CGU HS Committee on River Ice Processes and the Environment

Presents

Short Course on River Ice Modelling

July 13, 2023

Coast Canmore Hotel

Canmore, Alberta

Bow River at Canmore, Alberta. February 2011. Photo Courtesy Dr. Mark Loewen, University of Alberta.

Course Notes for

Short Course on River Ice Modelling

Presented by:

Canadian Geophysical Union, Hydrology Section, Committee on River Ice Processes and the Environment.

July 13, 2023

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Short Course on River Ice Modelling

July 13, 2023 – Coast Canmore Hotel and Conference Centre, Canmore, AB

Contents

1. Introduction to This Course

Course Welcome

Welcome to the CRIPE Short Course on River Ice Modelling!

This course will introduce current modelling practices for static ice covers, simple ice jams, and river ice processes through a combination of lecture material and hands-on exercises, all of which have been prepared by course developers with extensive river ice modelling experience. We hope that this course will serve as a practical introduction to those who do not have any river ice modelling experience, and a valuable refresher to those who do.

The learning outcomes for this course are:

- Obtain a basic understanding of river ice processes.
- Become familiar with the ice processes on the Peace River, and understand why we seek to model them.
- Become familiar with the HEC-RAS model for the purposes of:
    - modelling a static ice cover,
    - modelling a simple ice jam, and
    - using advanced features (e.g. modifying bank station, interpolating cross sections) to improve an ice jam model.
- Obtain a basic understanding of river ice process modelling.
- Become familiar with the River1D ice process model for the purposes of:
    - setting up a thermal ice process model and
    - calibrating a thermal ice process model.

We hope you enjoy the course!

~The CRIPE Short Course Committee

Course Developers

Julia Blackburn, Ph.D., P.Eng.

Julia is currently a Post-Doctoral Fellow at the University of Alberta. She recently completed her Ph.D. in Water Resources Engineering at the University of Alberta. She also completed her M.Sc. in Water Resources Engineering at U of A and her B.Sc. in Geological Engineering at Queen's University. Since 2007 she has either been working for the University of Alberta or working on her Ph.D. Most of this work has focused on the development and application of the University of Alberta's River1D model. Her current research is focused on integrating water quality modelling capabilities in to River1D for the purpose of studying winter water quality in rivers. She lives and works from her home near Salmon Arm, BC.

Michael Brayall, M.Sc., P.Eng.

Michael is a River Hydraulics and Ice Engineer with Alberta Environment and Protected Areas' River Forecast Centre. He has worked on a wide range of water resources projects for the past 15 years specializing in hydraulic modelling. Michael completed his M.Sc. at the University of Alberta with his project focusing on ice jam modelling in the Hay River delta. He has used HEC-RAS to simulate ice jams on rivers throughout Alberta and the Northwest Territories.

Joe Groeneveld, M.Eng., P.Eng.

Joe is a senior Water Resources engineer in the Hatch Calgary office with a solid background in hydraulics and hydrology developed through his 35 years of progressive experience. He completed his B.Sc. in Civil Engineering at the University of Alberta, followed by his M. Eng in Water Resources also at the University of Alberta. Over his career, Joe has been involved in a wide range of water resources projects and studies, including hydrology studies, dam safety studies, hydraulic structure design, flood hazard evaluation, and hydropower design. Joe has also accrued considerable expertise in river ice engineering and modelling, and has been the lead engineer for numerous ice related projects across Canada.

Dan Healy, Ph.D., P.Eng.

Dan is a Principal at Northwest Hydraulic Consultants Ltd. He has worked on a wide range of water resources projects for more than 20 years and has considerable experience leading and implementing both small and large flood studies. Dan's post graduate studies were completed at the University of Alberta where he focused on river ice processes, including physical ice jam model studies and a detailed comparison of the RIVJAM and ICEJAM ice jam profile models.

Kevin Lees, Ph.D., P.Eng.

Kevin is a Water Resources Engineer at Hatch Ltd. in Calgary. He completed his B.Eng. in Water Resources Engineering at the University of Guelph, and his Ph.D. in Civil Engineering at the University of Manitoba. Kevin's doctoral research focused on numerical modelling of ice-affected hydraulics and river ice processes in Northern Manitoba. He has over 10 years of experience between research and consulting, and has worked on a wide-range of water resources topics (including hydrometric monitoring, environmental impact assessments, flood hazard mapping, IDF/PMF modelling, and hydraulic structure design). Kevin provides river ice expertise to Hatch projects across Canada.

Vincent McFarlane, Ph.D., P.Eng.

Vincent is an Assistant Professor in the Department of Civil and Environmental Engineering at the University of Alberta. He completed his B.Sc., M.Sc., and Ph.D. studies at the U of A, followed by a Postdoctoral Fellowship at the University of Manitoba, with his primary research focus on frazil ice formation, the river supercooling process, and the freeze-up energy budget. Most recently, Vincent worked on a wide range of projects as a hydrotechnical specialist with Stantec Consulting Ltd. before rejoining the U of A in his current role.

Jennifer Nafziger, Ph.D., P.Eng.

Jennifer is an Assistant Professor in the Department of Civil and Environmental Engineering at the University of Alberta. She completed her Ph.D in Water Resources Engineering at the University of Alberta and her B.A.Sc. in Geological Engineering at the University of Waterloo. Jennifer has worked with river ice processes across Canada, including in Alberta, the Northwest Territories, New Brunswick, and Newfoundland. Prior to joining the University of Alberta, Jennifer was a River Hydraulics and Ice Engineer with Alberta's provincial River Forecast Centre and was on the ground during major ice jam flooding events in Alberta.

Course Contributors

Thank you to the following people who provided input to and/or reviewed the course materials, including the river ice model summaries: Spyros Beltaos, Steve Daly, Mikko Huokuna, Martin Jasek, Karl-Erich Lindenschmidt, Jarrod Malenchak, Yuntong She, Hung Tao Shen, Wael Taha, and Benoit Turcotte. Their assistance was invaluable, but we assume complete responsibility for any errors or shortcomings that may be in these materials. Thank you to Johnson Kau and Alyssa Sandeman for their extensive testing of the course materials and assistance with developing the printed version of the course notes. Thanks to Jason Kinsella and Heropa for help with providing the virtual machines for today's exercises.

Disclaimer and Waiver

River ice modelling programs are presented in this course for educational purposes only. These programs are large and extensive. We cannot cover their complete use in a course of this duration. The goal of this course is to provide participants with an introductory modelling experience using real world examples and based on real world engineering experience. However, many modifications have been made to the example data make them appropriate for an education environment. The modelling approaches illustrated in this course are based on the course developers' experience. It is important to recognize that this is not the only possible approach, and alternative methods may exist that yield equally viable results.

The content of this course is not a substitute for professional engineering advice nor is it a substitute for additional formal training or mentorship from experienced users. It is the responsibility of modellers to evaluate all model assumptions and approaches in the context of their particular application and to practise within their own competent scope of practise. By participating in this course, you acknowledge that the course content is not engineering advice.

The version of River1D used in this course is a special educational release. Publicly-available releases will differ somewhat from the version showcased here.

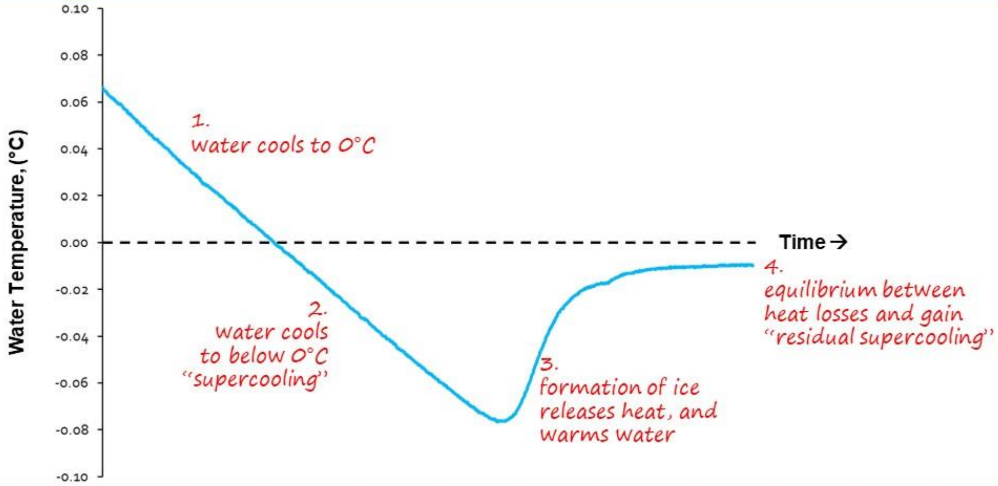
2. Introduction to River Ice Processes and Modelling

Introduction to River Ice Processes

Freeze-up

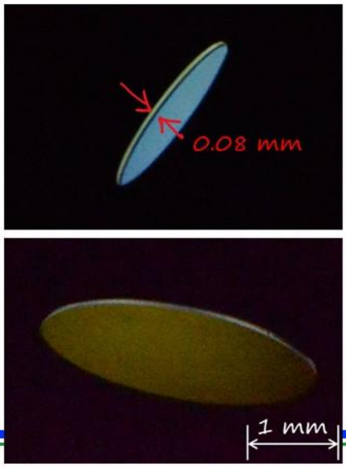
- The period of time when a river transitions from open water conditions to ice-affected conditions
- Water temperature cools and then ice forms

Water Supercooling Curve



Frazil Ice

- Tiny ice crystals that form in ***turbulent, supercooled*** water



frazil crystals

frazil floc

frazil pans

see McFarlane et al. (2014)

