flood simulations, to avoid sudden storage fluxes due to a loss of equilibrium between long term and hourly event models.
- These can occur due to:
    - Discontinuity in time steps (daily to hourly)
    - Discontinuity in some model parameters:
        - Baseflow, percolation coefficients and exponents
        - Time of concentration / time to peak
        - Likely others...

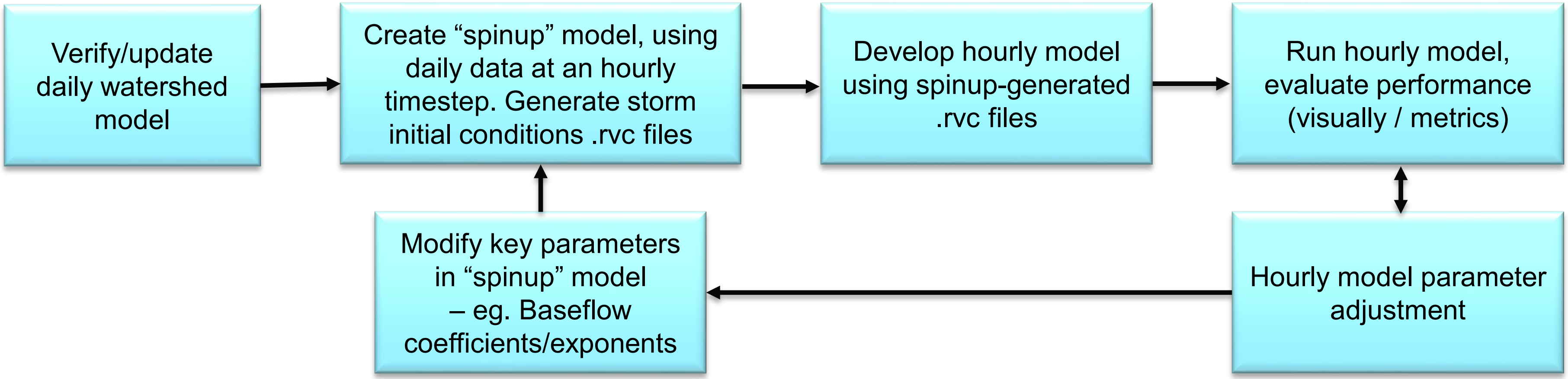


Extreme Flood Calibrations

- The "spinup" model acts as a bridge between the long term (usually daily) model, and the hourly storm model.
- I find it simplest to use a long-term hourly model run with daily forcing data as the spinup model, adjusting only the necessary parameters that create unstable behaviour in the hourly model.
- Other spinup setups can work too – for example, running and omitting results from a few days prior to the hydrograph start.
- Calibration of the hourly event models is therefore iterative, as spinup model and .rvc files need to be updated when certain parameters change in the hourly storm model.

Extreme Flood Calibrations

- The general workflow we follow to develop extreme flood calibrations, starting with a daily model, is as follows:



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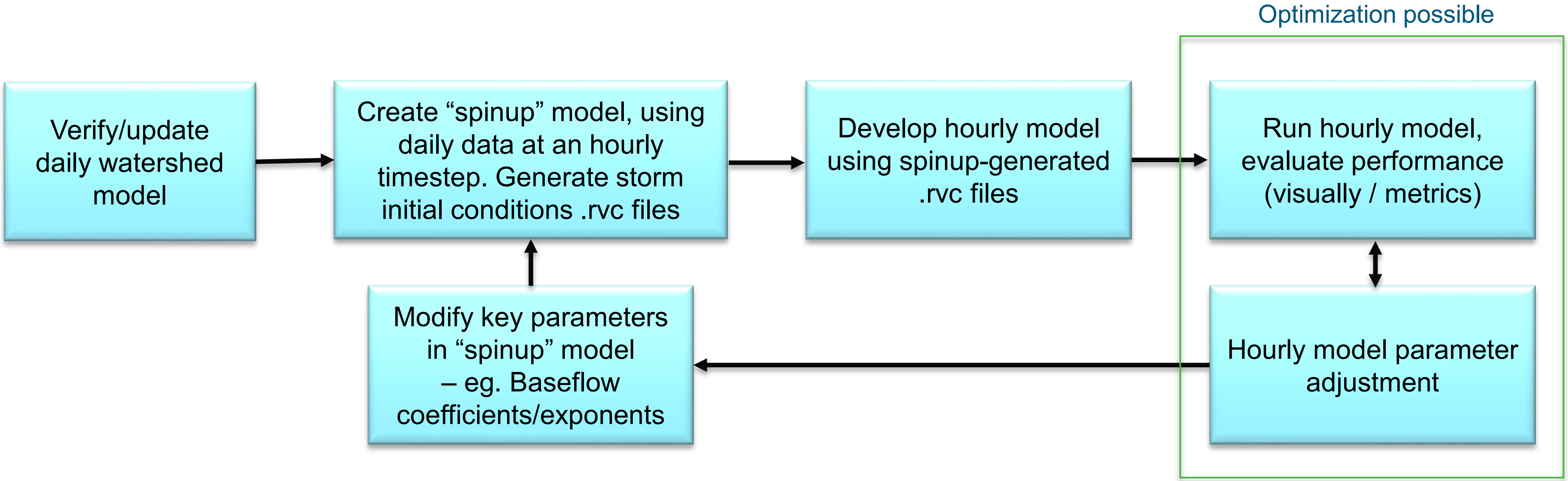
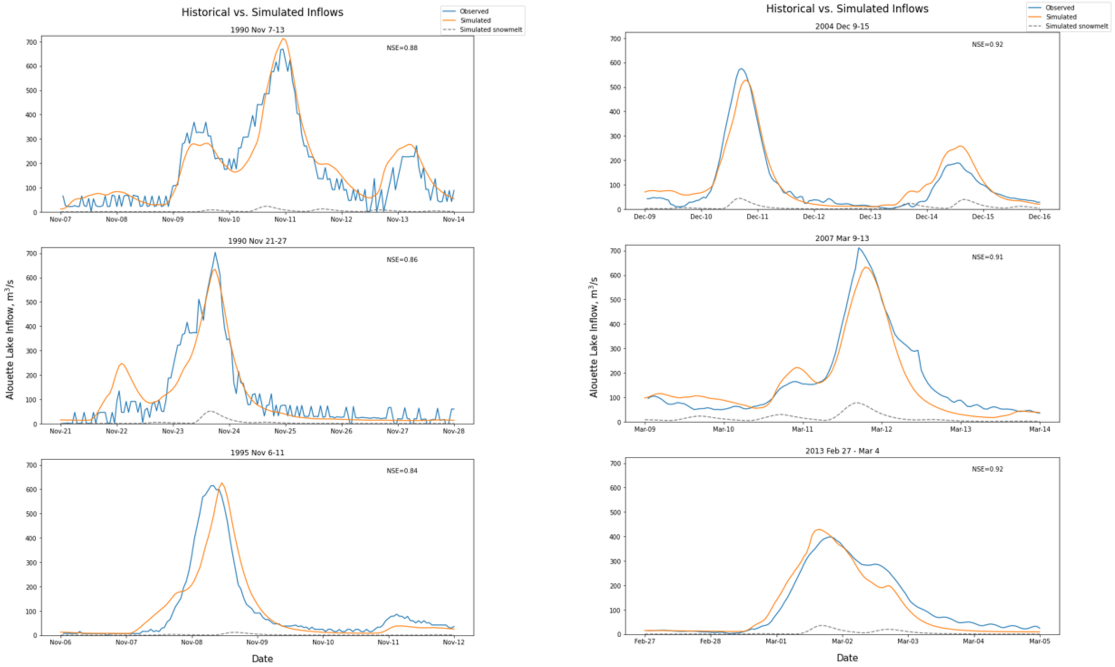


Extreme Flood Calibrations

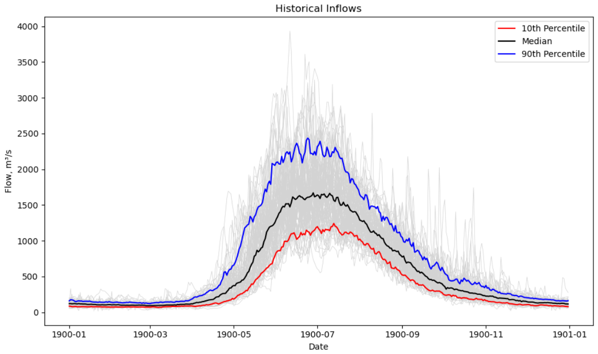
- Helpful to automate running/viewing of results for manual calibrations. I use python to plot storm hydrographs / print key outputs, using the IDE to toggle between different iterations to compare visually.

