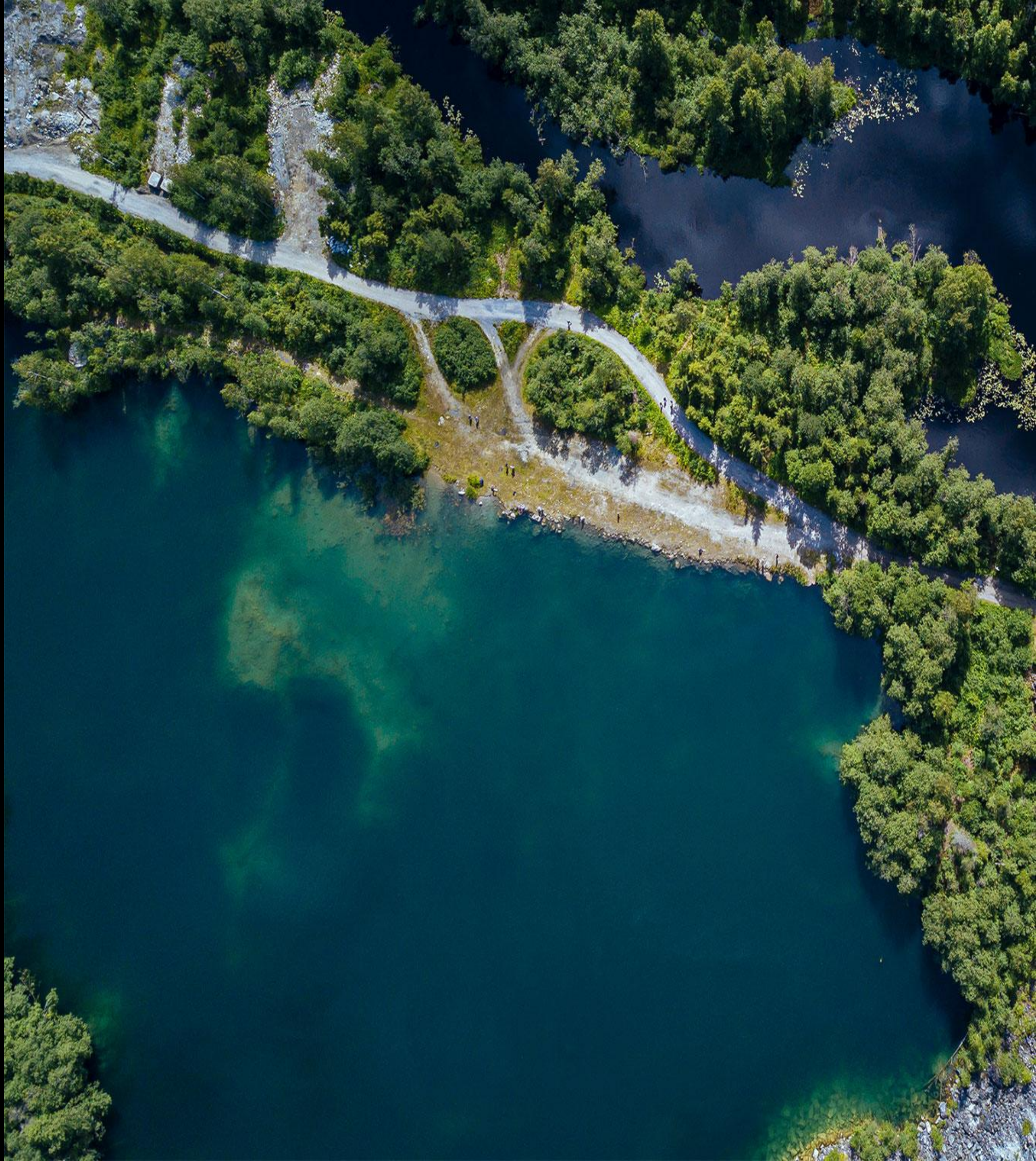
SUBTRACTIVE FLOW METHODOLOGY FOR FLOOD MAPPING AT TRIBUTARY CONFLUENCE

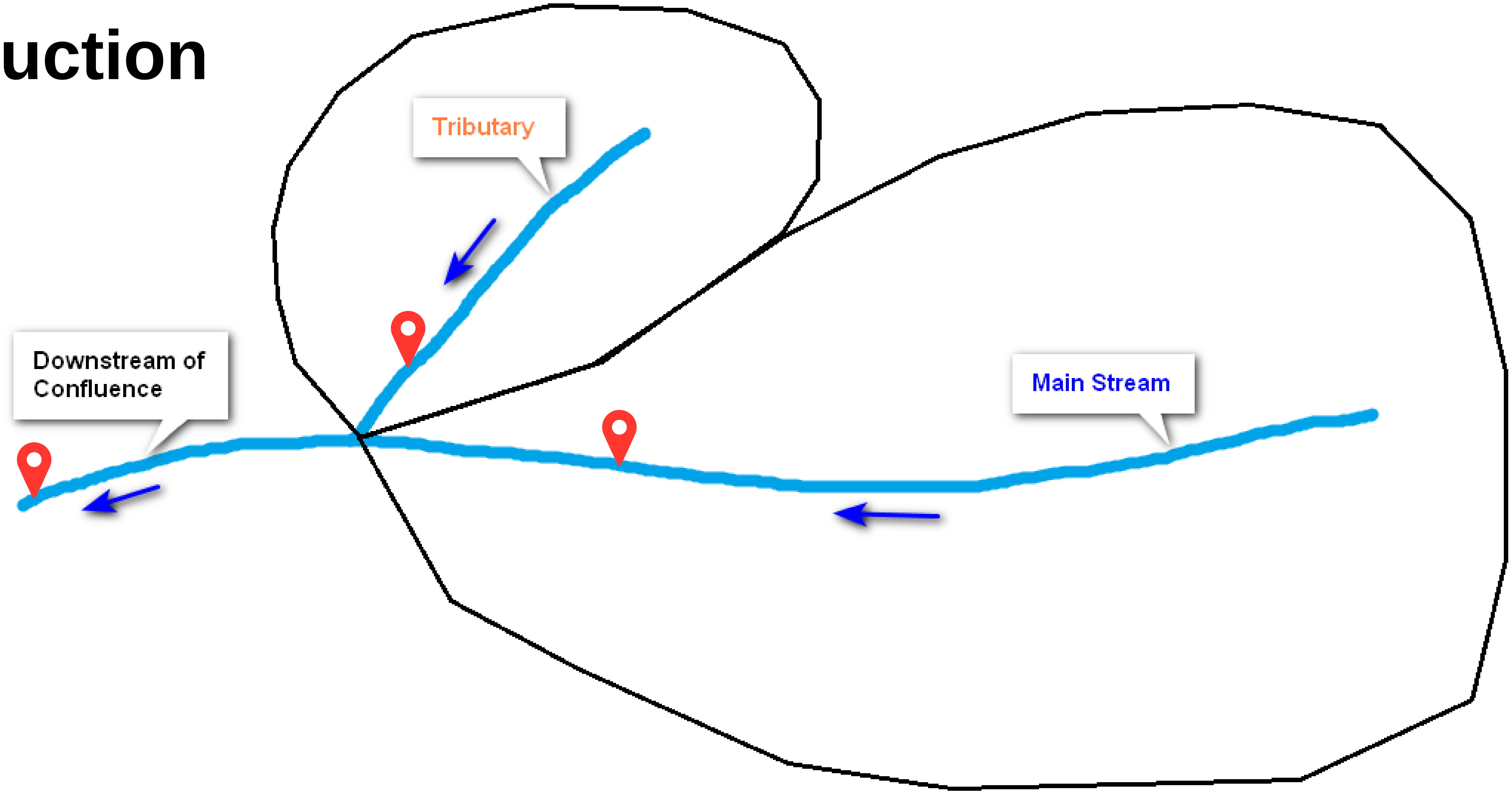


Wolf Ploeger | February 2025

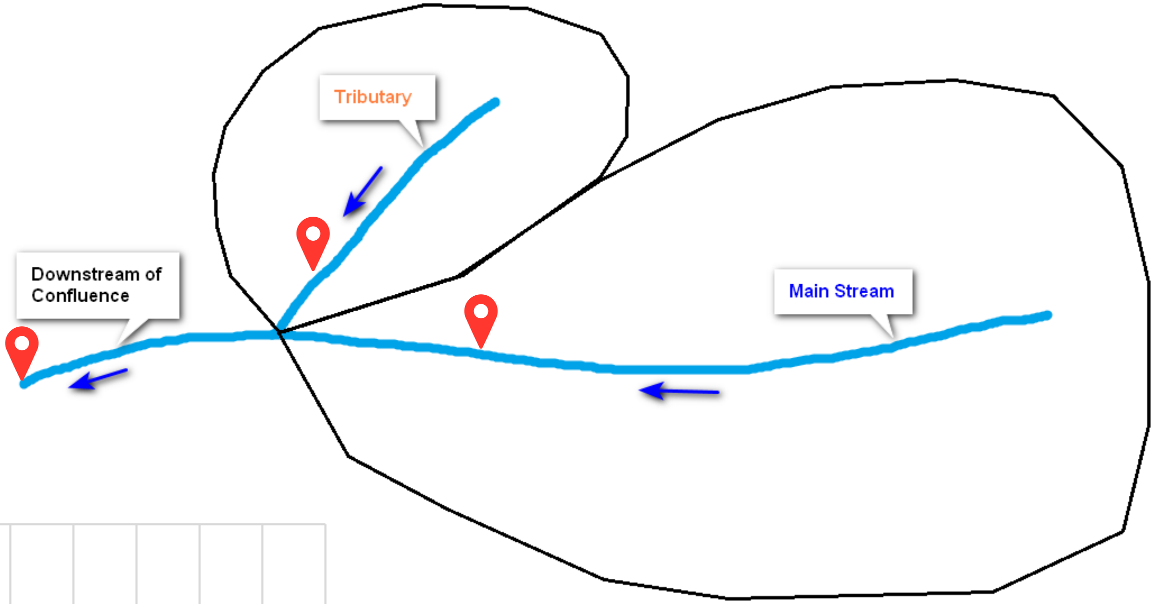