Border Ice

- Ice cover that forms where velocities are slower

- Often forms at the banks of the river

Photo: J. Nafziger

Anchor Ice

- Forms on the bed of rivers, beneath the water flow

Photo: Kananaskis River Tributary, S. Emmer/V. McFarlane/J. Nafziger

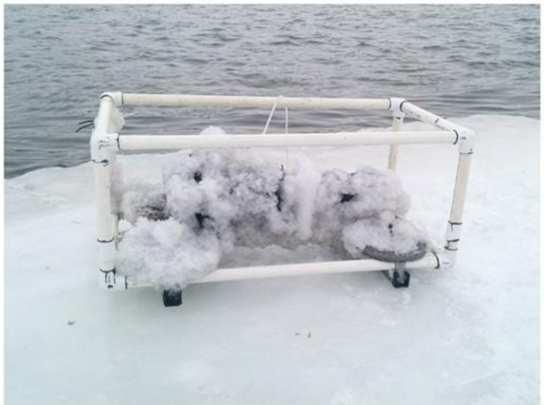
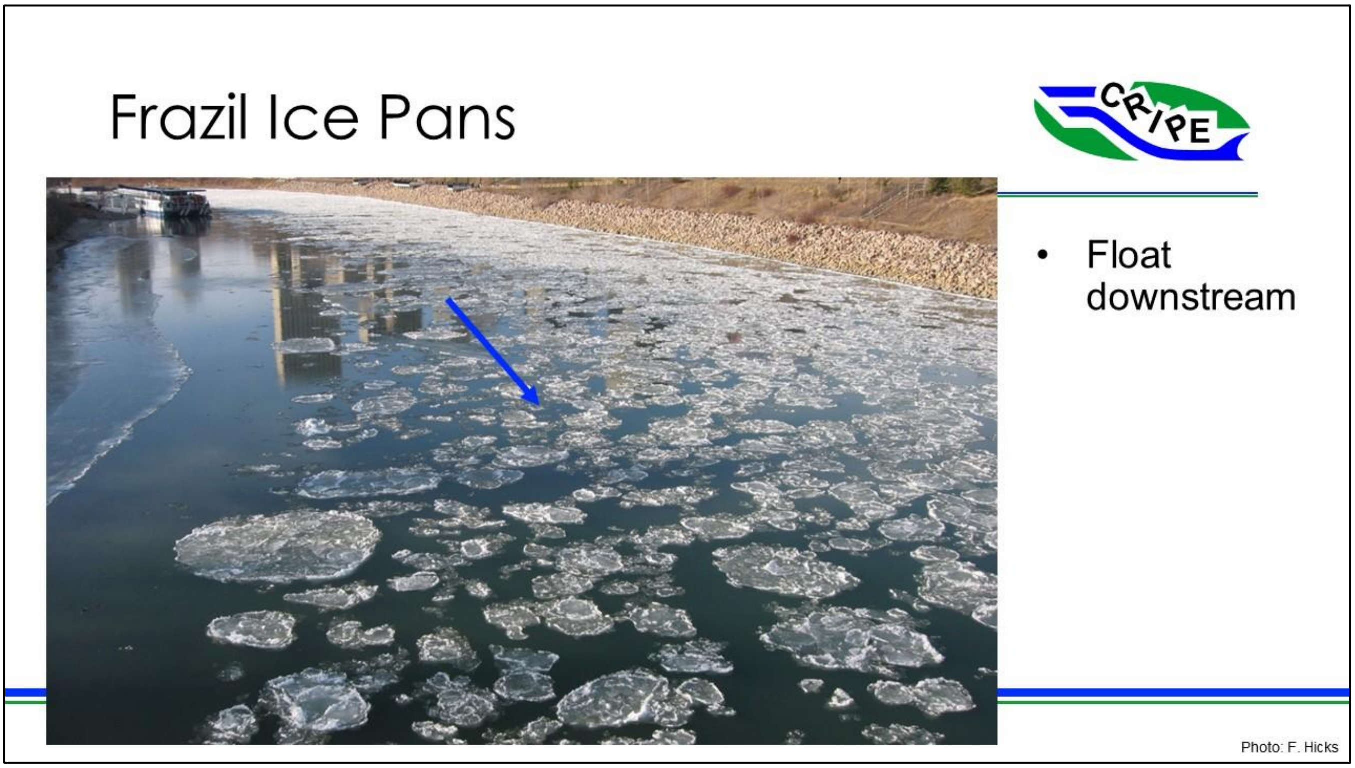


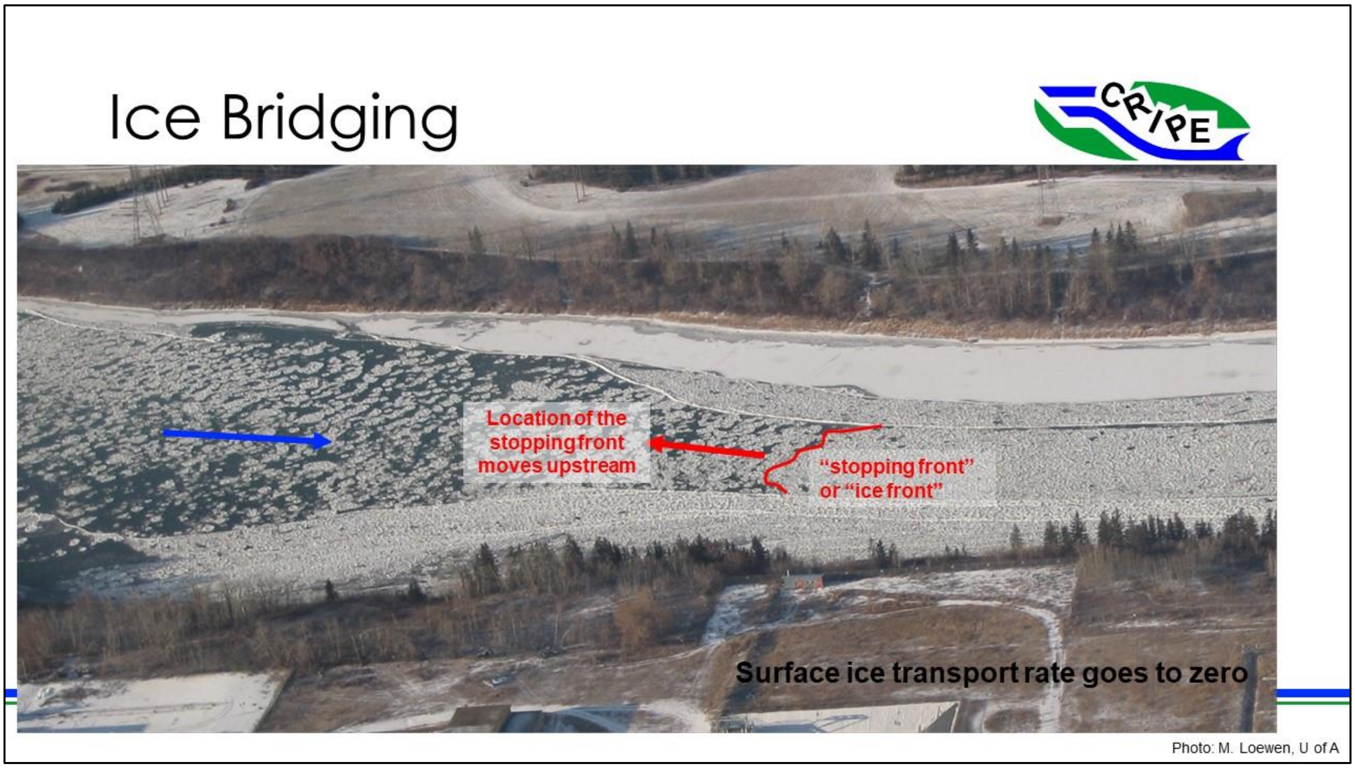
Photo: V. McFarlane



Frazil Ice Pans

- Float downstream

Photo: F. Hicks



Ice Bridging

Location of the stopping front moves upstream

“stopping front” or “ice front”

Surface ice transport rate goes to zero

Photo: M. Loewen, U of A

Ice Bridging

Photo: M. Loewen, U of A

Juxtaposed Ice Cover

- Frazil pans edge to edge

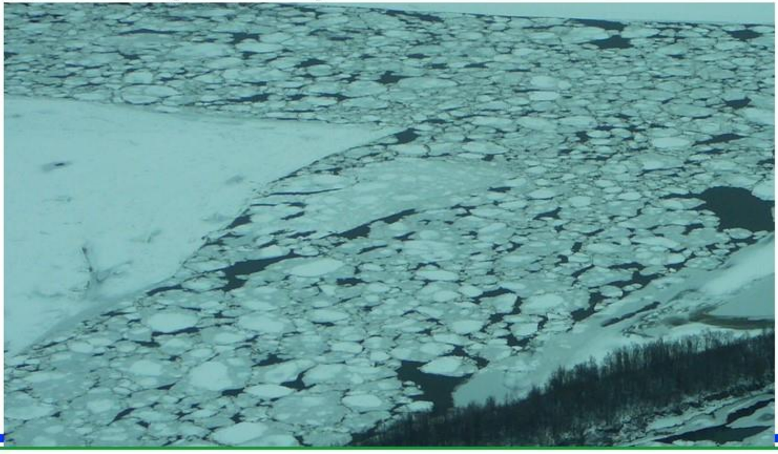


Photo: F. Hicks

"Hummocky" Ice Cover

- Collapsed juxtaposed ice cover, thicker and rougher
- "Consolidated ice cover", "freeze-up ice jam"

Photo: Bow River at Calgary, J. Blackburn

Mid-Winter Ice Processes

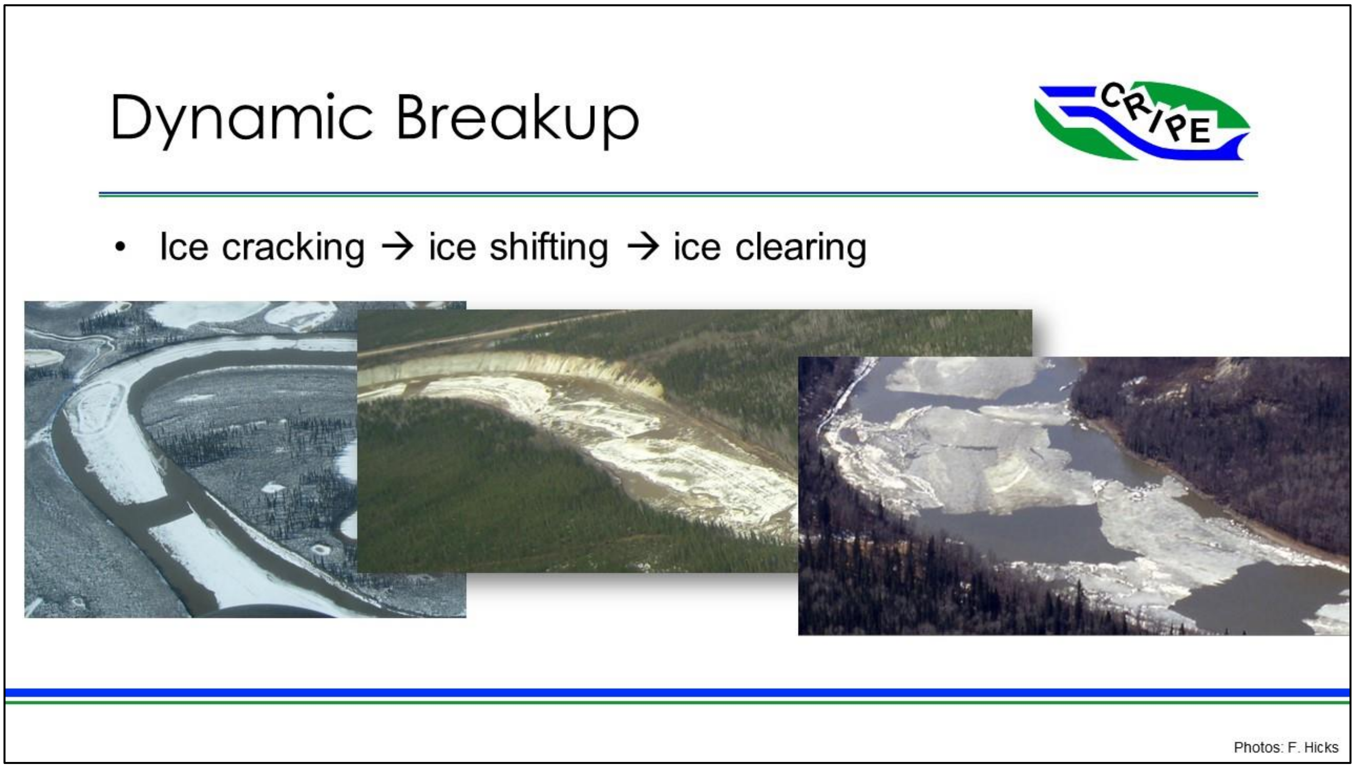
- Thermal ice thickening
- Snowfall – provides thermal insulation
- Aufeis formation and overflow

Breakup – First Processes

- Melting snow on ice surface
- Weakening of ice cover – melting from top and underside
- Melting of snow on the land
  - Increase in river discharge and water levels