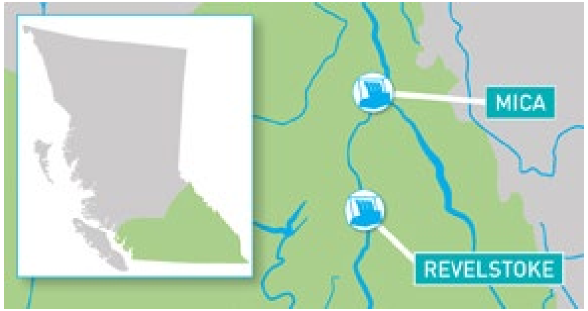


Storm	NSE	Volume error (%)	Hourly peak error (%)	24-hour peak error (%)	Snowmelt to total volume (%)	Obs. peak* (m^3/s)	Obs. 24-hour peak* (m^3/s)
1990 Nov_1	0.88	7	7	1	2	669	493
1990 Nov_2	0.86	0	-10	-10	4	704	453
1995 Nov	0.84	-4	2	-8	1	615	408
1997 Mar	0.88	29	-13	3	10	480	375
2002 Jan	0.81	2	-14	-8	13	460	315
2003 Oct	0.92	14	8	14	0	602	420
2004 Dec	0.92	11	-8	-7	8	575	373
2007 Mar	0.91	-9	-11	-12	10	711	476
2013 Feb	0.92	-8	8	4	5	398	342
2015 Feb	0.94	-1	-2	3	7	332	282
2021 Nov	0.92	-13	-20	-13	2	626	459
Mean	0.89	2	-5	-3			

Case Study – Mica PMF Study

- Mica Dam is located on the Columbia River, 137 km north of Revelstoke, BC.
- First in a series of three major dams on the Columbia River.
- Watershed area 21,156 km^2.
- Snowmelt dominated inflow hydrograph



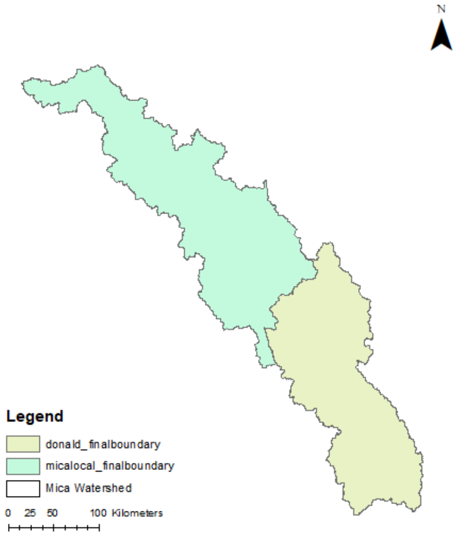


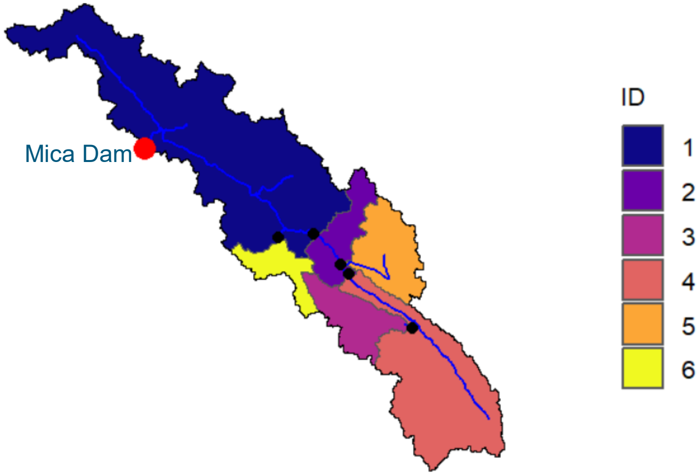
Mica PMF – Model Comparison

- Two Raven-based watershed models calibrated for this study: UBC Watershed Model and “HBVS”

Mica PMF – Model Comparison

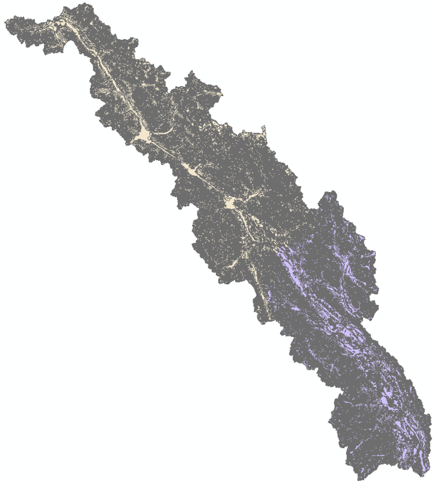
	UBC Watershed Model	HBVS
Sub-basins:	2 – Mica Local, Donald	6 – Divided at WSC gauges, main outlets





Mica PMF – Model Comparison

	UBC Watershed Model	HBVS
HRU Division:	37 (Donald) 38 (Mica Local) Nine elevation bands, split by land cover and aspect	776 Split based on sub-basin, elevation, land cover, slope and aspect

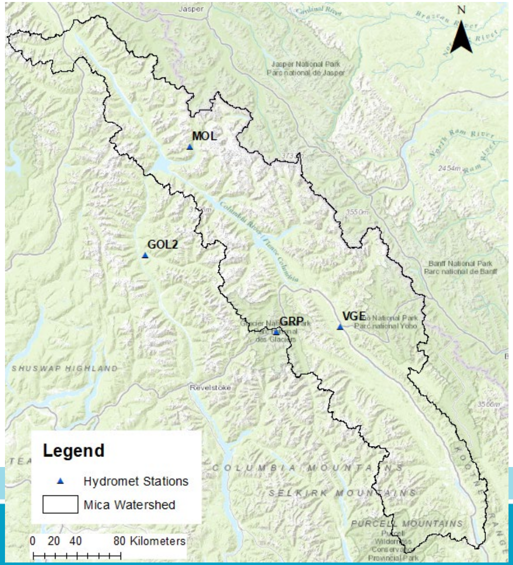


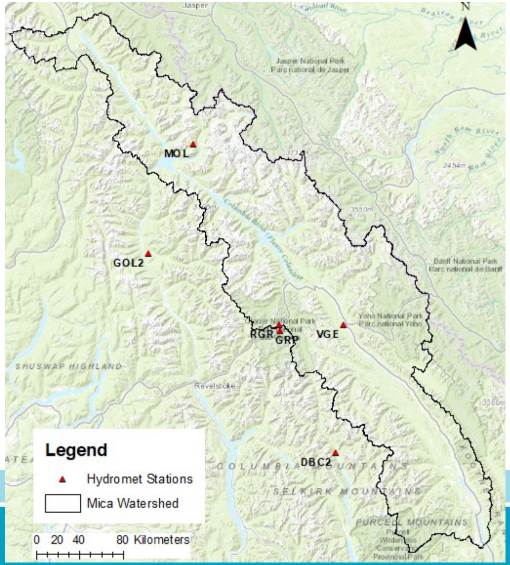
Mica PMF – Model Comparison

	UBC Watershed Model	HBVS
Routing:	None (lumped). Donald and Mica Local inflows added together to get Mica Total inflow.	Semi-distributed with routing between sub-basins.