Agenda

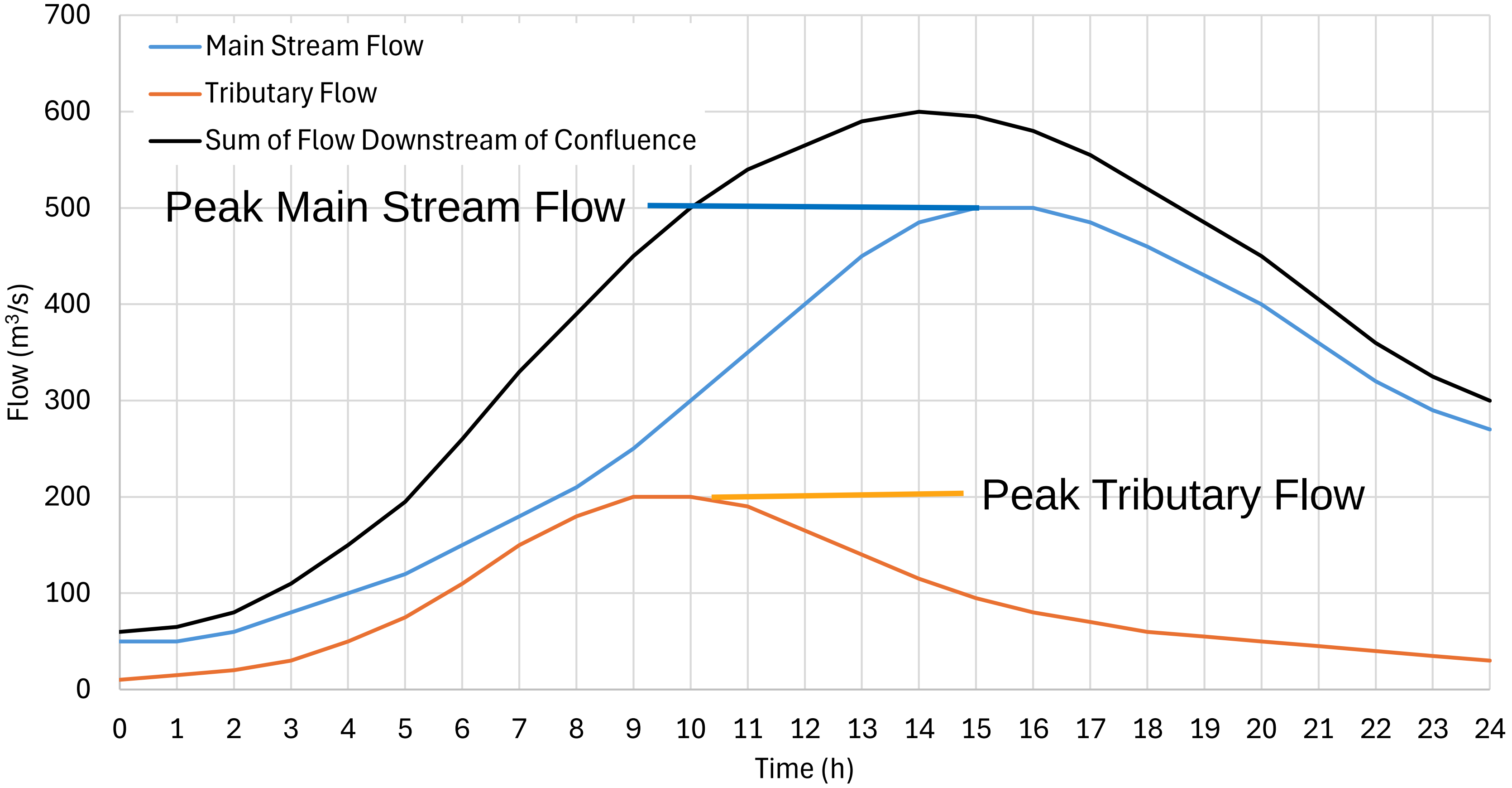
- Introduction
- Flows at Tributary Confluences
- Modelling Flow Changes 1D vs. 2D Modelling
- Example: Kicking Horse River confluence at Golden, BC
- Conclusion