Thermal Breakup

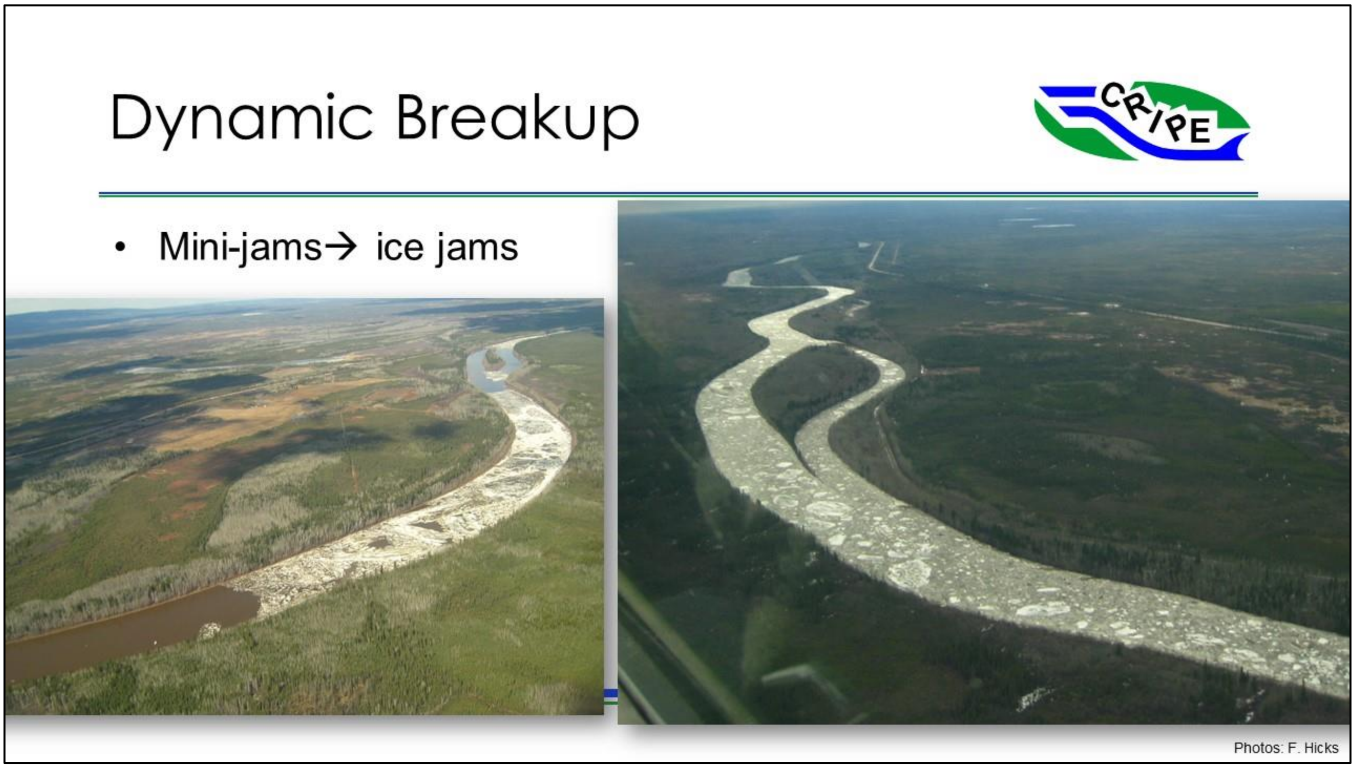
- Ice cover melts largely in place, little ice movement
- Ice weakening, open leads
- Ice appears to decay
- Localized movement of weak ice pieces
- Not enough flow to dislodge large pieces of ice



Dynamic Breakup

- Ice cracking → ice shifting → ice clearing

Photos: F. Hicks



Dynamic Breakup

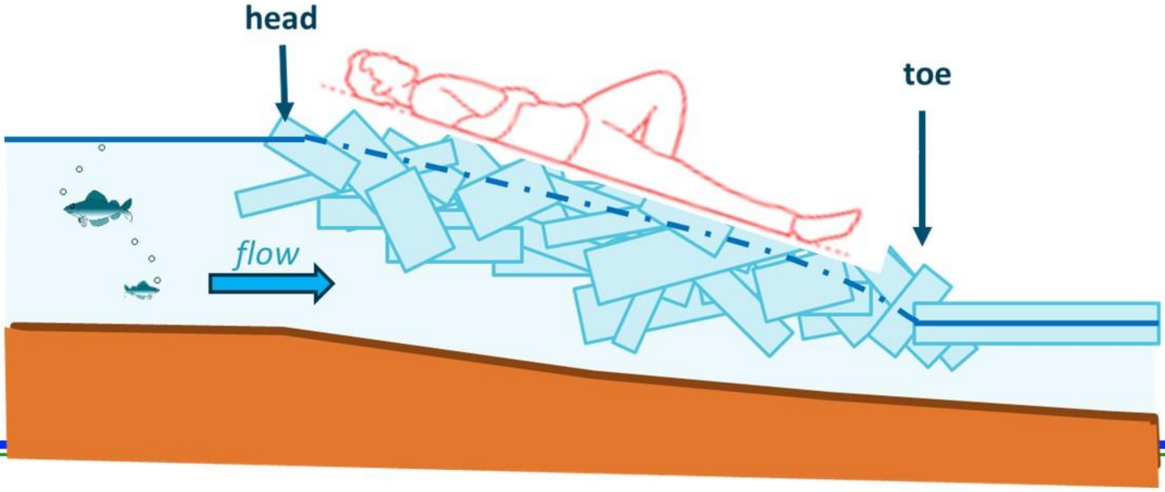
- Mini-jams→ ice jams

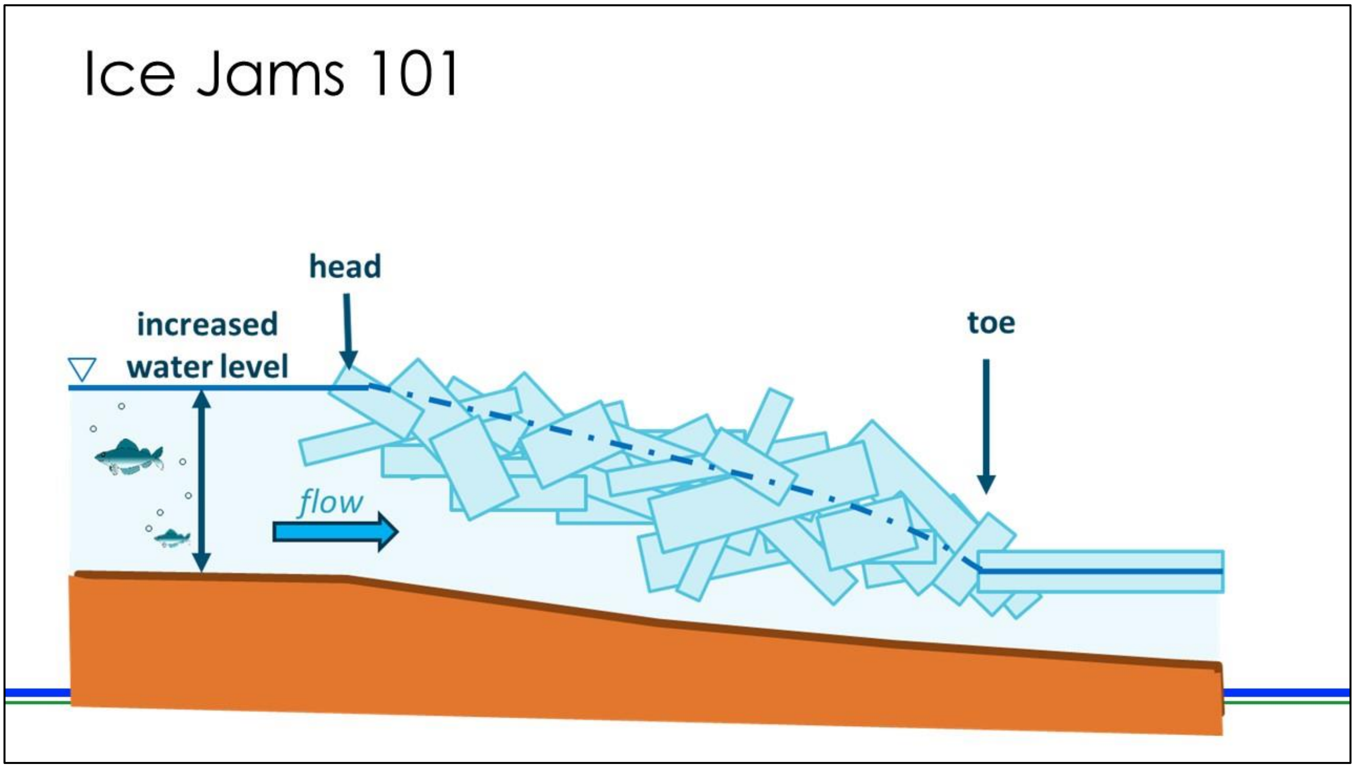
Photos: F. Hicks

Large Ice Jams

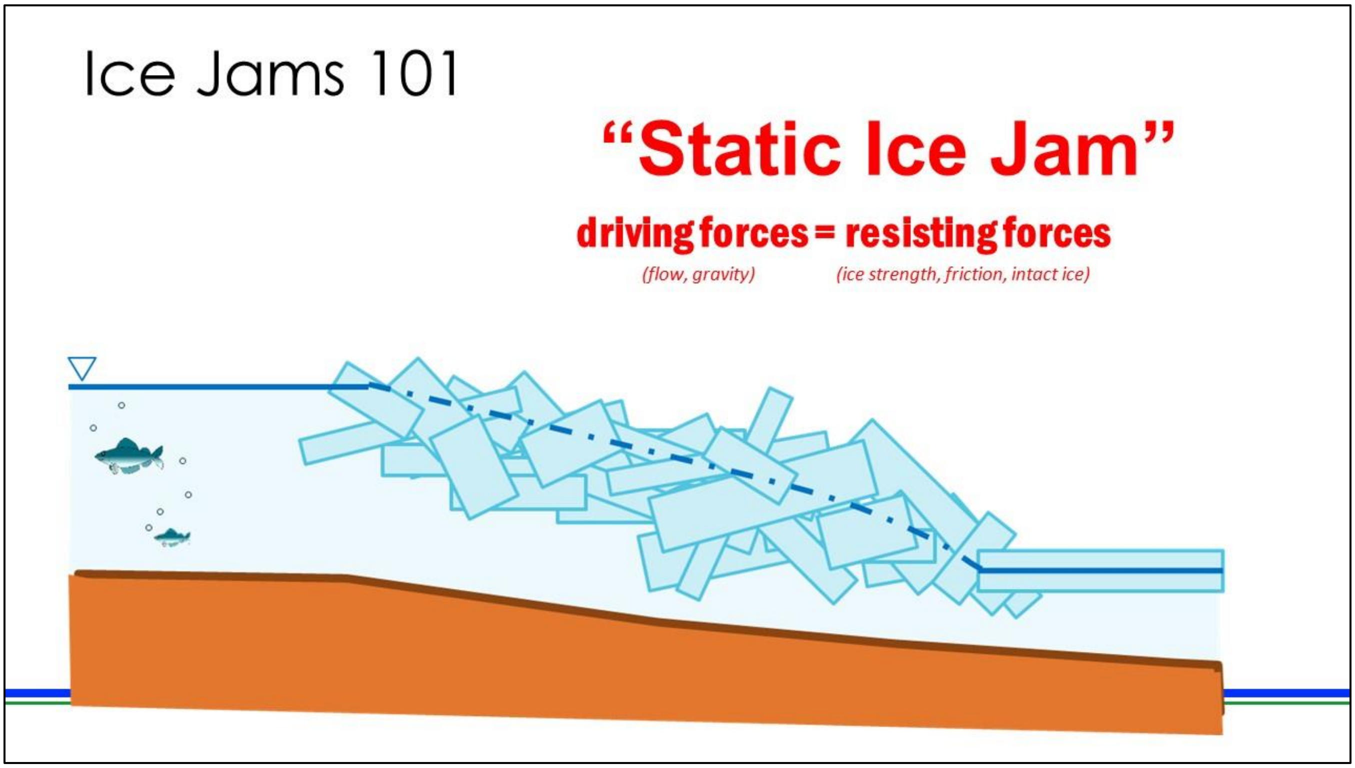
Photo: Alberta Environment and Protected Areas