Mica PMF – Model Comparison

	UBC Watershed Model	HBVS
Forcing data:	Donald – 2 (GRP, VGE) Mica Local – 4 (GRP, MOL, GOL2, VGE) Gauge weights used to develop inputs for each HRU	6 (GRP, RGR, MOL, GOL2, VGE, DBC2) Nearest neighbour interpolation to distribute gauge data based on lat/lon coordinates and elevations.



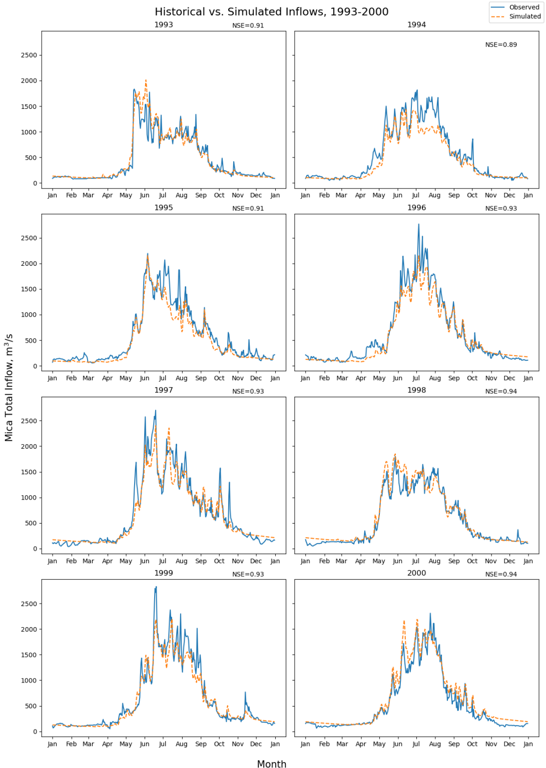


Mica PMF – Model Comparison

Calibration (daily):

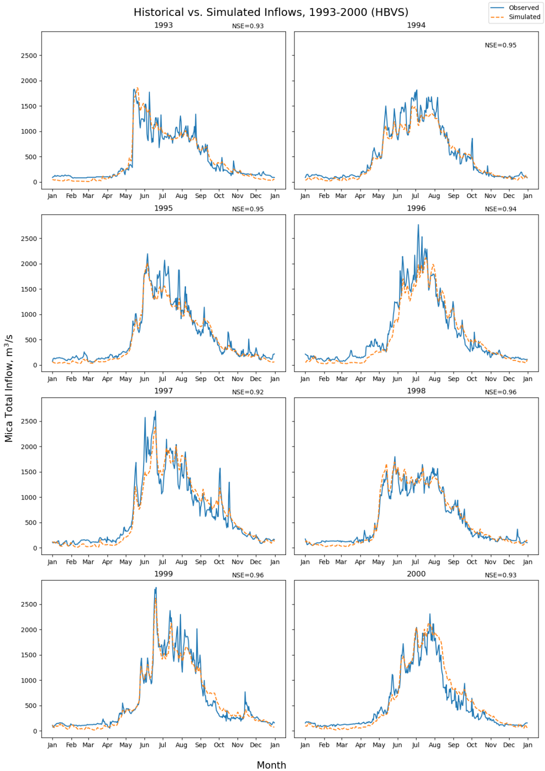
UBC Watershed Model

NSE=0.93, KGE=0.95



HBVS

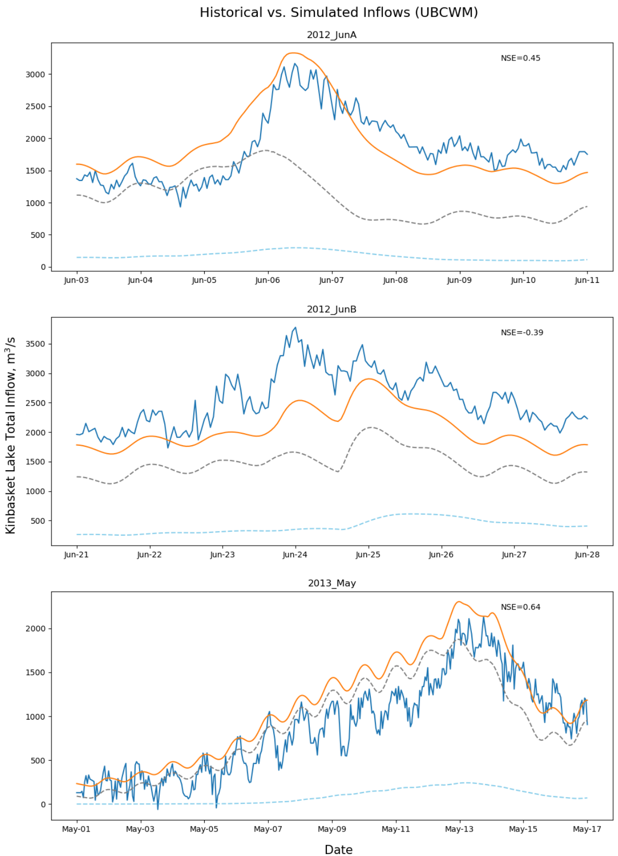
NSE=0.94, KGE=0.96



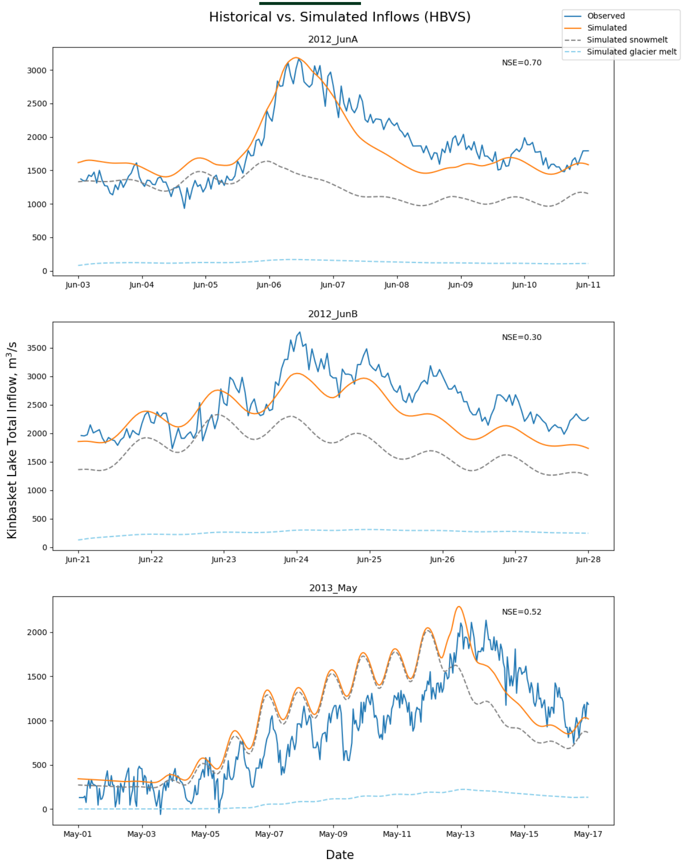
Mica PMF – Model Comparison

Calibration (hourly):