Introduction



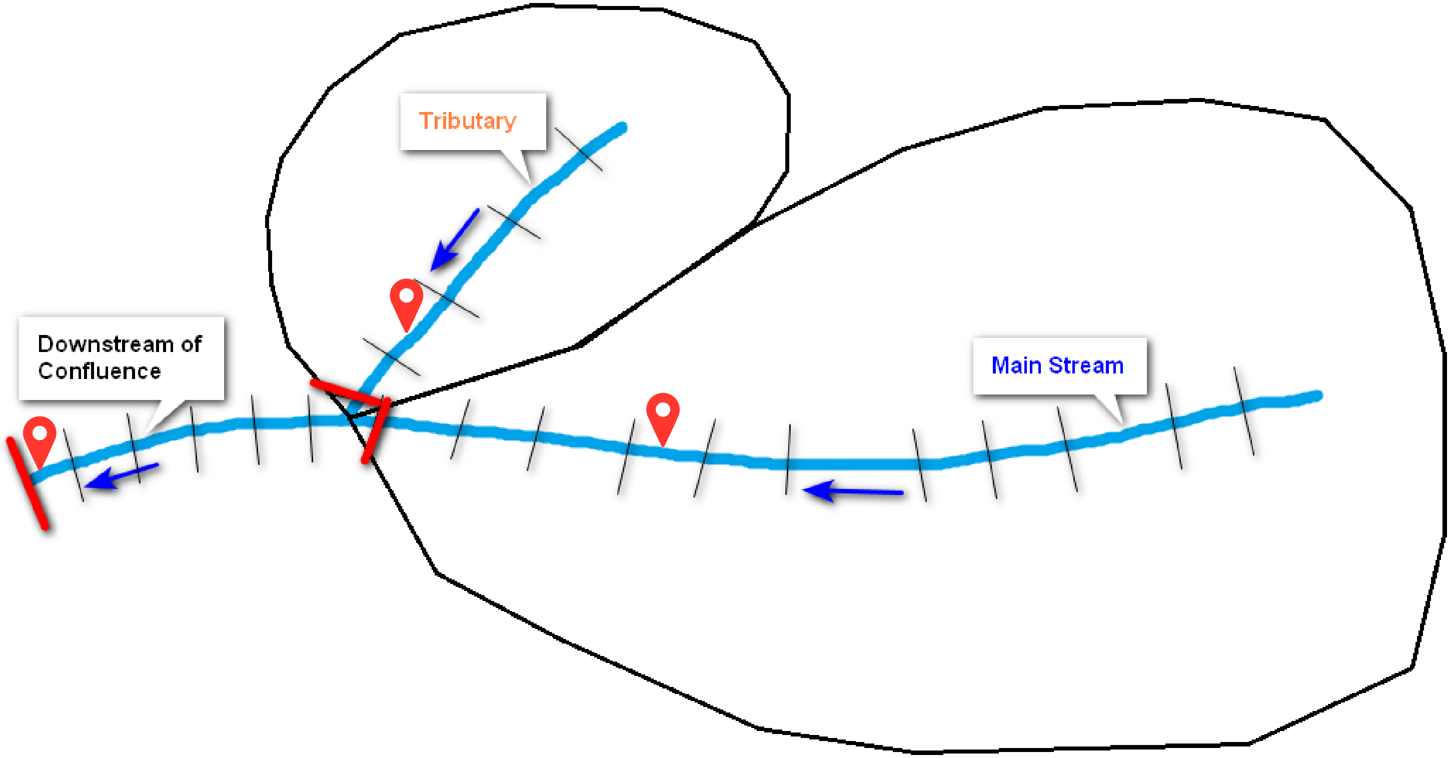
Introduction





Peak flow downstream is less than addition of peak Main Stream and Tributary flows

Hydrology
1D Steady State



1. Flood Frequency Analysis

a) Main Stream u/s of Tributary

b) Main Stream d/s of Tributary

c) Tributary

2. Flow change locations

a) Main Stream downstream boundary condition

b) Main Stream cross section immediately upstream of Tributary

c) Tributary upstream of confluence

No	Location	Flow (m^3/s)
A	Main Stream - Upstream of Confluence	500
B	Tributary – Upstream of Confluence	200
C	Main Stream - Downstream Boundary	600

(C < A + B)

Hydrology
1D/2D Unsteady State

1. Hydrology Assessment

a) Flood Frequency Analysis

b) Flood Volume Analysis

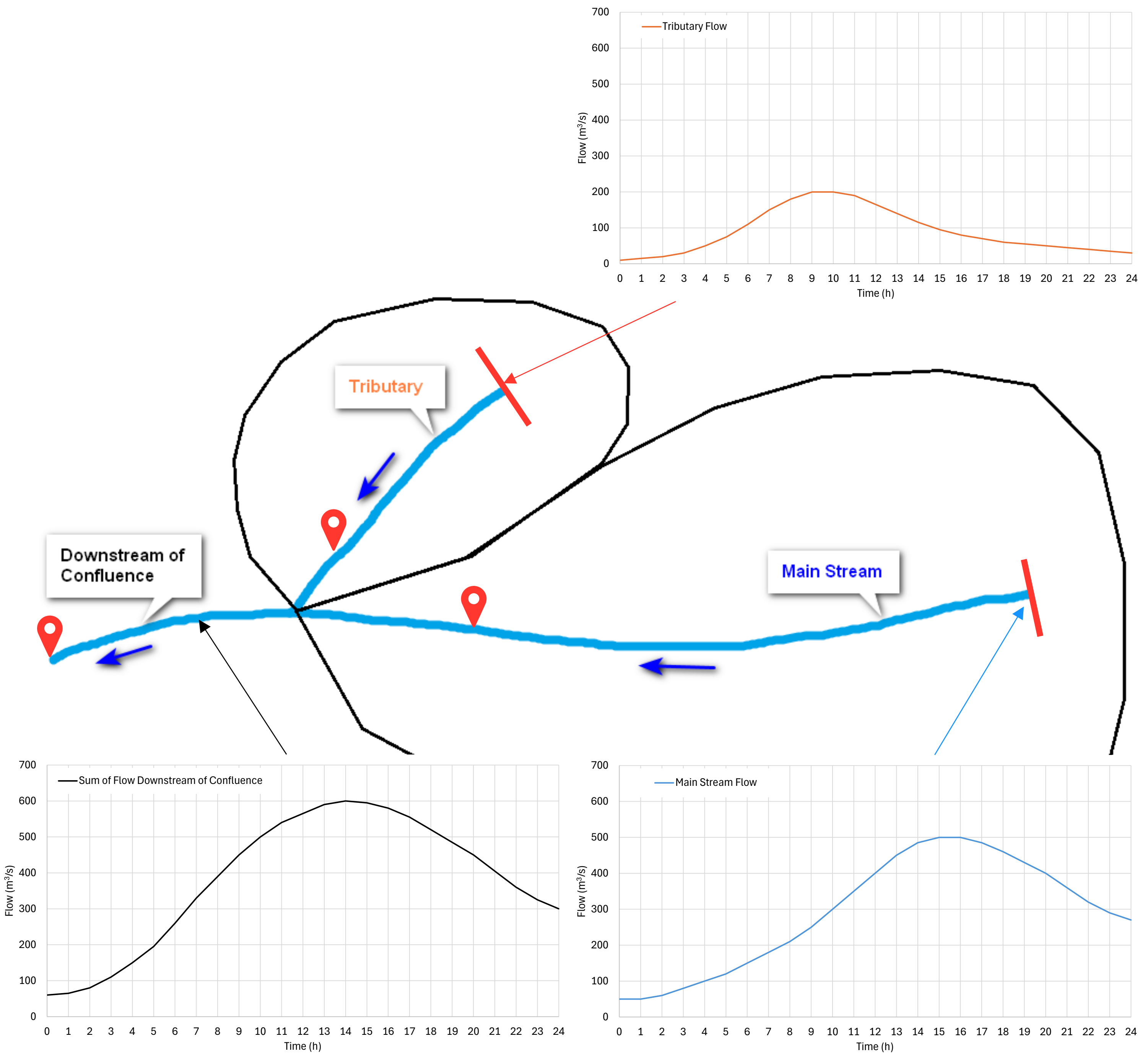
c) Design Flood Hydrograph Development (shape, timing)