Ice Jams 101





Ice Jams 101



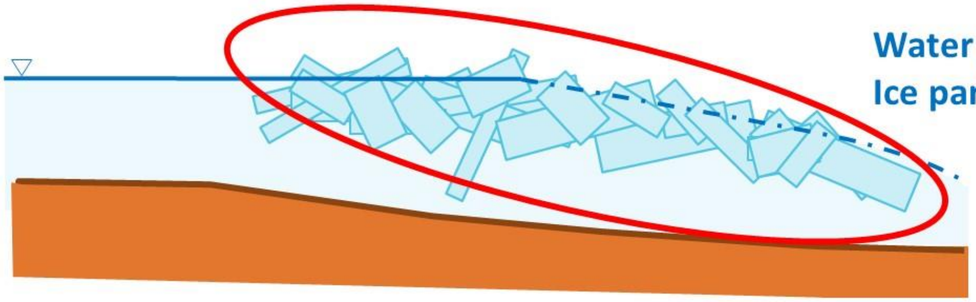
Ice Jams 101

"Static Ice Jam"

driving forces = resisting forces

(flow, gravity) *(ice strength, friction, intact ice)*

Ice Jams 101: Javes and Ice Runs



driving forces > resisting forces

(flow, gravity) *(ice strength, friction, intact ice)*

Ice jam release

Water part = jave
Ice part = ice run

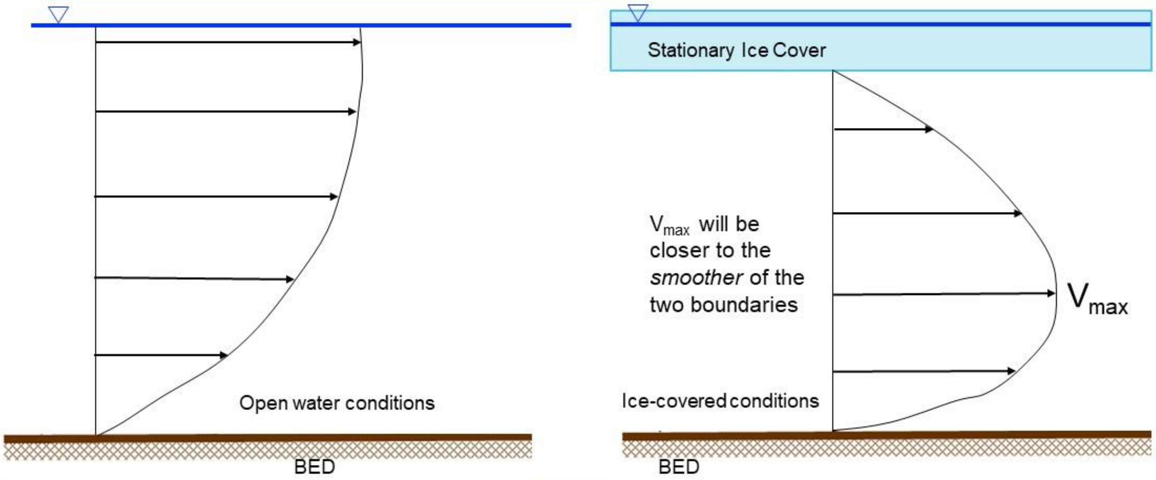
After Release: Shear Walls

photo courtesy of Alberta Environment

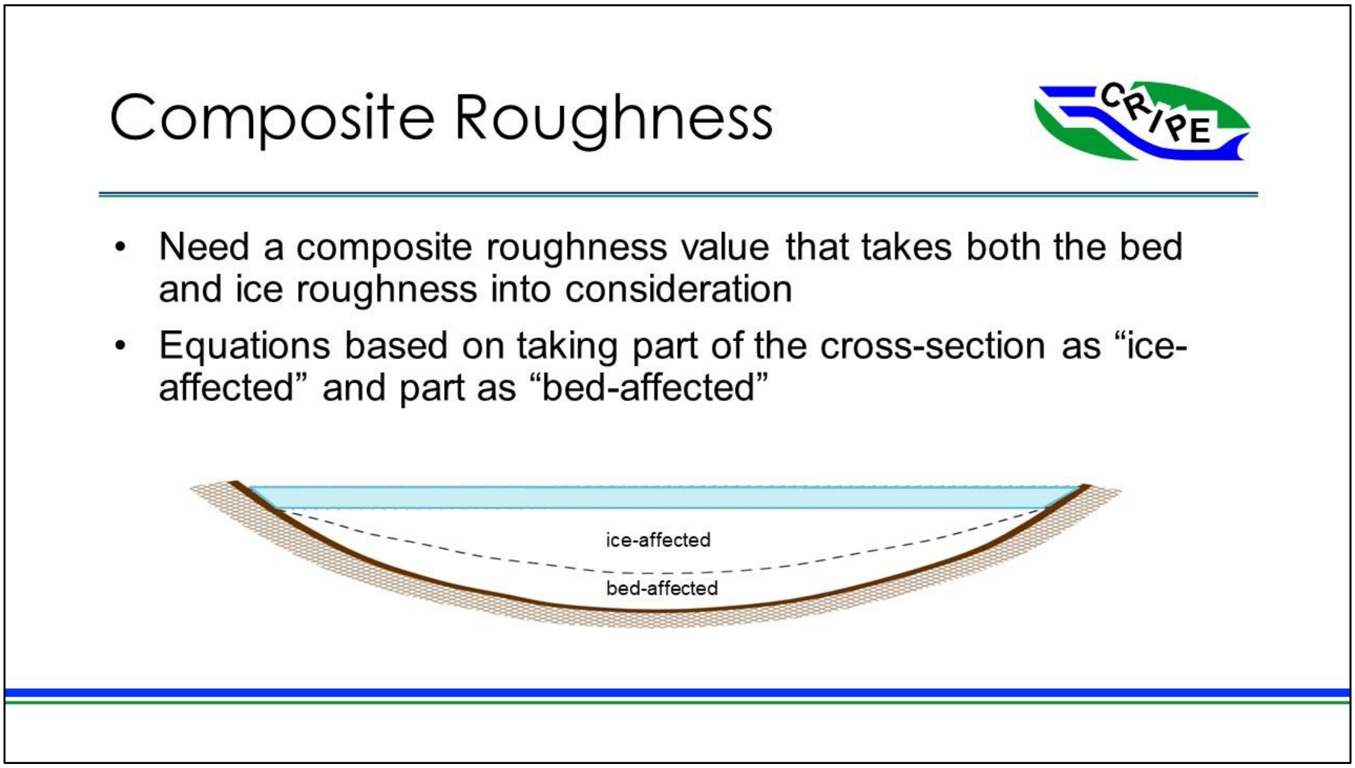
River Ice Hydraulics

- River ice resists the river flow
  - Floats with 92% of its thickness submerged
  - Ice-covered channel has a much larger wetted perimeter
- Therefore, for the same flow, an ice-covered channel will have a higher water level
- Therefore, open water rating curves are not applicable to ice-affected conditions
  - Makes discharge estimation more difficult

Velocity Profiles



V_{max} will be closer to the *smoother* of the two boundaries



Composite Roughness

- Need a composite roughness value that takes both the bed and ice roughness into consideration
- Equations based on taking part of the cross-section as “ice-affected” and part as “bed-affected”

Composite Roughness

$$\frac{n_t}{n_2}=\left[\frac{1+\Phi\left(\frac{n_1}{n_2}\right)^2}{1+\Phi}\right]^{1/2}$$

Pavlovskiy 1931

$$\frac{n_t}{n_2}=\frac{1+\Phi}{1+\Phi\left(\frac{n_2}{n_1}\right)}$$

Lotter 1933

$$\frac{n_t}{n_2}=\left[1+\Phi\left(\frac{n_1}{n_2}\right)^{3/2}\right]^{2/3}$$

Belekon 1938

$$\frac{n_t}{n_2}=\left[\frac{1+\Phi\left(\frac{n_1}{n_2}\right)^{3/2}}{1+\Phi}\right]^{2/3}$$

Sabaneev 1948

$$\frac{n_t}{n_2}=\frac{1}{\sqrt{1+\Phi}}\left(\frac{n_1}{n_2}\right)\left[\Phi^{3/4}+\left(\frac{n_2}{n_1}\right)^{3/2}\right]^{2/3}$$

Chow 1959

$$\frac{n_t}{n_2}=\frac{1}{\sqrt{2}}\left(\frac{R}{R_2}\right)^{1/6}\left[\left(\frac{V_2}{V}\right)^2+\left(\frac{V_1}{V}\right)^2\left(\frac{n_1}{n_2}\right)^2\left(\frac{R_2}{R_1}\right)^{1/3}\right]^{1/2}$$

Hancu 1967

n = Manning’s roughness coefficient
R = hydraulic radius, (=A/P)
A = flow cross section area
P = wetted perimeter
Y_{max} = water depth from boundary surface

$\Phi = P_1/P_2$
1 – smoother boundary
2 – rougher boundary

Examples of some different composite roughness equations available.