UBC Watershed Model



HBVS



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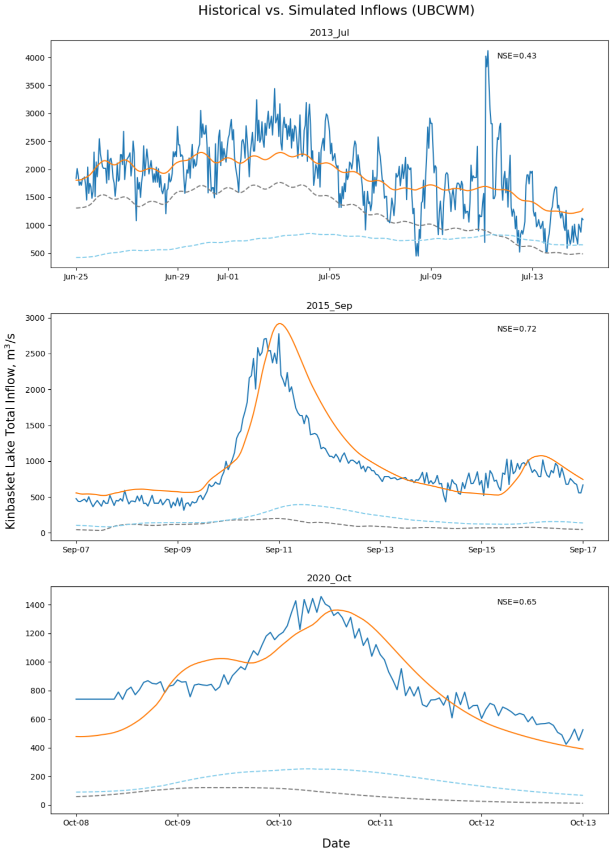

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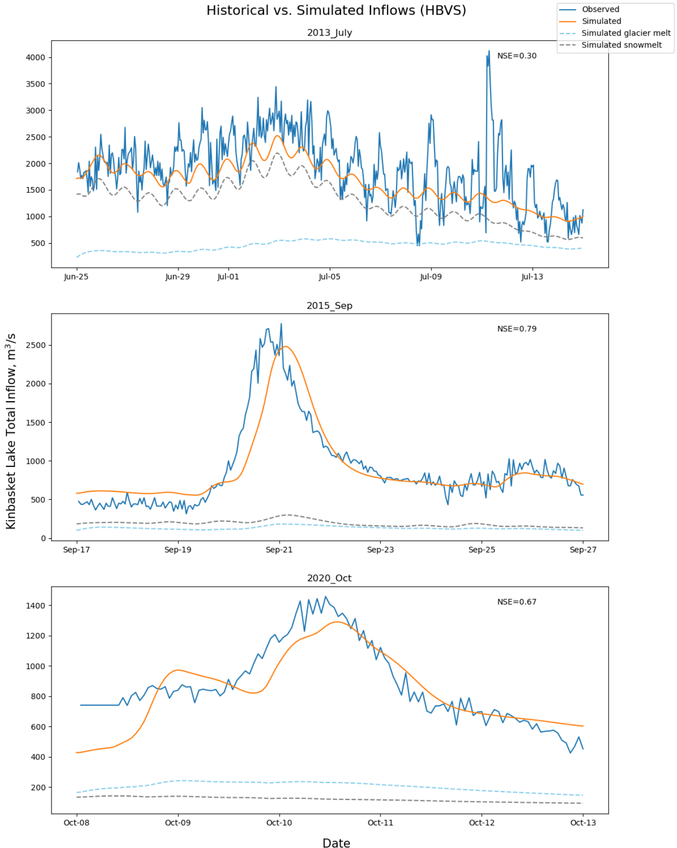

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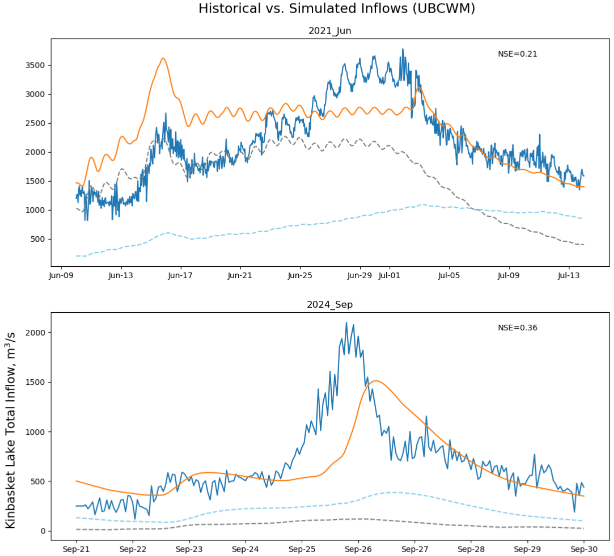

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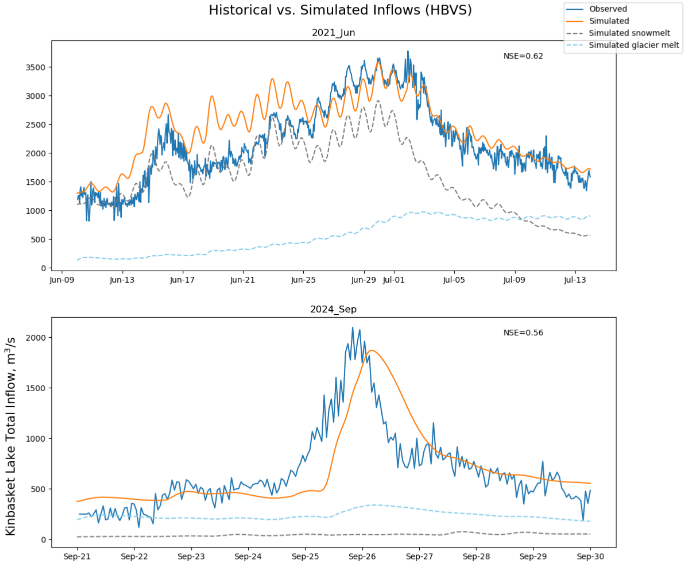


Mica PMF – Model Comparison

Calibration (hourly):

UBC Watershed Model

Storm	NSE	Volume error (%)	Hourly peak error (%)	24-hour peak error (%)
2012_JunA	0.45	3	5	10
2012_JunB	-0.39	-19	-23	-18
2013_May	0.64	27	8	16
2013_Jul	0.43	-2	-44	-19
2015_Sep	0.72	11	5	13
2020_Oct	0.65	-4	-6	-2
2021_Jun	0.21	9	-4	2
2024_Sep	0.36	-4	-28	-14
Average	0.38	3	-11	-1

HBVS

Storm	NSE	Volume error (%)	Hourly peak error (%)	24-hour peak error (%)
2012_JunA	0.70	-1	1	3
2012_JunB	0.30	-9	-19	-12
2013_May	0.52	23	7	6
2013_Jul	0.30	-13	-39	-18
2015_Sep	0.79	0	-11	-4
2020_Oct	0.67	-4	-11	-7
2021_Jun	0.62	11	-5	-2
2024_Sep	0.56	2	-11	3
Average	0.56	1	-11	-4

- Both models perform fairly well for emulation of hourly flood hydrographs. HBVS is better, but not significantly.
- How will these models compare in extrapolation for large floods?