2. Design Flood Hydrographs as Upstream Boundary Conditions

a) Main Stream upstream boundary condition

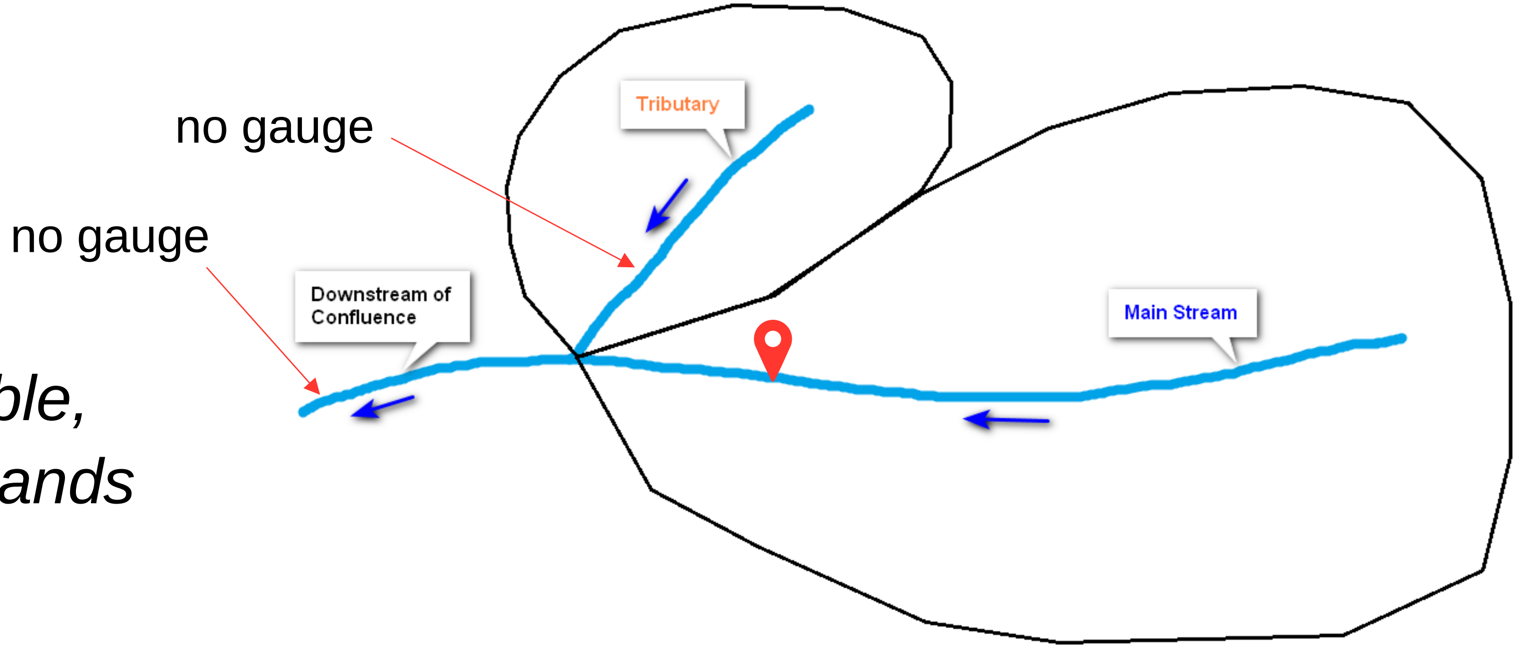
b) Tributary upstream boundary condition

3. Flow Downstream of Confluence is Result of Simulation



Challenge:

Limited hydrology data is available, but topographic complexity demands 2D modelling?

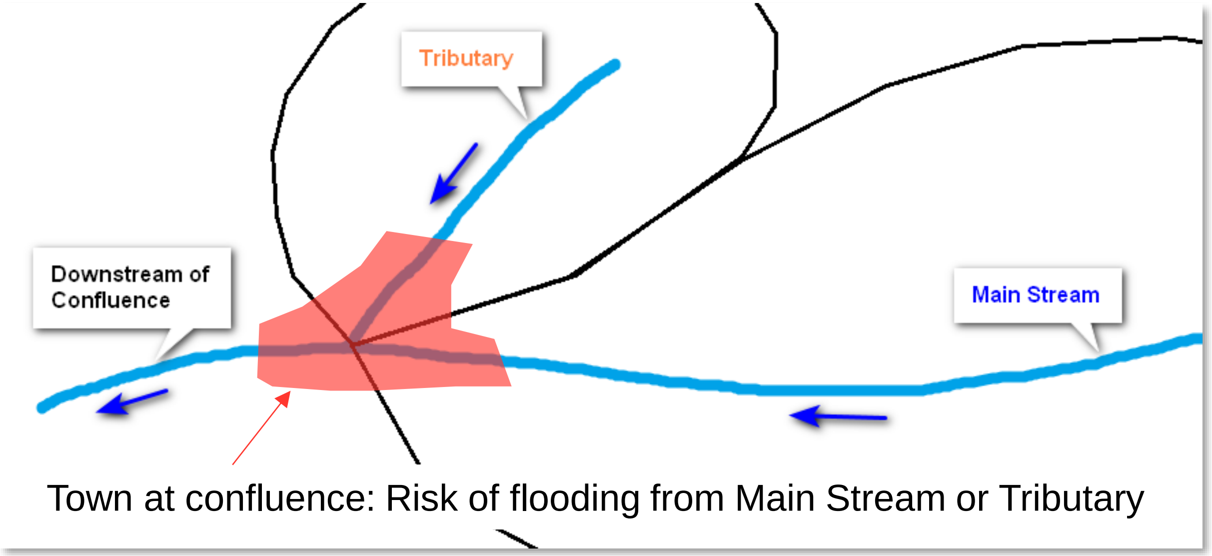


Option: Regional analysis to estimate peak flow and volume, transfer measured hydrograph from nearby stream/station, estimate timing (but how?) -> Unsteady 2D modelling

Option: Rainfall runoff modelling to estimate flood hydrograph (but how to calibrate?) -> Unsteady 2D modelling

Option: Regional analysis to estimate peak flows -> Quasi steady state 2D modelling (ramp up to constant peak flow, similar to 1D steady state approach) wsp

Flood Mapping

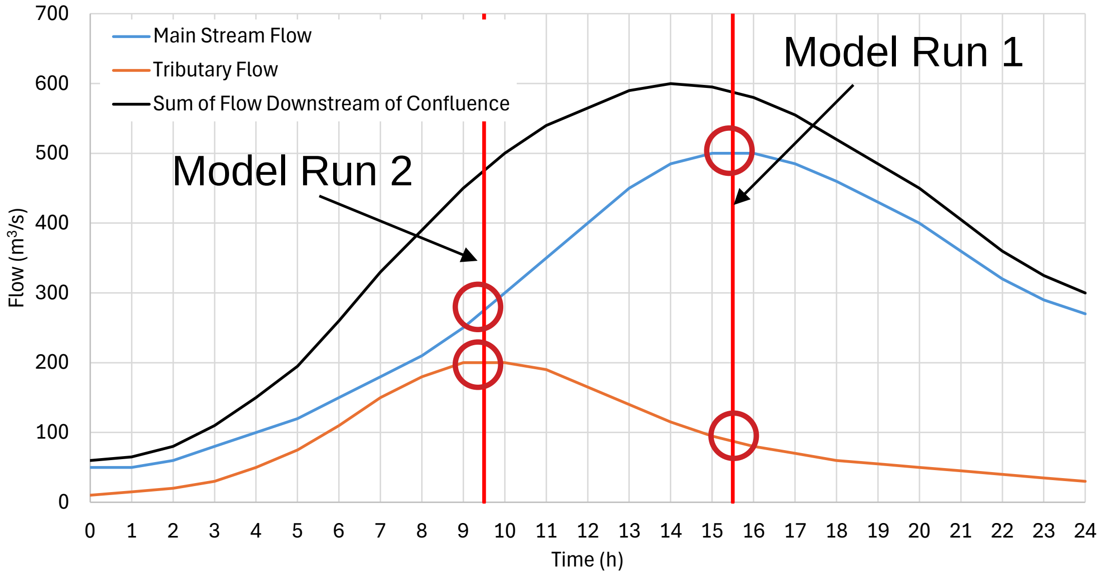


1D Model - Steady State Standard Approach:

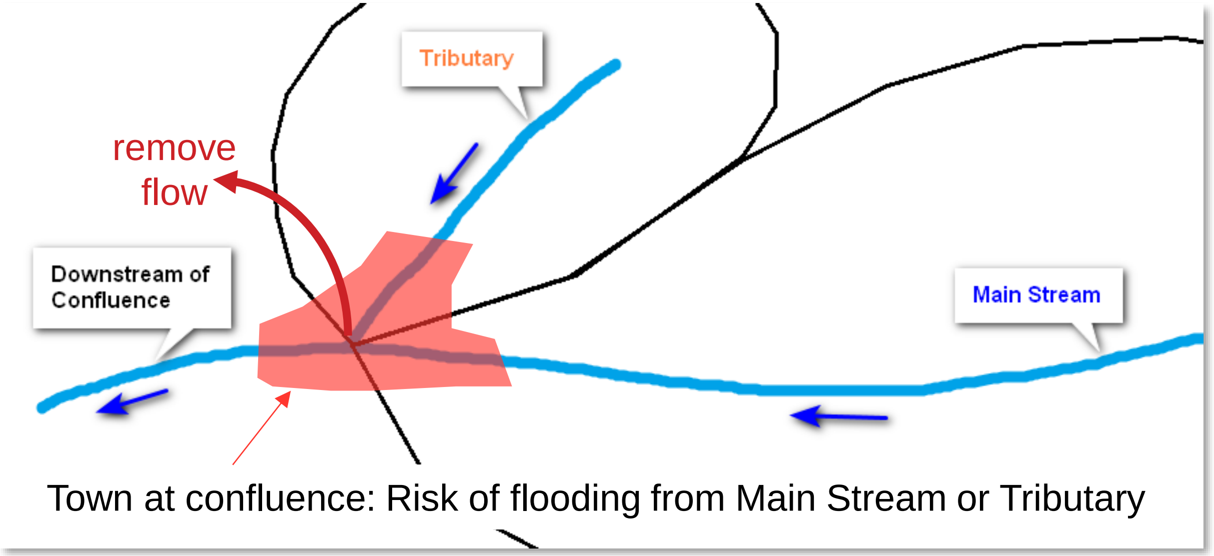
- Set flow change locations, flow does not have to add up
- Run model once, peak water levels at each cross section

2D Model - Steady State Approach A

- Model Run 1: Peak Main Stream flow and regional contribution of Tributary flow (less than peak flow)
- Model Run 2: Peak Tributary flow with corresponding flow in Main Stream (less than peak flow)
- Overlay results



Flood Mapping



1D Model - Steady State Standard Approach:

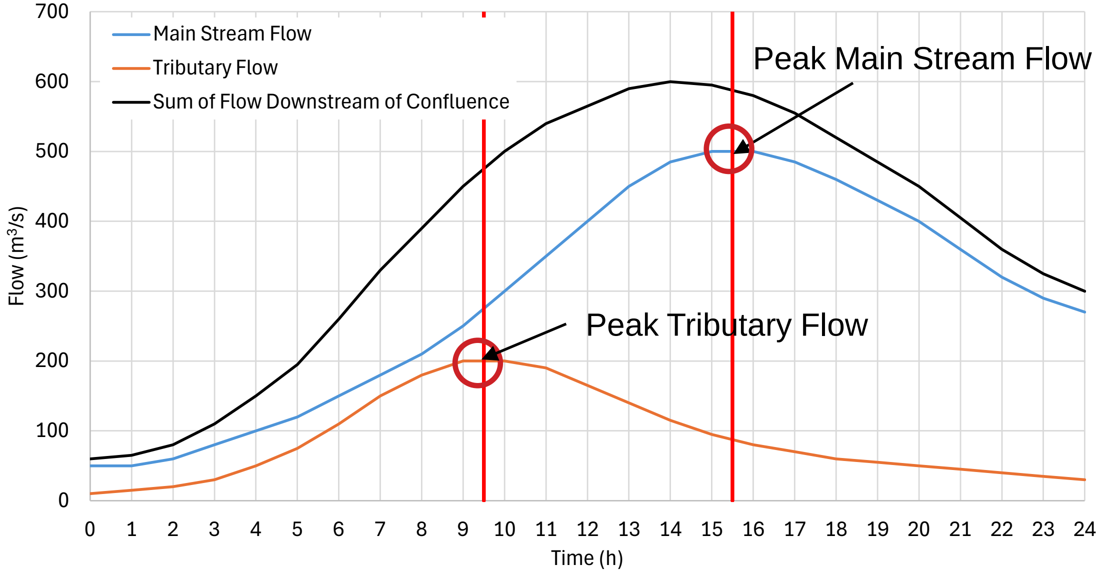
- Set flow change locations, flow does not have to add up
- Run model once, peak water levels at each cross section

2D Model - Steady State Approach A (Overlay)

- Model Run 1: Peak Main Stream flow and regional contribution of Tributary flow (less than peak flow)
- Model Run 2: Peak Tributary flow with corresponding flow in Main Stream (less than peak flow)
- Overlay results

2D Model – Steady State Approach B (Subtract Flow)

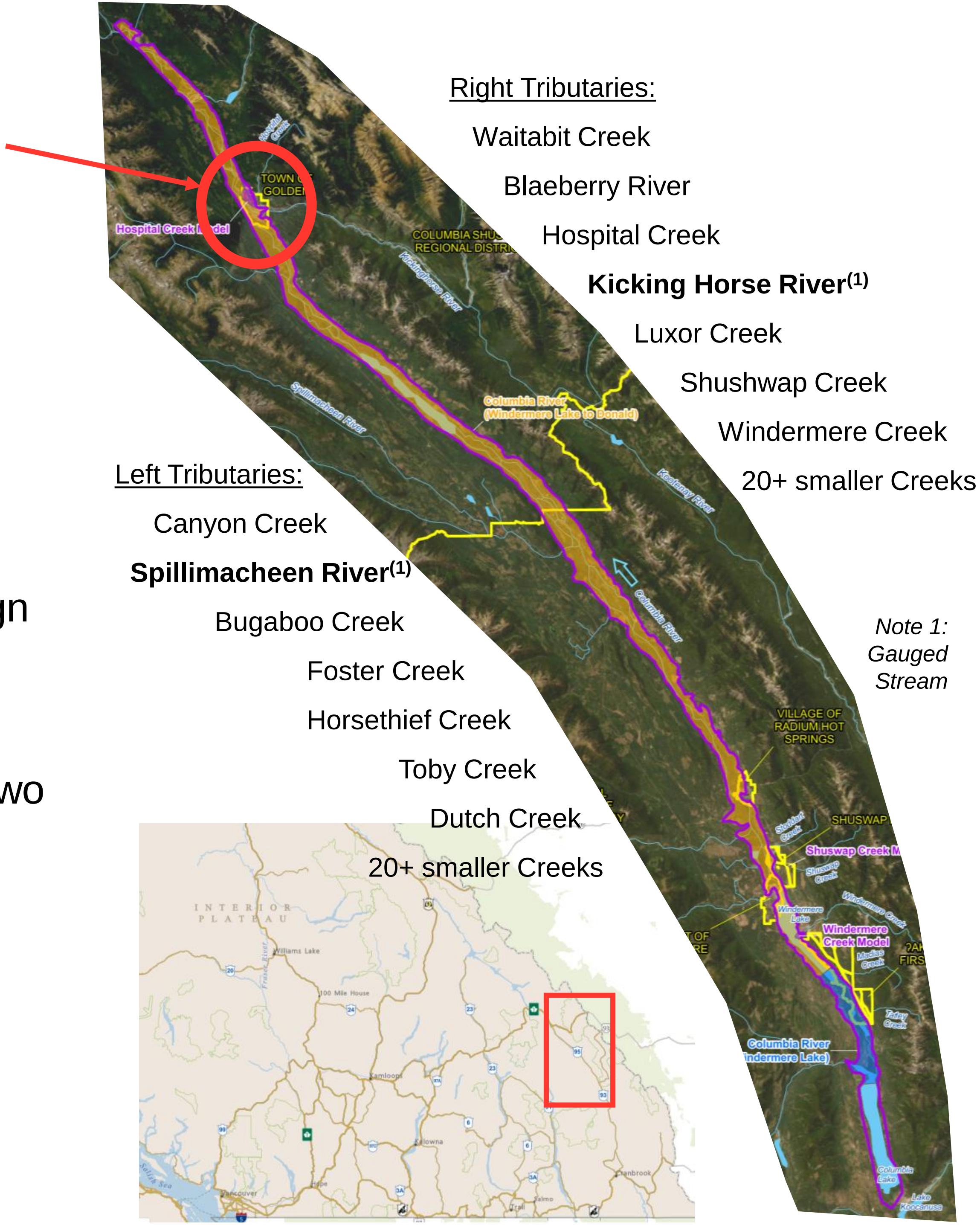
- Peak flow in both Main Stream and Tributary
- Remove excess flow at confluence (similar to what happens in a 1D steady state model)
- **One model run, no hydrograph, no overlay of results**