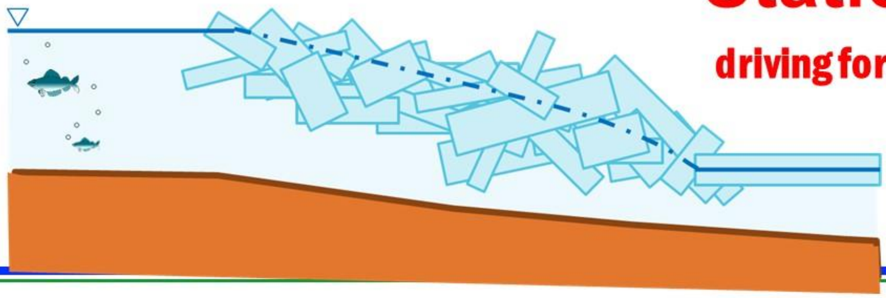
- HEC-RAS uses the Sabaneev equation

Ice Jam Modelling

- Kennedy (1958) suggested a log jam is like a “floating granular mass”
  - Theory adopted for ice jams

“Static Ice Jam”

driving forces = resisting forces



Ice Jam Force Balance Eqn

$$\frac{d(\sigma_x t)}{dx} + \frac{2\tau_b t}{B} = \rho' g S_w t + \tau_i$$

Where:

σ_x = *longitudinal stress*
t = *ice accumulation thickness*
τ_i = *shear stress on the underside of the ice*
τ_b = *shear resistance on the banks*
B = *ice jam width*
ρ' = *ice density*
g = *gravitational acceleration*
S_w = *water surface slope*

See: USACE, 2022. HEC-RAS Hydraulic Reference Manual

Ice Jam Force Balance Eqn

Change in Stress in the Streamwise Direction

$$\boxed{\frac{d(\sigma_x t)}{dx}} + \boxed{\underset{\textcircled{1}}{\frac{2\tau_b t}{B}} = \underset{\textcircled{2}}{\rho' g S_w t} + \underset{\textcircled{3}}{\tau_i}}$$

External Stresses

Assumptions

- σ_x, t, τ_i are constant across the cross section width
- Longitudinal stress is not transferred to the channel banks due to
  - Changes in Channel Width
  - River Bends

See: USACE, 2022. HEC-RAS Hydraulic Reference Manual

Ice Jam Stability Equation

HEC-RAS solves this form of the ice jam stability equation:

Change in ice jam thickness in longitudinal direction

$$\boxed{\frac{dt}{dx}} = \frac{1}{2k_x\gamma_e}\left[\rho' g S_w + \frac{\tau_i}{t}\right] - \frac{k_0 k_1 t}{B}$$

Where:

k_x = $\tan^2(45 + \Phi/2)$

Φ = *angle of internal friction of the ice jam*

γ_e = $0.5\ \rho' g(1-s)(1-e)$

s = *specific gravity of ice*

e = *ice jam porosity*

k_0 = $\tan \Phi$

k_1 = *coefficient of lateral thrust*

See: USACE, 2022. HEC-RAS Hydraulic Reference Manual

Ice Jam Stability Equation

HEC-RAS solves this form of the ice jam stability equation:

Change in ice jam thickness in longitudinal direction

$$\boxed{\frac{dt}{dx}} = \frac{1}{2k_x\gamma_e}\left[\underset{②}{\rho' g S_w} + \underset{③}{\frac{\tau_i}{t}}\right] - \underset{①}{\frac{k_0 k_1 t}{B}}$$

① Shear Stress on Banks
  - Thickness (t)

② Weight of the Ice Jam
  - Thickness (t), Porosity (e), Slope (S_w)

③ Shear Stress on the Bottom of Ice
  - Slope (S), Ice Roughness (n_i)

See: USACE, 2022. HEC-RAS Hydraulic Reference Manual

HEC-RAS Solution Procedure

A: Water level is computed from downstream to upstream using the standard step method and input ice jam thickness

B: Ice thickness at upstream end of jam is used as a boundary condition, and then solves the ice jam stability equation from upstream to downstream

- A + B is one “global” iteration
- Global convergence based on a specified threshold on the change in ice thickness and water level

See: USACE, 2022. HEC-RAS Hydraulic Reference Manual

Ice Jam Strength Parameters

- Coefficient of Internal Strength (Friction), *μ*
  - Common ice jam strength parameter in the literature
  - Lumped variable for difficult to determine parameters such as
    - Lateral Stress
    - Bank Friction
    - Angle of Internal Friction
    - Porosity
    - Cohesion
- HEC-RAS requires Angle of Internal Friction (*Φ), Porosity (P),* and the ratio of lateral to longitudinal pressure (k_1)

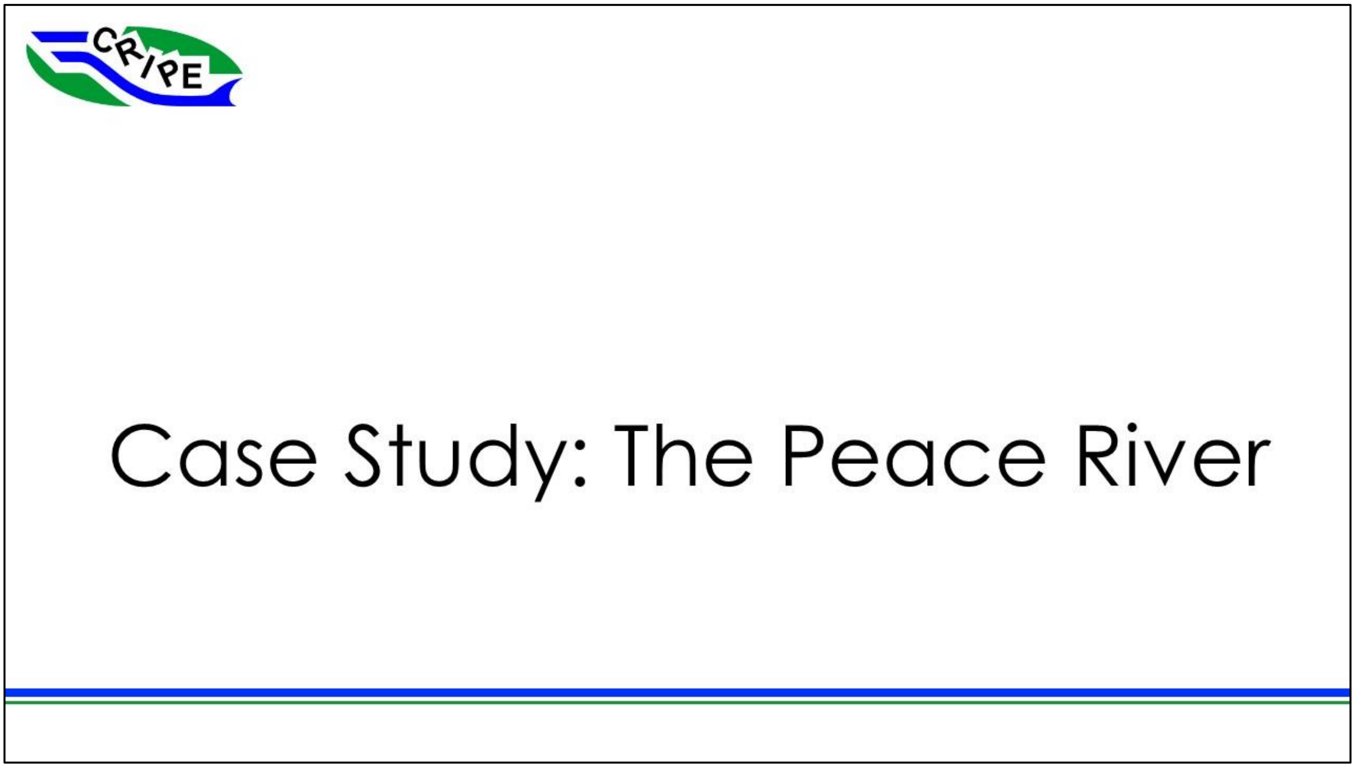
$$\mu = tan(\Phi)\, tan^2(45 + \frac{\Phi}{2})k_1(1 - P)$$

See: White, 1999

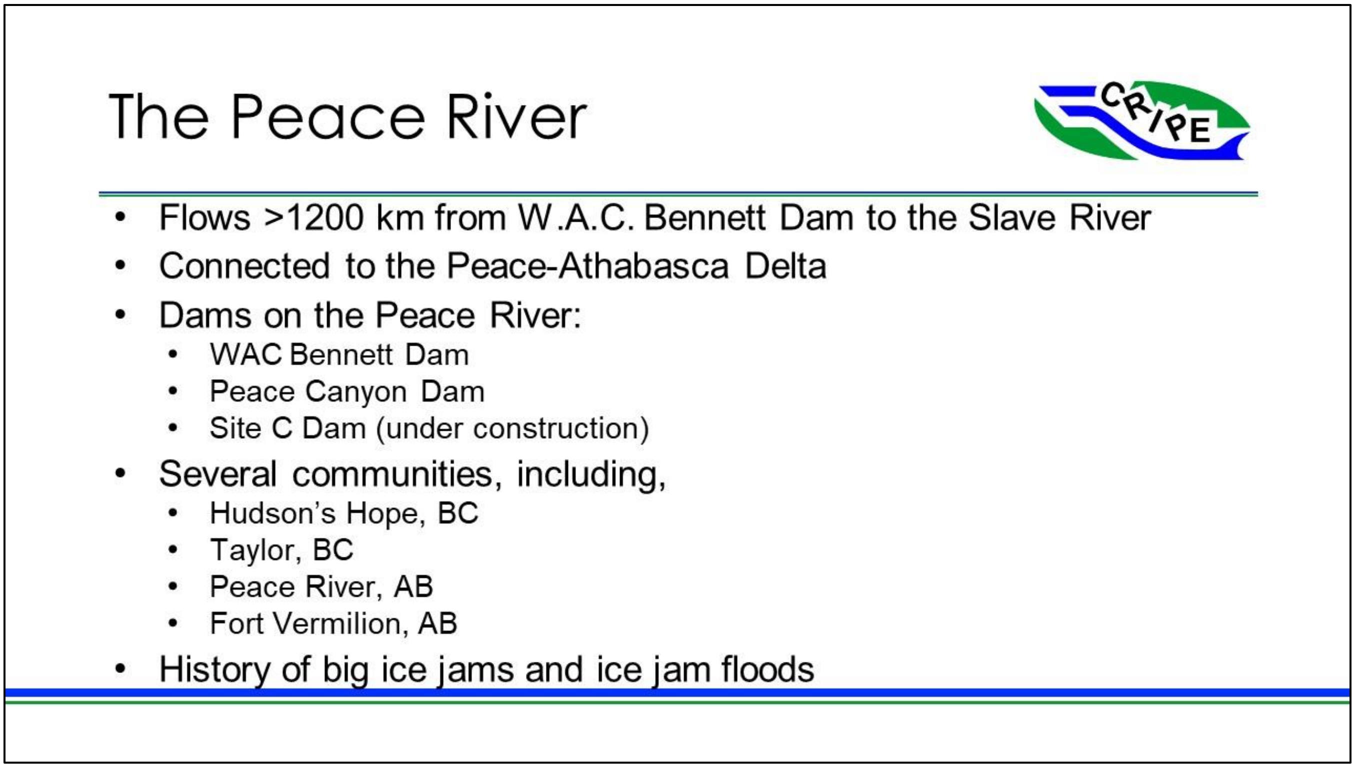
"Wide" vs. "Narrow" Channel Ice Jams

- Terminology vague but distinction helpful (see Beltaos, 1995)
- "Wide" channel ice jam
  - Forms through the collapse or shoving of an ice accumulation
  - Ice jam thickens to the point it can withstand stresses placed on the accumulation
    - The stresses (weight, flow shear stress) are proportional to width of the accumulation
- "Narrow" channel ice jam
  - Thickness controlled by flow conditions at upstream end of the ice jam, which controls how incoming ice floes are incorporated into an accumulation