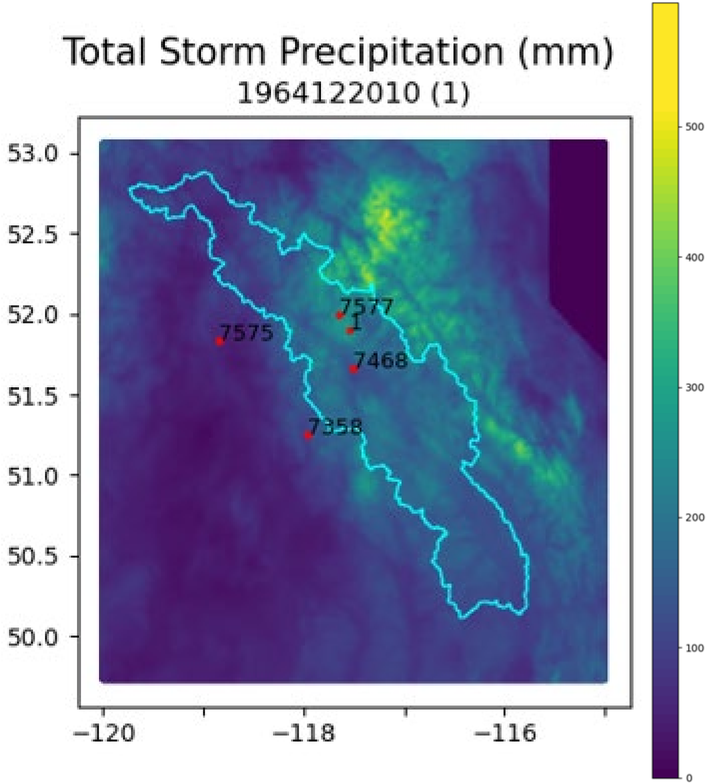
Mica PMF – PMF Input Development

- CDA PMF Scenarios:

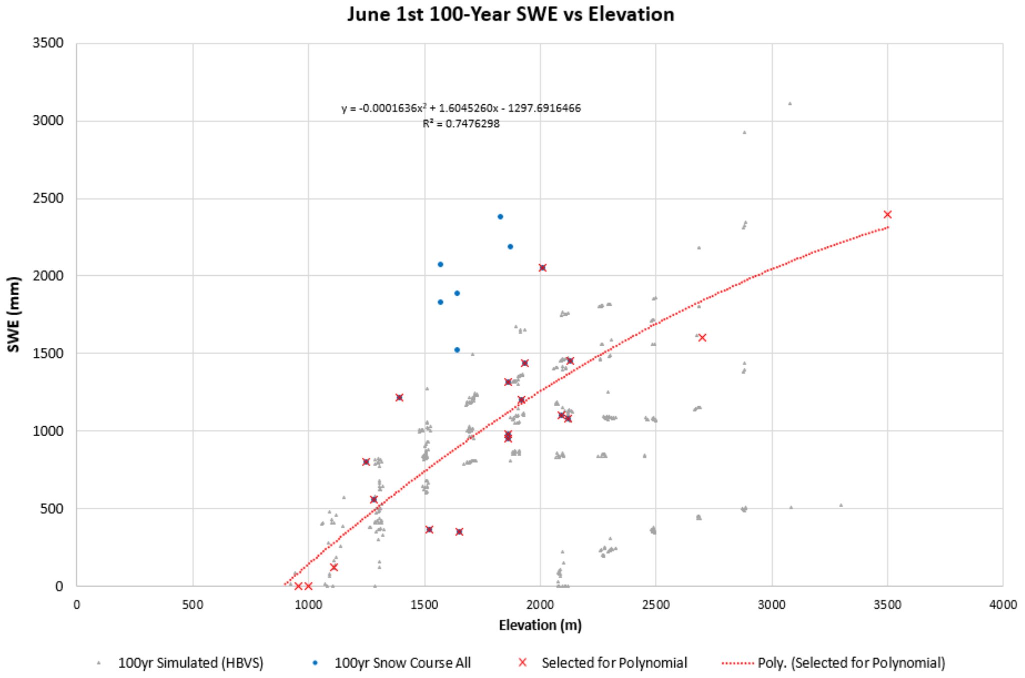
	Initial Condition	Sequence		
Spring	100-year snowpack	100-year Critical Temperature Sequence	Transition period	PMP Storm
	Probable Maximum Snow Accumulation	100-year Critical Temperature Sequence	Transition period	100-year Storm
Late Summer/Autumn (+ Winter in coastal regions)	No/Average Snowpack	100-year antecedent Storm	Transition period	PMP Storm

Mica PMF – PMF Input Development

- MetPortal used to develop PMP for the basin which is based on a storm that occurred in 1964
- Spatial / temporal PMP storm pattern distributed to each HRU to generate a single input file per HRU – Python calculates basin average precipitation at each time step
- Temperatures – storm temperature file provided by MetPortal, location shifted and lapsed to elevation of each HRU
- Use a Raven GaugeWeights file to link each HRU to its corresponding gauge inputs
- Details → *King, L. M. and Micovic, Z. (2022) Application of the British Columbia MetPortal for Estimation of Probable Maximum Precipitation and Probable Maximum Flood for a Coastal Watershed. Water 14(5):785.*



Mica PMF – PMF Input Development

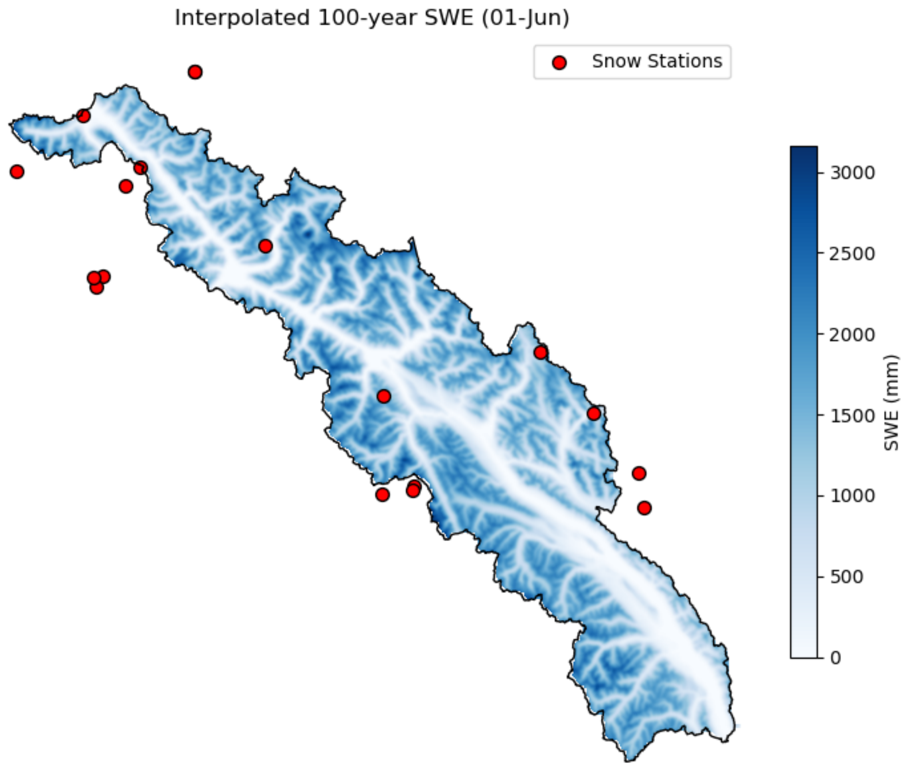


- Snow inputs – compare simulated to estimated 100-year snowpack from snow course data (Python frequency analysis)
- In previous studies – estimate trendline and fit curve. This could oversimplify spatial variation in snowpack for such a large basin.
- Using Raven simulated 100-year SWE looks promising, as there is some overlap between the simulated values and the observations but may not be defensible as not tied to observations directly.

Mica PMF – PMF Input Development

- Decision to spatially map 100-year observed SWE from snow course data, using locally-weighted linear regression on elevation.