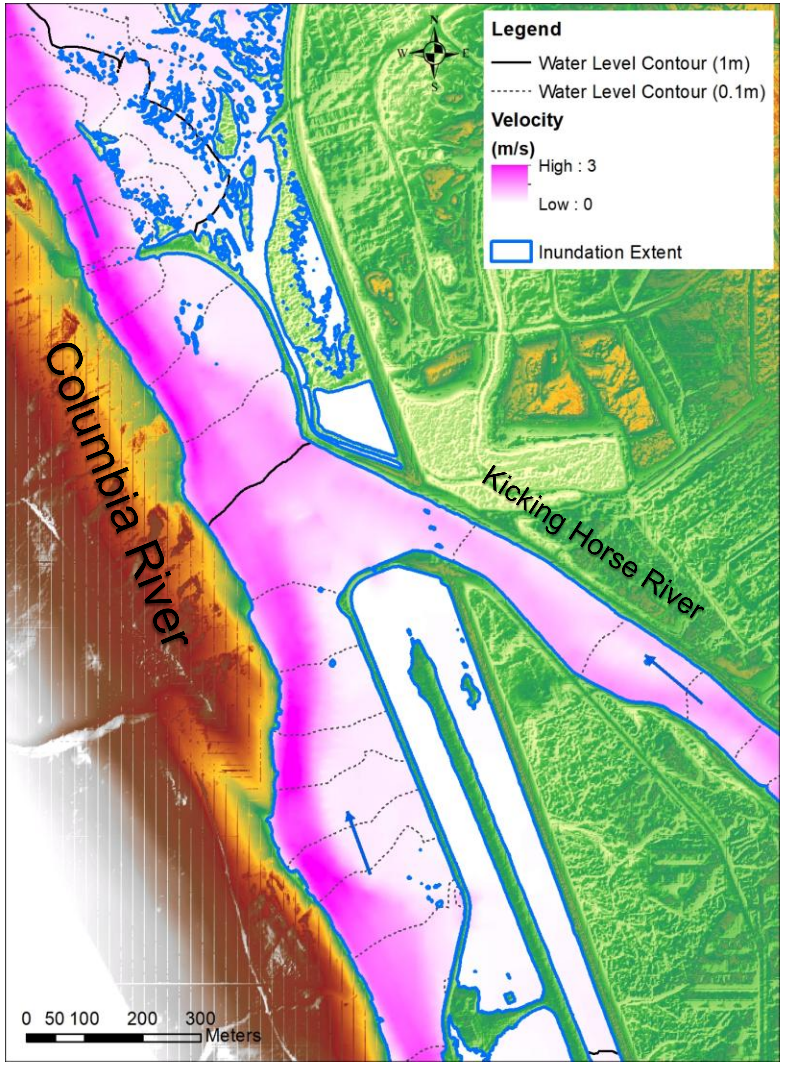
Case Study: Town of Golden

(confluence of Kicking Horse River with Columbia River)

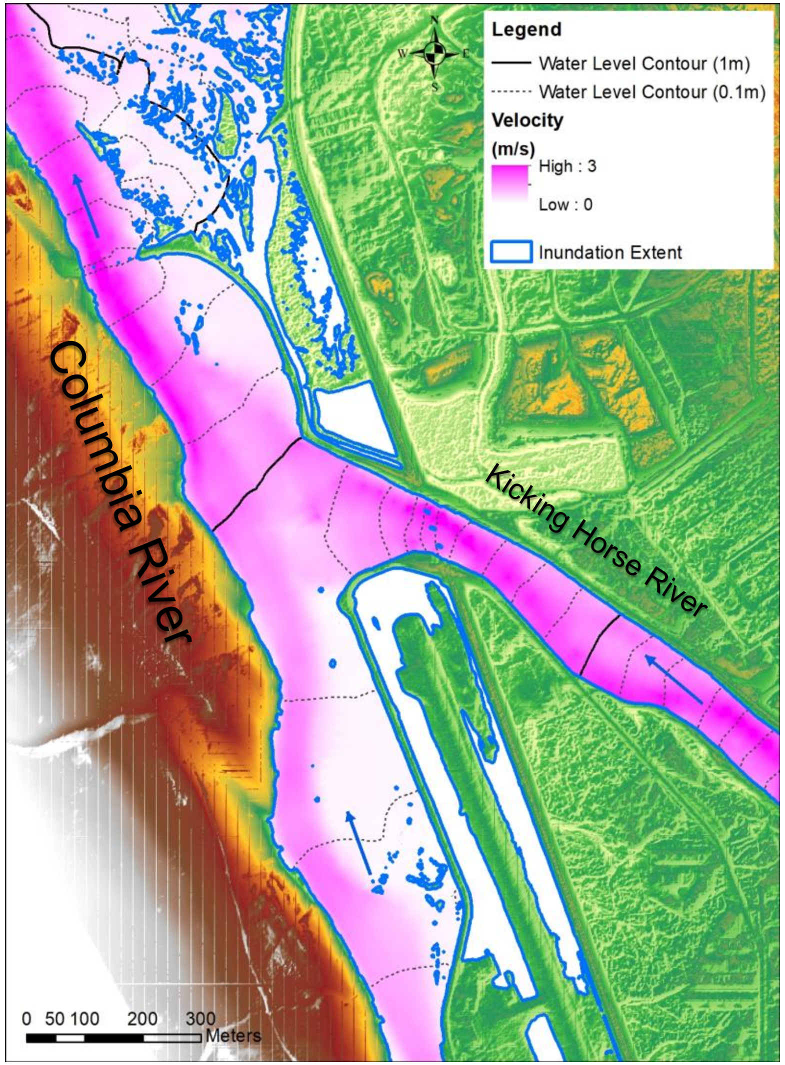
- Part of the FBC Flood Study: Columbia River to Donald
- Complex floodplain along this reach -> 2D HEC-RAS model
- Limited flow data for larger tributaries: Development of design flood hydrographs would introduce a lot of uncertainty
- Peak runoff from tributaries is non-coincident with Columbia River peak flows (Columbia River floods are attenuated by two large lakes (Columbia Lake and Windermere Lake)
- Regional analysis -> flood frequency analysis
- Steady state modelling of peak flood flows