3. Introduction to Your Case Study: The Peace River

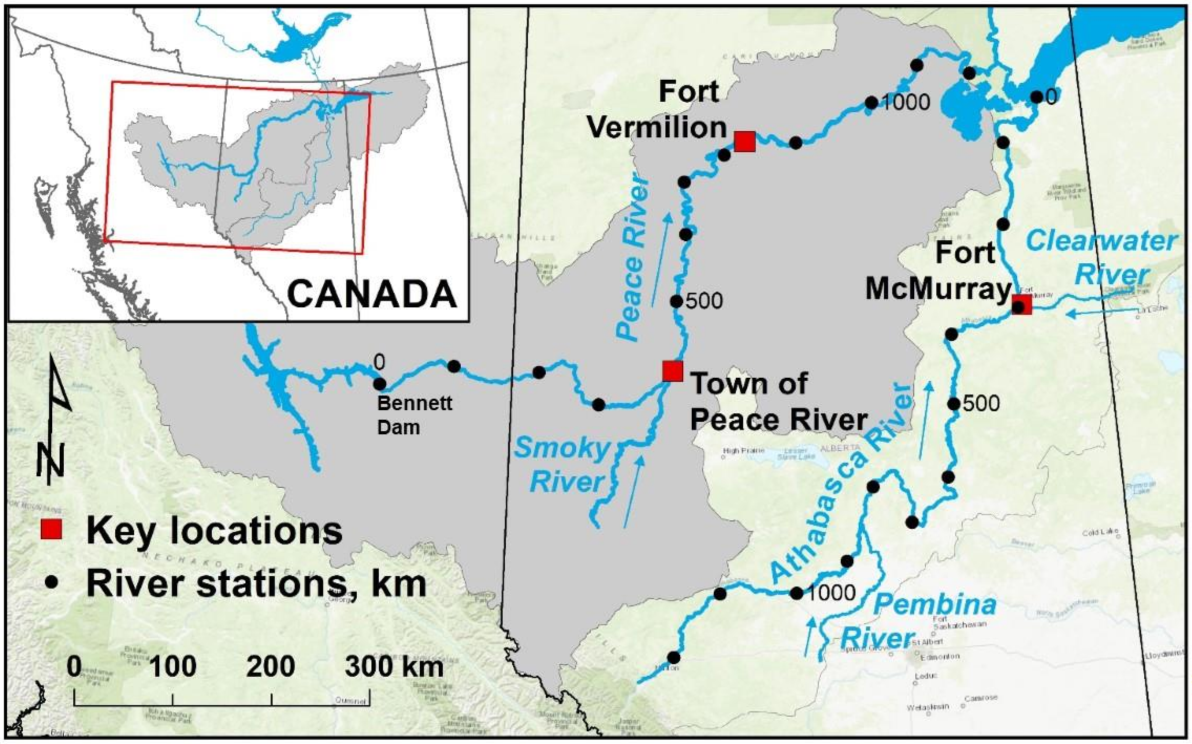


Case Study: The Peace River



The Peace River

- Flows >1200 km from W.A.C. Bennett Dam to the Slave River
- Connected to the Peace-Athabasca Delta
- Dams on the Peace River:
    - WAC Bennett Dam
    - Peace Canyon Dam
    - Site C Dam (under construction)
- Several communities, including,
    - Hudson's Hope, BC
    - Taylor, BC
    - Peace River, AB
    - Fort Vermilion, AB
- History of big ice jams and ice jam floods



Town of Peace River

- Has flooded in various ways:
  - Open water flooding – e.g. 1990
  - Freeze-up Ice Jam – e.g. 1992
  - Breakup Ice Jam – e.g. 1997
- We will model two of these floods:
  - 1990 and 1997

http://www.edmontonjournal.com EDMONTON'S NEWSPAPER SINCE 1903 April 20, 1997

Peace River mops up

4,000 residents evacuated; downtown under 2 metres of water as ice dams river

DON THOMAS
Journal Staff Writer

Peace River

Residents of Peace River are mopping up today after heavy flooding forced the evacuation Saturday of some 4,000 people in the town of 6,900.

Townsfolk began returning to their homes late Saturday, but much of the central business district remained under as much as two metres of brown, silty water.

Crews using high-capacity pumps and a dozen big vacuum trucks struggled to pump water trapped behind the town's protective dikes.

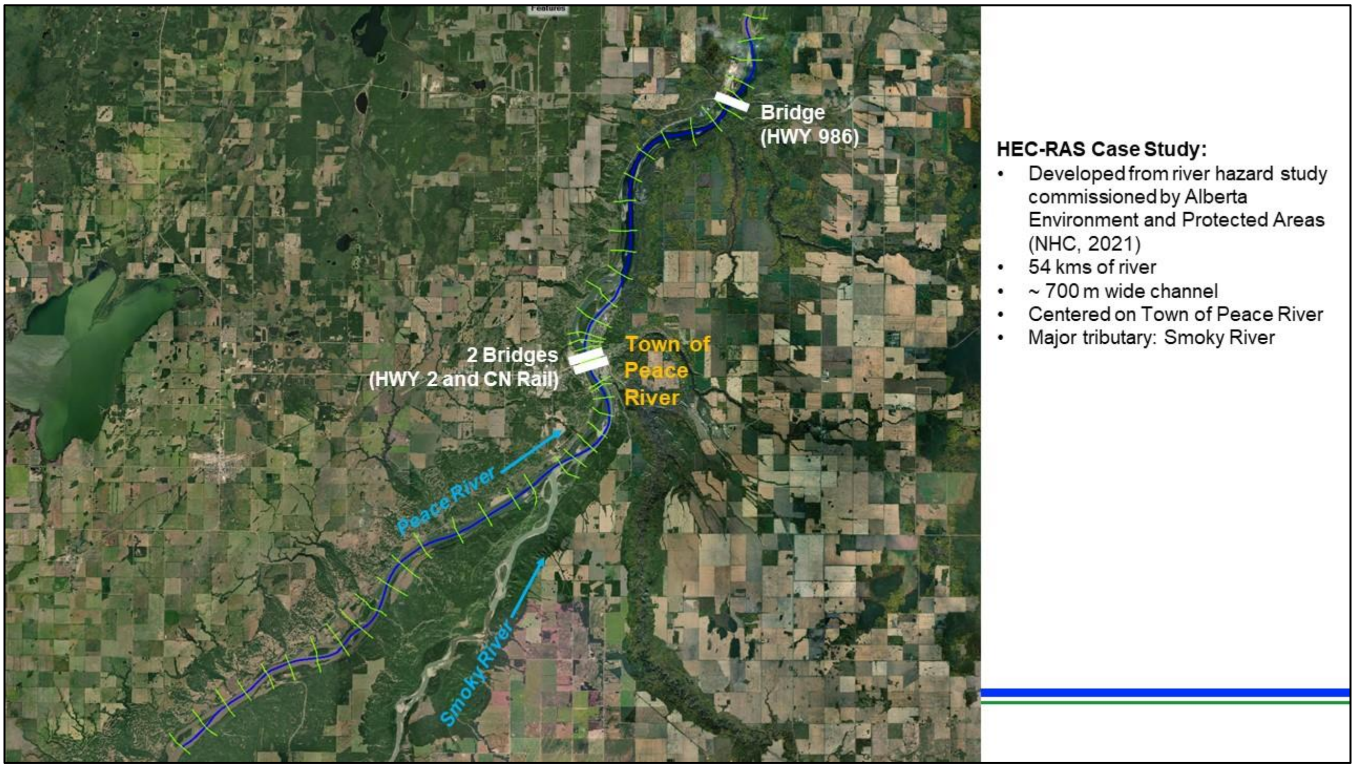
Residential areas in the town were spared from the flood.

The extent of the damage is not known, but officials from Alberta Disaster Services are assessing the situation and an announcement on flood relief is expected Tuesday, said deputy mayor Betty Kruse.

The flooding began without warning about 5 a.m. Saturday as metre-

Photos by Shaughn Butts, *The Journal*

Downtown Peace River lies submerged on Saturday after floodwaters breached a dike where a bridge crosses the Heart River (foreground). Below right, town workers Albert Winnicky and Nelson Mathews ride above the floodwater in the bucket of a front-end loader.



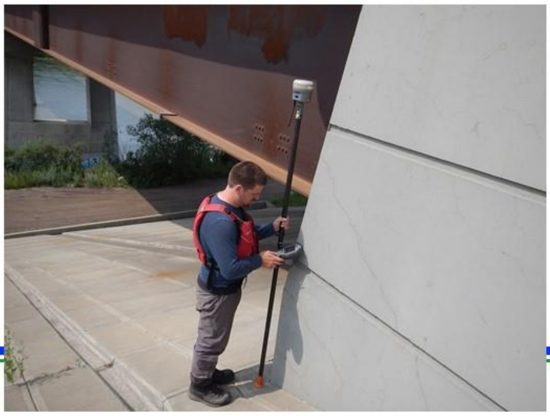
HEC-RAS Case Study:
- Developed from river hazard study commissioned by Alberta Environment and Protected Areas (NHC, 2021)
- 54 kms of river
- ~ 700 m wide channel
- Centered on Town of Peace River
- Major tributary: Smoky River

HEC-RAS Model Development

- Geometry data provided in the HEC-RAS model
- 54 cross-sections
- Details of 3 bridges

Cross-Section Development

- Channel portion surveyed by boat
- Ground stations near the channel surveyed on foot



Cross-Section Development

- Surveyed cross-sections combined with a high-resolution LiDAR digital elevation model (DEM)
  - LiDAR was flown specifically for this study
  - LiDAR was verified with third-party verification survey on the ground

Ice-Process Modelling

- Will model the progression of freeze-up along a ~830 km reach of the Peace River:
  - From the W.A.C. Bennett Dam downstream to near Fort Vermilion
- Model geometry based on an operational model used by Alberta Environment and Protected Areas and BCHydro
- Why would we want to model such a long river reach??
  - Operational decision making tool for freeze-up flood prevention

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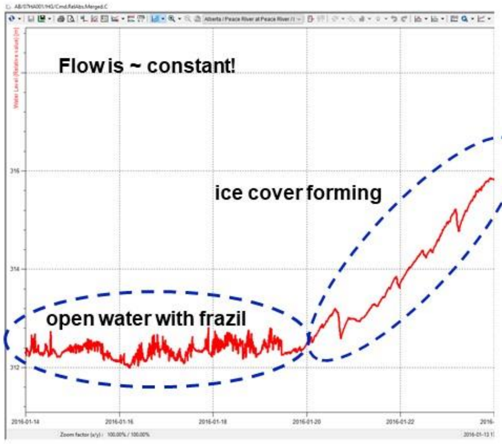
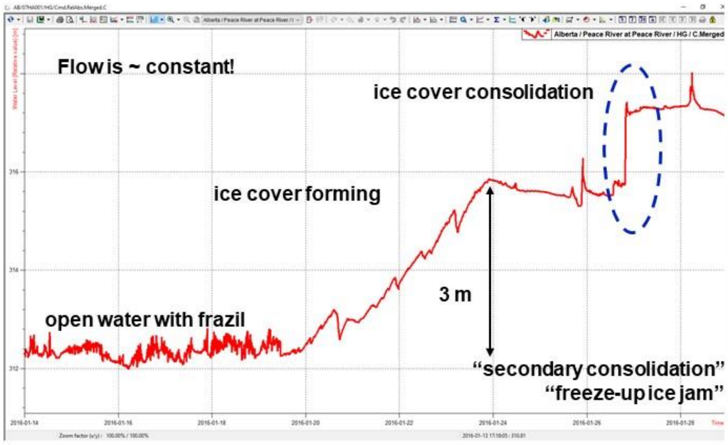
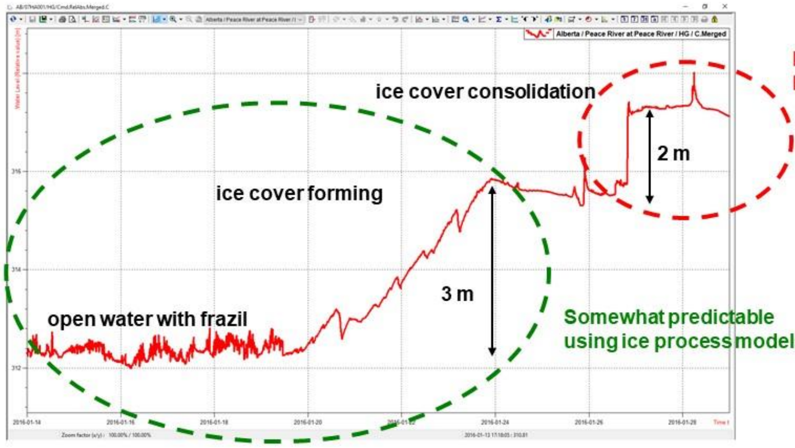
Freeze-up at Peace River



Freeze-up at Peace River



Freeze-up at Peace River



Ice jam mechanics less predictable:

Depends on:
- **Ice strength**
- **Freezing/melting**
- **Weather**

Good research question!