- This better reflects the spatial variation within the watershed, though may still be conservative → Is it reasonable to have a consistent, 100-year snowpack across such a large basin?



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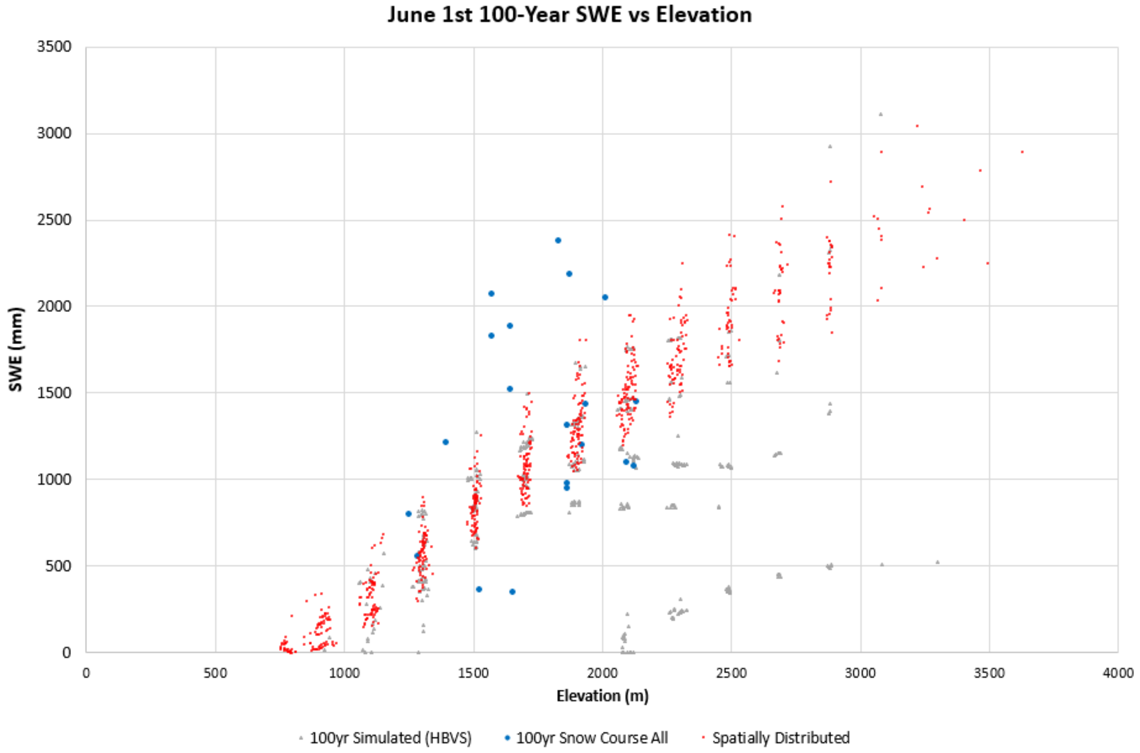
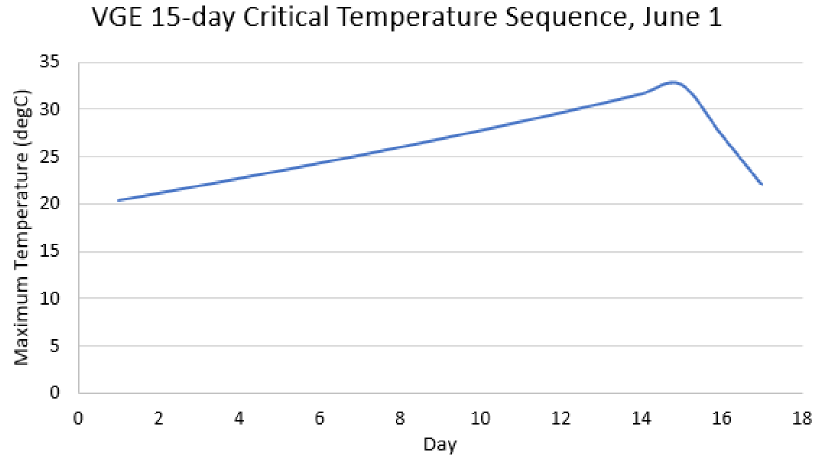


- Spatially mapped 100-year SWE averaged over each HRU and used in initial conditions .rvc files for spring PMF scenarios.
- Spatially mapped HRU estimates found to agree fairly well with both observed and simulated 100-year estimates.
- Approach allows for a direct comparison between HBVS and UBC models which would not be possible using the simulated estimates.

Mica PMF – PMF Input Development

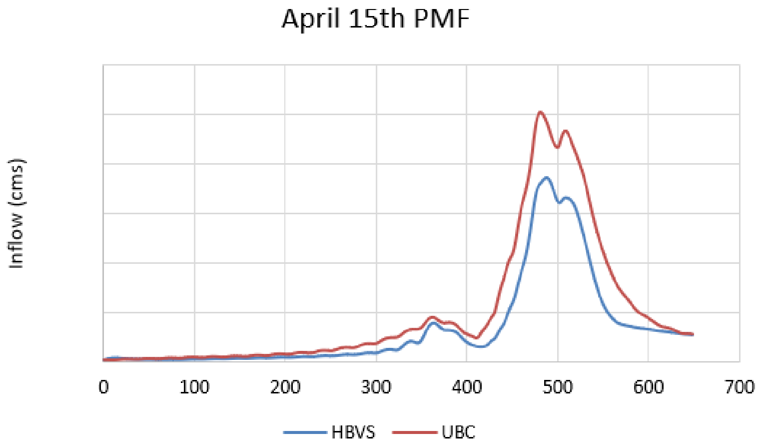
- Hot temperature sequences derived for VGE gauge by performing frequency analysis of maximum cumulative multi-day temperature sequences up to various simulation start dates.
- 15-day hot temperature sequence, 2-day return to average temperatures, followed by the PMP.
- Sequences lapsed up for each HRU based elevation and assumed lapse rate.
- Different sequence lengths need to be verified in sensitivity analysis (we test 5, 10 and 15-day lengths in SEFUP)

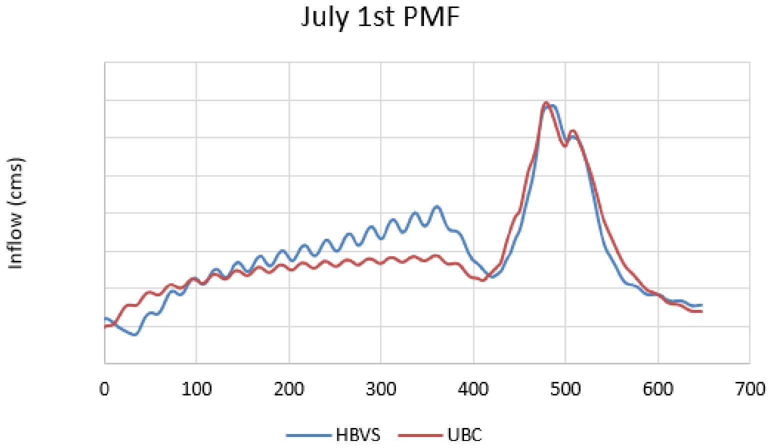


Mica PMF Results

- Preliminary results indicate significant difference between models for some scenarios – up to 26%! UBC producing higher inflows.
- July 1st peak inflows quite similar.