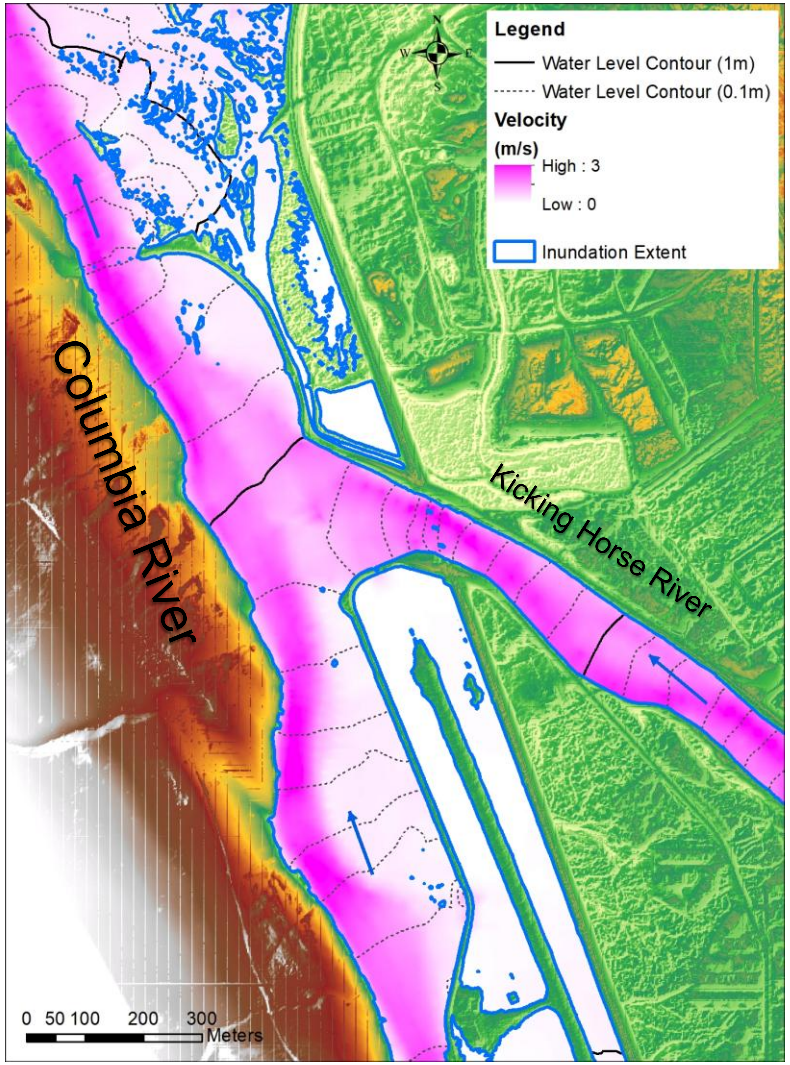
Overlay Method



Peak Flow in Columbia River
(regional contribution from Kicking Horse River)



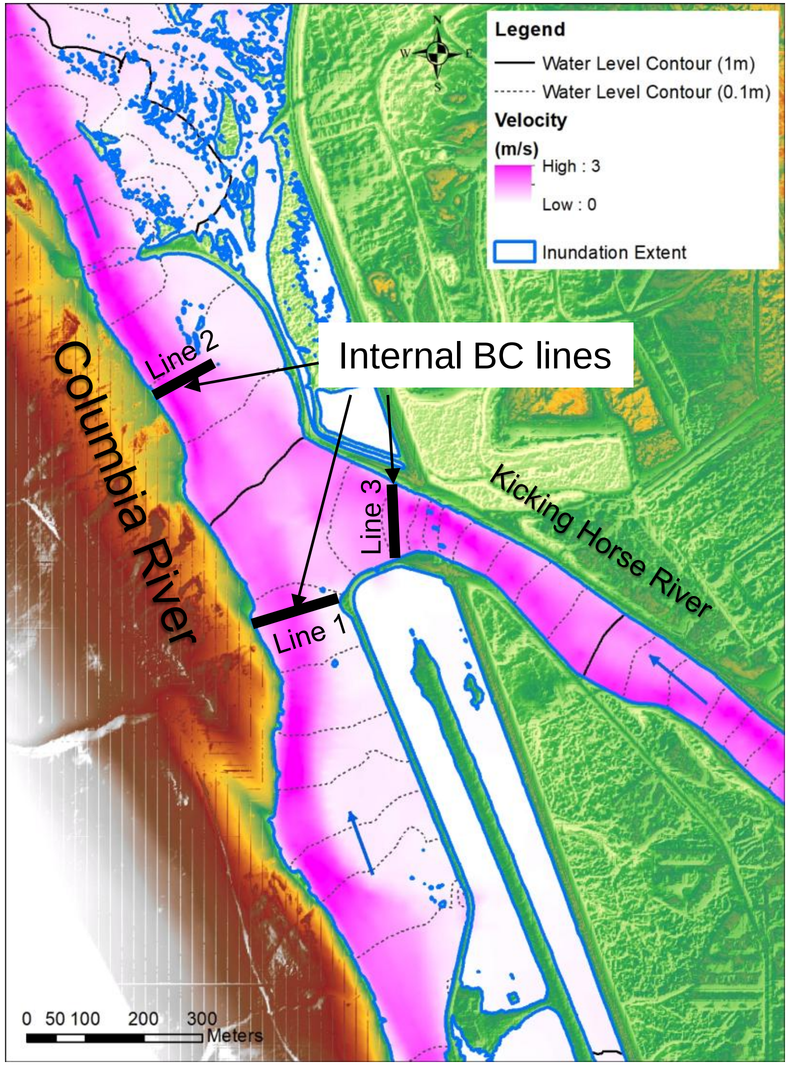
Peak Flow in Kicking Horse River
(flow in Columbia River at time of peak Kicking Horse River flow)



Overlay
(Maximum water levels and flow velocities from both model runs)

Subtractive Flow Method

1. Establish three internal boundary condition (BC) lines near confluence (where 1D cross sections near confluence would be)
2. Split flow amount that needs to be removed between BC lines as negative flow
3. Iterative Optimization
   - Run model
   - Compare water level results with Overlay Method
   - Change split between BC lines
   - Repeat steps above until difference between methods is minimal