Scenario	Peak inflow difference (%)
Apr15 (Spring PMP)	-26
May1 (Spring PMP)	-19
May15 (Spring PMP)	-13
Jun1 (Spring PMP)	-11
Jun15 (Spring PMP)	-8
Jul1 (Spring PMP)	-1
Jul15 (Spring PMP)	-7
Aug1 (Spring PMP)	-9
Aug15 (Spring PMP)	-18
Aug (Late Summer/Fall)	-26
Sep (Late Summer/Fall)	-19
Oct (Late Summer/Fall)	-13
Nov (Late Summer/Fall)	-11





Mica PMF Results

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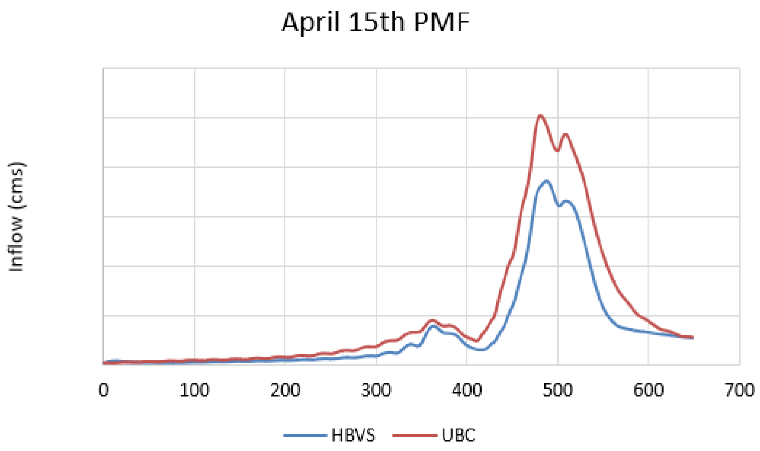
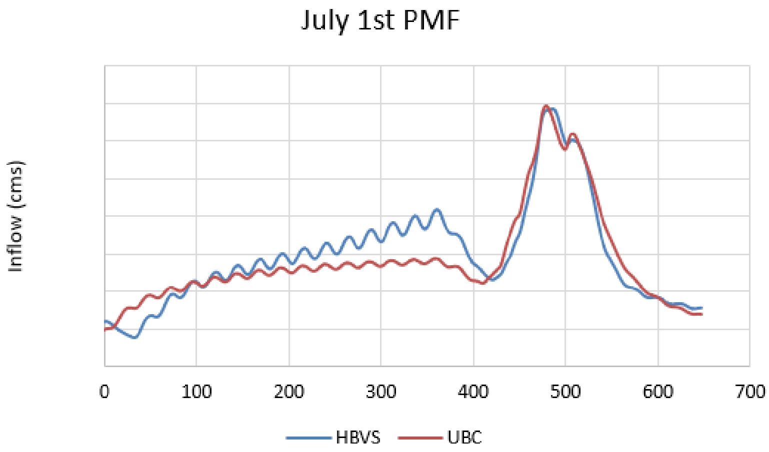
- Typically, the upper bound sensitivity scenario from SEFUP studies is based on the 95th percentile PMP and is generally <=20% greater than the base case estimate.





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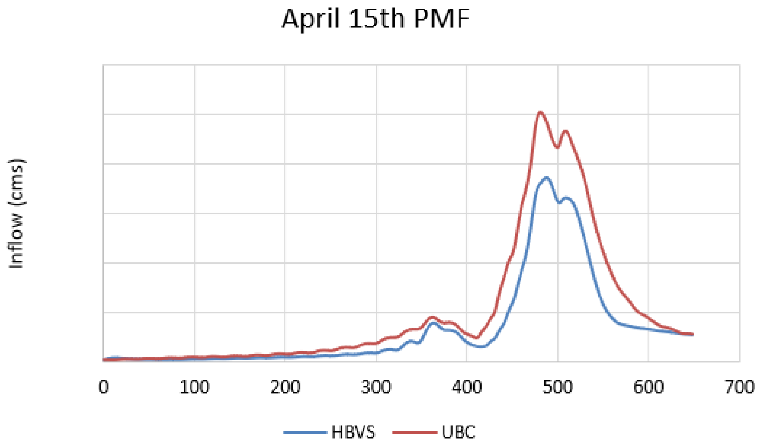
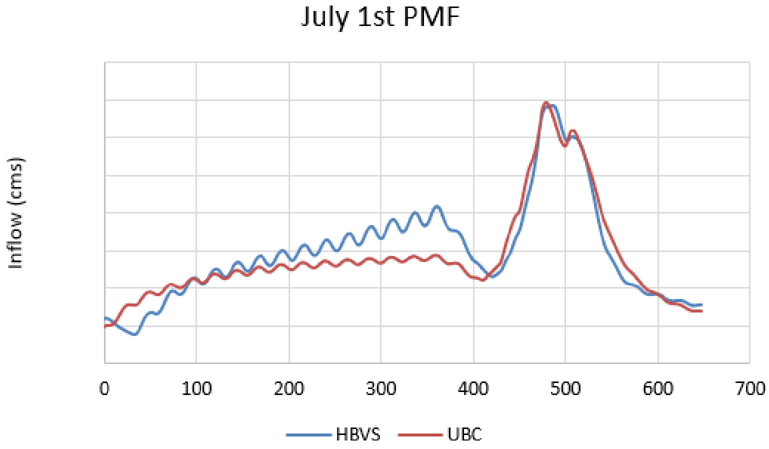
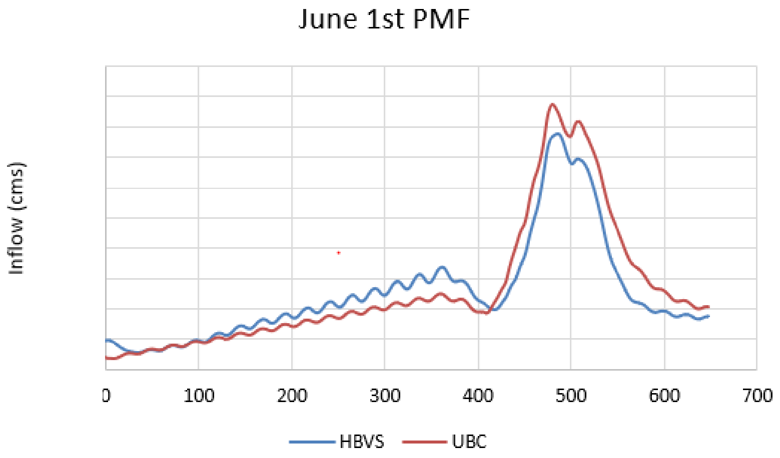
- Typically, the upper bound sensitivity scenario from SEFUP studies is based on the 95th percentile PMP and is generally <=20% greater than the base case estimate.
- This implies model uncertainty could exceed PMP uncertainty!

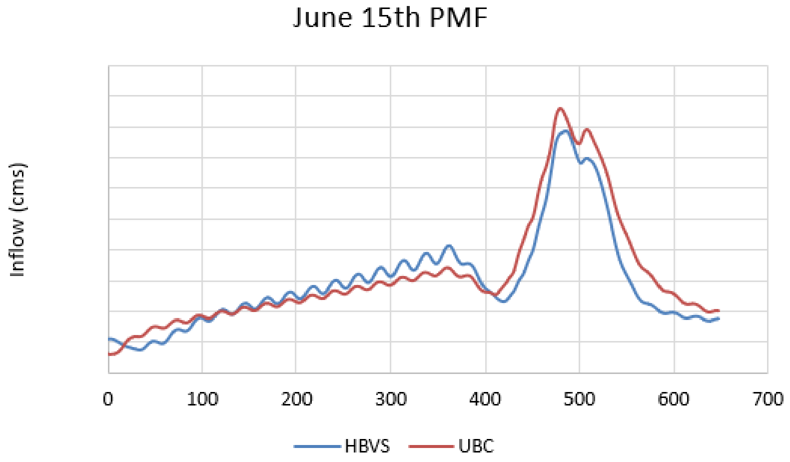




Mica PMF Results

- UBC model has peak inflows occurring on June 1st. HBVS model has peak inflows occurring on June 15th.

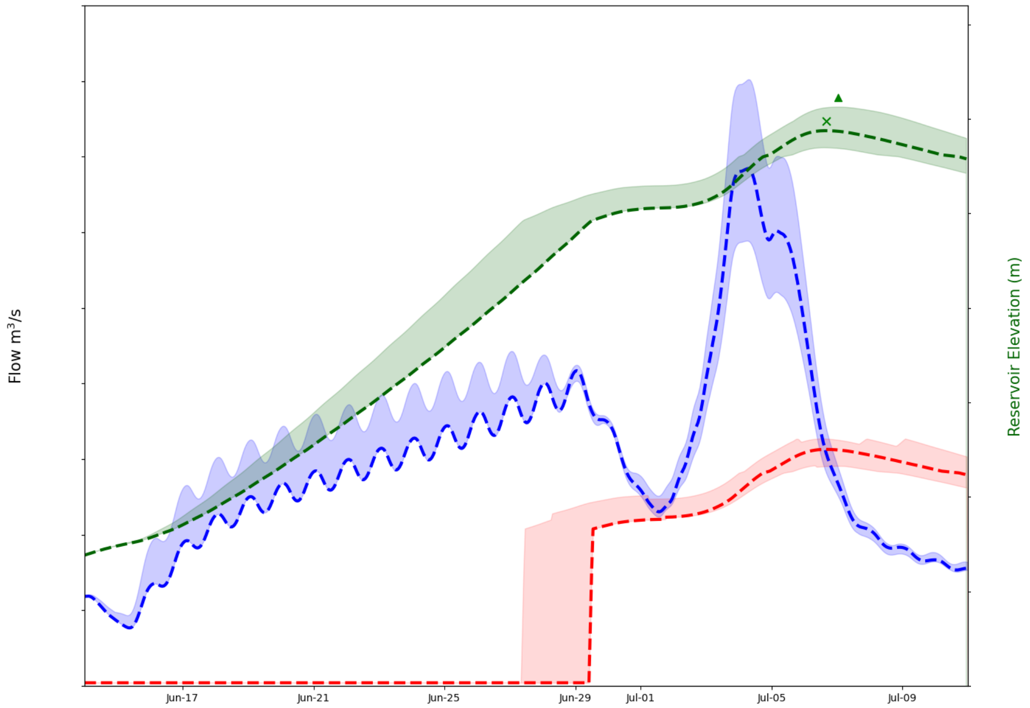




Mica PMF Results

- Governing PMF scenario is July 1st, based on preliminary routing with HBVS model (highest reservoir elevations). This is because there are higher starting reservoir elevations than in earlier scenarios.
- BC Hydro is presenting our PMFs as a value with uncertainty, moving away from a single estimate.

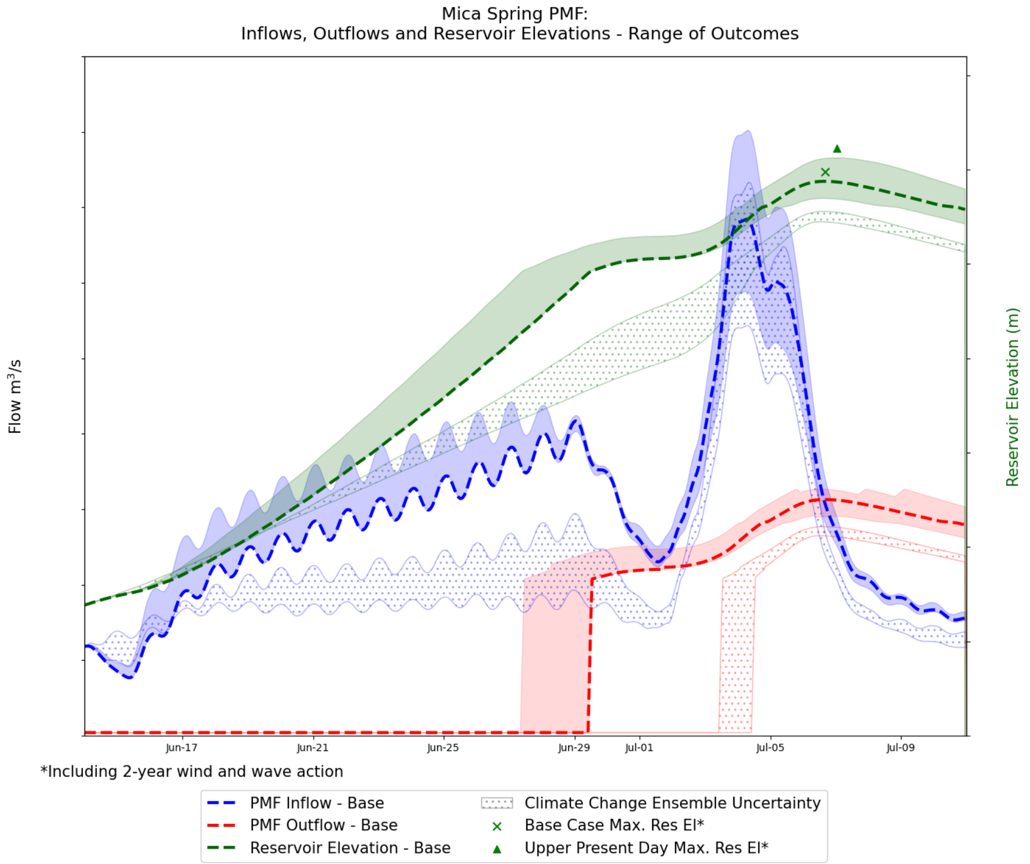
Mica Spring PMF:
Inflows, Outflows and Reservoir Elevations - Range of Outcomes



*Including 2-year wind and wave action

Mica PMF Results

- Climate change also being considered – see *King, L. M. and Micovic, Z. (2024) Characterizing climate change uncertainty on extreme floods using open access data portals. CDA 2024 Annual Conference. September 22-25, Niagara Falls, Canada.*



Mica PMF Results Discussion

- Why such a big difference between HBVS and UBC models?
    - Different snowmelt/glacier melt equations and assumptions.
    - UBC model has slightly higher rain/snow transition temperature (0.2-0.3°C)
    - Potential “compensating parameters” effect - some purely speculative examples of this:
        - Perhaps in the HBVS model, I increased the precipitation multipliers in the forcing data (+10-15%), instead of turning up some percolation / infiltration parameters.
        - Perhaps in the UBC model, the slightly higher rain/snow threshold is compensating for higher lapse rates.
        - Difficult to pin these down...

Mica PMF Results Discussion

- How to limit the difference to the extent possible?
  - Get to know the model parameters. What ones are most sensitive? Is it possible our model is compensating for an unrealistic value of one parameter elsewhere? Are the values we've selected reasonable?
  - May need to revisit calibrations and iterate if something becomes obvious based on results comparison.
  - Ensure a wide variety of high inflow events are considered – rain, rain on snow, and snowmelt – to get the most robust calibrations possible.
  - Consider using optimization to determine multiple acceptable parameter sets and compare results using different .rvp files.

Conclusion

- Nine SEFUP studies completed so far.
- The first few calibrations were a bit rocky as we learned the nuances of Raven and got into the weeds of the modelling.
- We now feel we have a defensible model calibration process in place, and calibration development is going much smoother for the latest studies.
- Important to ensure parameters are reasonable in extrapolating calibrations for extreme floods; consider wide range of inflow events for hourly storm calibrations.
- Could consider including multiple models or parameter sets in future studies as this could be a substantial source of uncertainty in PMF estimates that isn’t typically considered (by us or any other dam owners, as far as I know).

Questions?

BC Hydro

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