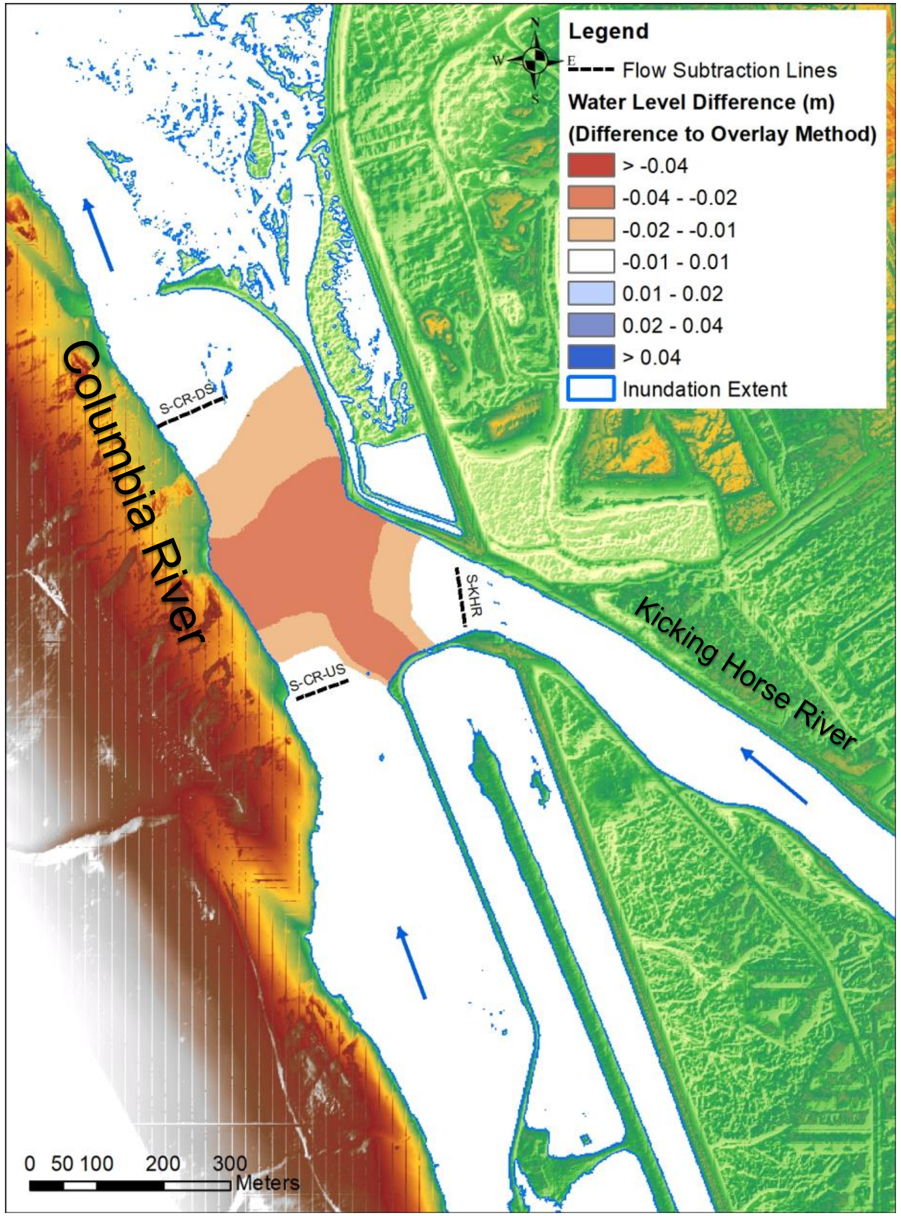


Optimization of Subtractive Flow

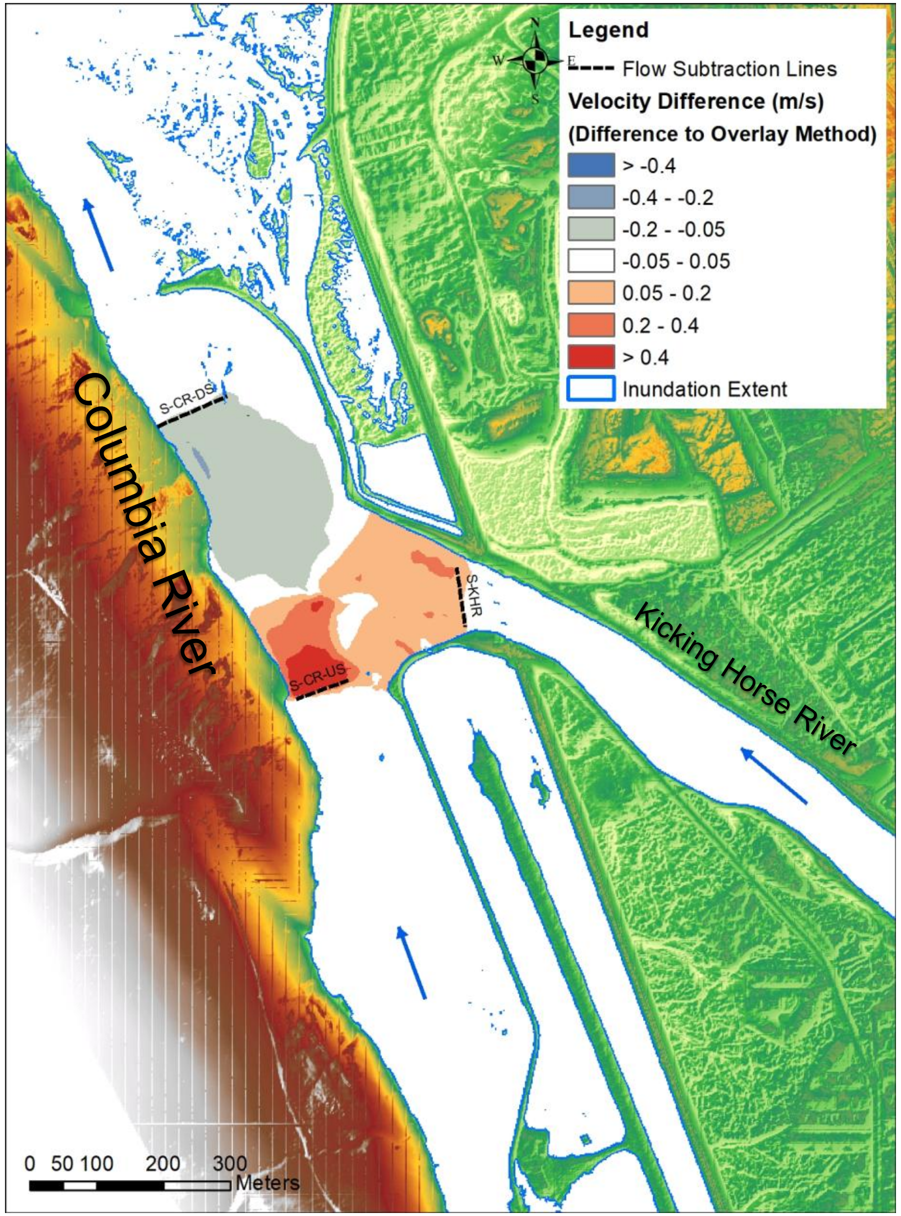
- Flow needs to be reduced by 360 m^3/s at confluence for 200-year peak instantaneous flow
- Optimization of flow reduction until water level difference to Overlay Method is minimal

Run	Inflow Columbia River	Inflow Kicking Horse River	Line 1	Line 2	Line 3	Downstream Flow in Columbia River	Max. Water level difference to Overlay Method
1	790 m^3/s	509 m^3/s	-109.5 m^3/s	-109.5 m^3/s	-141 m^3/s	939 m^3/s	-0.05 m to +0.05 m
…	790 m^3/s	509 m^3/s	Optimization of flow subtraction			939 m^3/s	
9	790 m^3/s	509 m^3/s	-240 m^3/s	-70 m^3/s	-50 m^3/s	939 m^3/s	-0.03 m to +0.00 m

Subtractive Flow Method



Left:
Water level differences compared to Overlay Method



Right:
Flow velocity differences compared to Overlay Method

Conclusions

- Absolute water level difference between Subtractive Flow method and Overlay Method was 0.03 m or less within immediate confluence area after optimization. No noticeable water level difference outside of confluence area.
- Absolute flow velocity difference between Subtractive Flow method and Overlay Method was less than 0.5 m/s within immediate confluence area after optimization. No noticeable flow velocity difference outside of confluence area.
- Optimization shows that majority of flow should be removed from Main Stream immediately upstream of confluence area.

Advantages

- Subtractive Flow method using quasi steady state modelling requires significantly less effort than full unsteady state modelling using hydrographs for all tributary inflows.
- Avoid effort, uncertainty and assumptions to develop hydrographs for ungauged streams.
- Model setup is streamlined, no need for multiple setups and runs for a given return period.
- No extra postprocessing in GIS required.

Disadvantages

- Uncertainty of results in immediate confluence area, especially for flow velocity.

THANK YOU

Special thanks to:
Fraser Basin Council and the Technical Committee for the “Columbia River to Donald” Flood Study

Richard Cunningham (WSP)