Somewhat predictable using ice process models

Want freeze-up levels low enough to accommodate water level rises from:
- formation of ice cover
- Potential ice cover consolidations

Freeze-up at Peace River

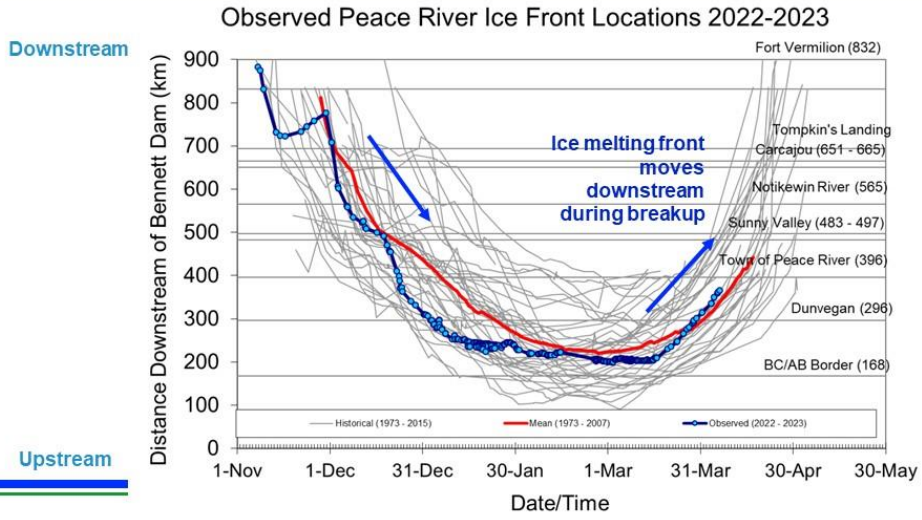
- We can influence freeze-up levels at Peace River by controlling flow at upstream dams
- However, need to limit length of time the “controlled flow” is implemented on the Peace River
  - Reduces BCHydro’s ability to generate electricity if demand is high
  - Want to have controlled flow *only during time when ice is forming at Peace River*
  - But:
    - Flow changes take days to reach Peace River
    - Need to plan hydropower production in advance, especially over holidays and weekends
- Therefore need to predict when freeze-up will occur at Peace River

Ice Front Progression Modelling

- “Ice Stopping Front” or “Ice Front” – the location where the ice cover is forming and the frazil pans are stopping to form an ice cover.

- *Monitor* ice front progression for model calibration
- *Model* ice front progression for prediction

Ice Front Progression Monitoring

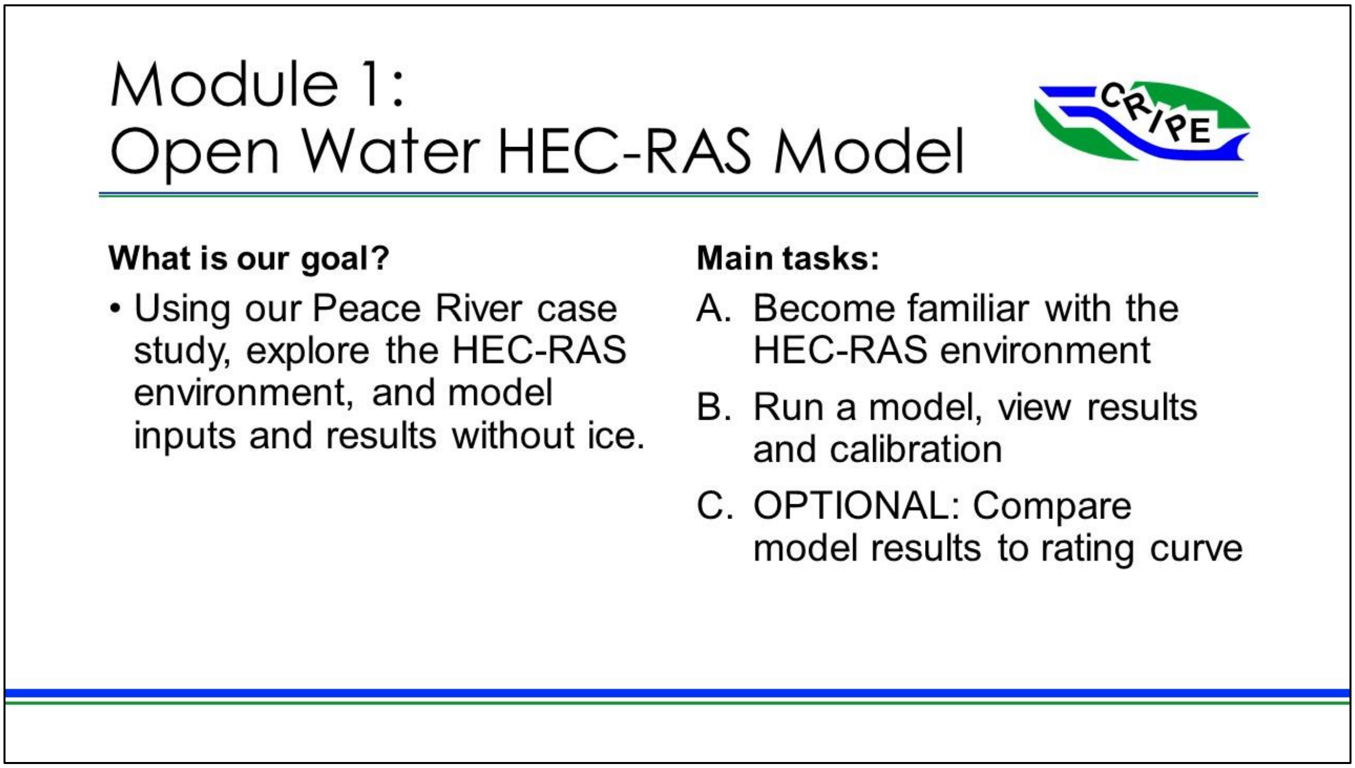


Ice melting front moves downstream during breakup

You will be modelling this in the afternoon.

4. HEC-RAS Modelling Exercises

Module 1: The Open Water Model



Module 1:
Open Water HEC-RAS Model

What is our goal?

- Using our Peace River case study, explore the HEC-RAS environment, and model inputs and results without ice.

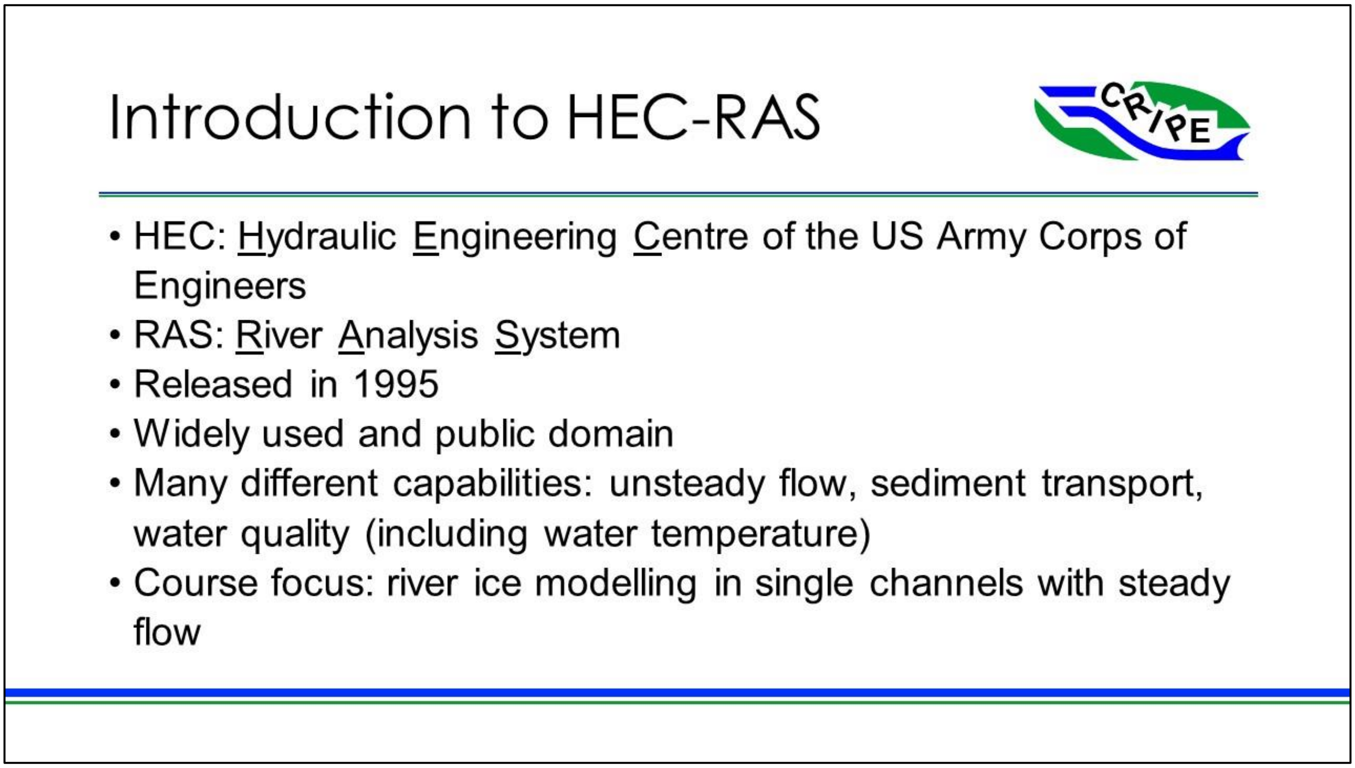
Main tasks:

A. Become familiar with the HEC-RAS environment

B. Run a model, view results and calibration

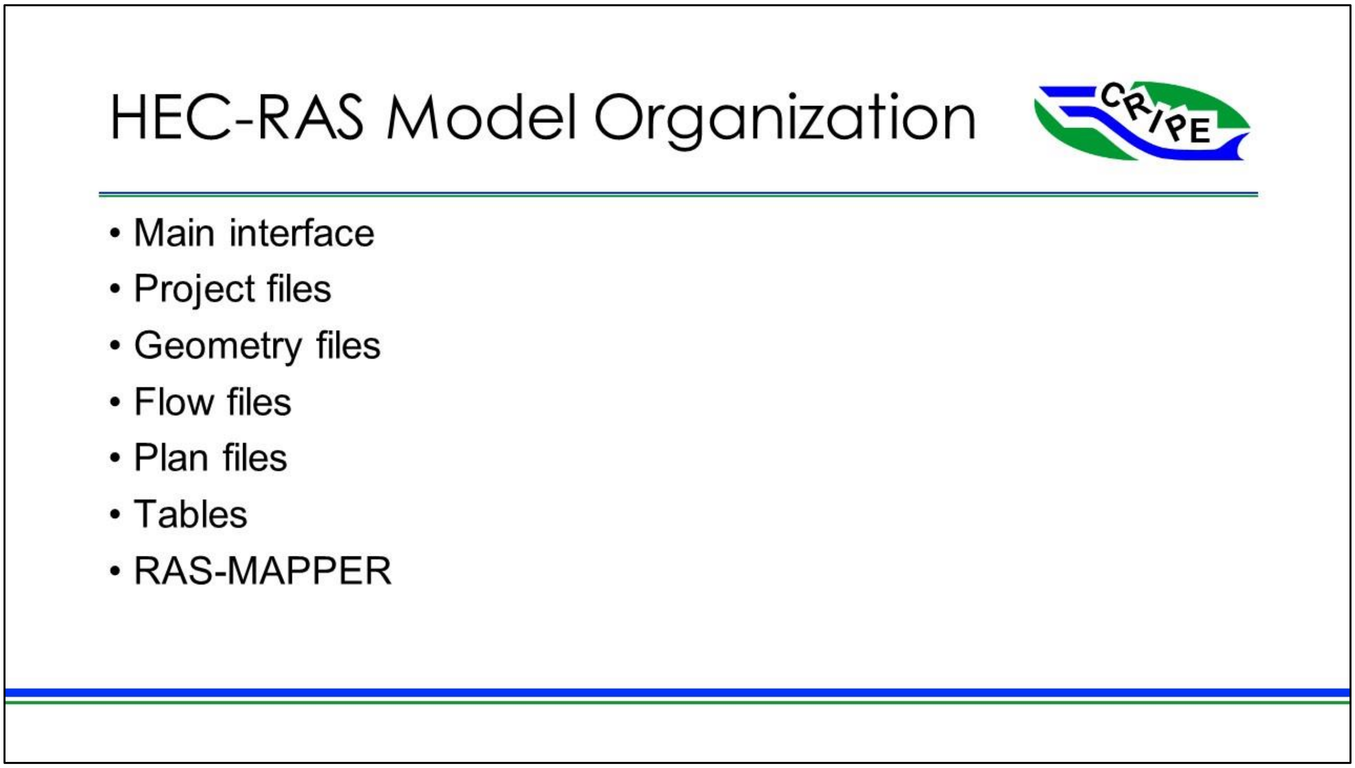
C. OPTIONAL: Compare model results to rating curve

Task 1A: Background Information



Introduction to HEC-RAS

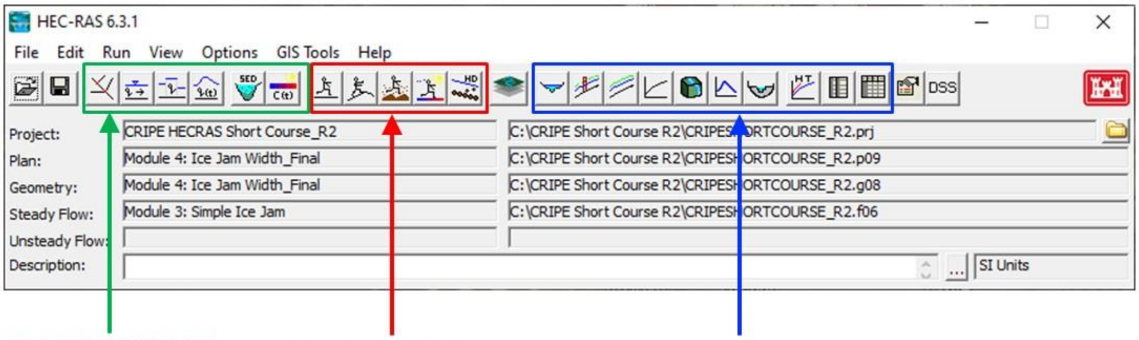
- HEC: Hydraulic Engineering Centre of the US Army Corps of Engineers
- RAS: River Analysis System
- Released in 1995
- Widely used and public domain
- Many different capabilities: unsteady flow, sediment transport, water quality (including water temperature)
- Course focus: river ice modelling in single channels with steady flow



HEC-RAS Model Organization

- Main interface
- Project files
- Geometry files
- Flow files
- Plan files
- Tables
- RAS-MAPPER

Main Interface



Project: CRIPE HECRAS Short Course_R2 C:\CRIPE Short Course R2\CRIPESHORTCOURSE_R2.prj
Plan: Module 4: Ice Jam Width_Final C:\CRIPE Short Course R2\CRIPESHORTCOURSE_R2.p09
Geometry: Module 4: Ice Jam Width_Final C:\CRIPE Short Course R2\CRIPESHORTCOURSE_R2.g08
Steady Flow: Module 3: Simple Ice Jam C:\CRIPE Short Course R2\CRIPESHORTCOURSE_R2.f06
Unsteady Flow:
Description: SI Units

DATA INPUT SIMULATION RESULTS

Geometry Files

- River centrelines
- River cross-sections
- Junctions
- Bridges and culvers
- Etc.
- **Roughness values (bed and ice)**
- **Defined ice cover thickness**
- **Ice jam location**

Steady Flow Files

- Discharge and discharge change locations
- Boundary conditions
- Rating curves
- Observed Water Surface Elevations
- Multiple steady flow “profiles” can be made in a single flow file

Plan Files

- Plan Files link a geometry file with a flow file

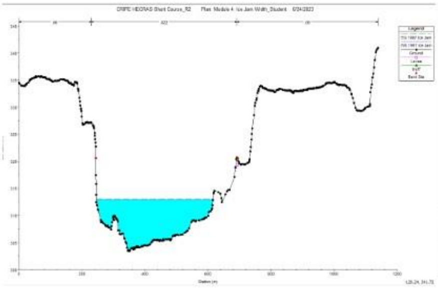
plan =

+

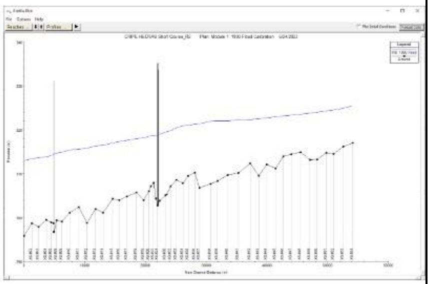
- Plans are **run** in the Steady Flow Analysis window

Views of A River

Plan



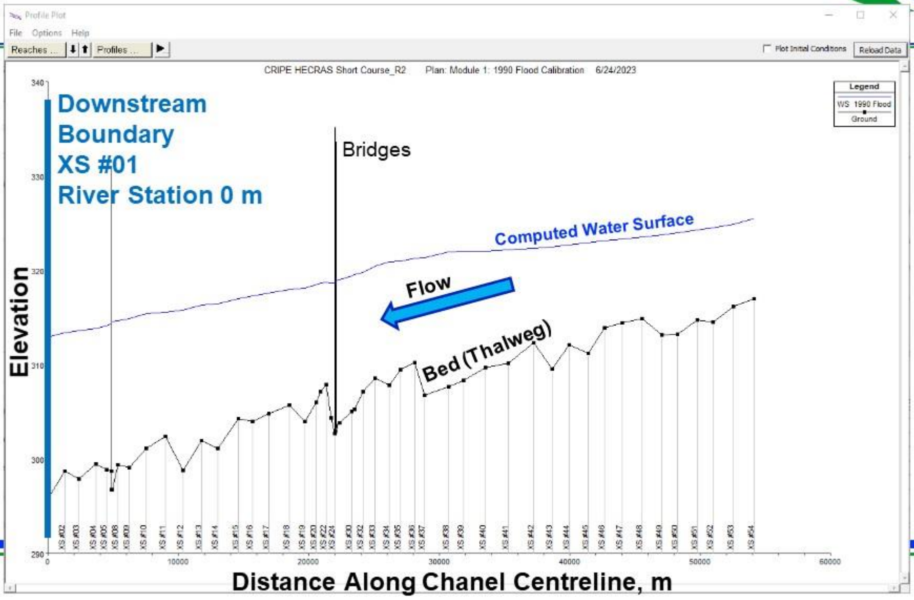
Cross-section



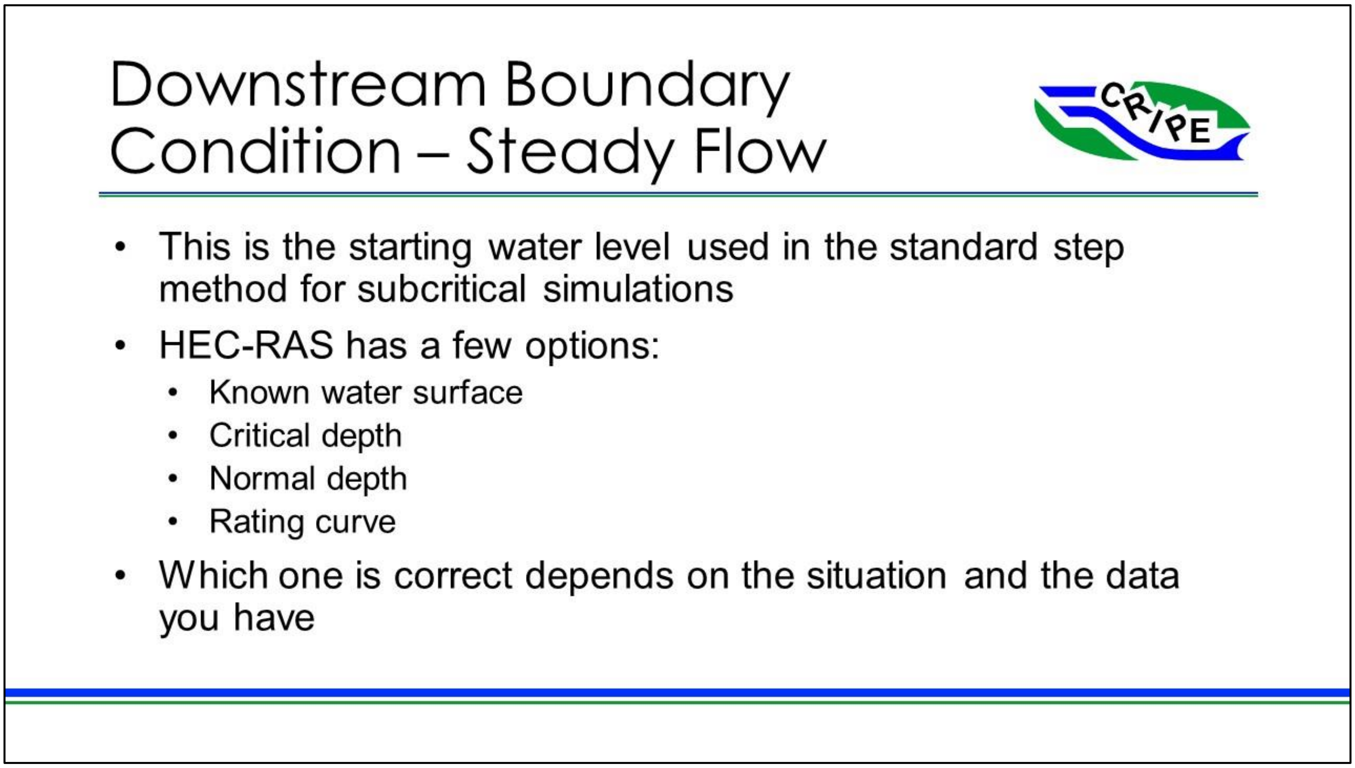
Profile

HEC-RAS River Profile

Downstream End

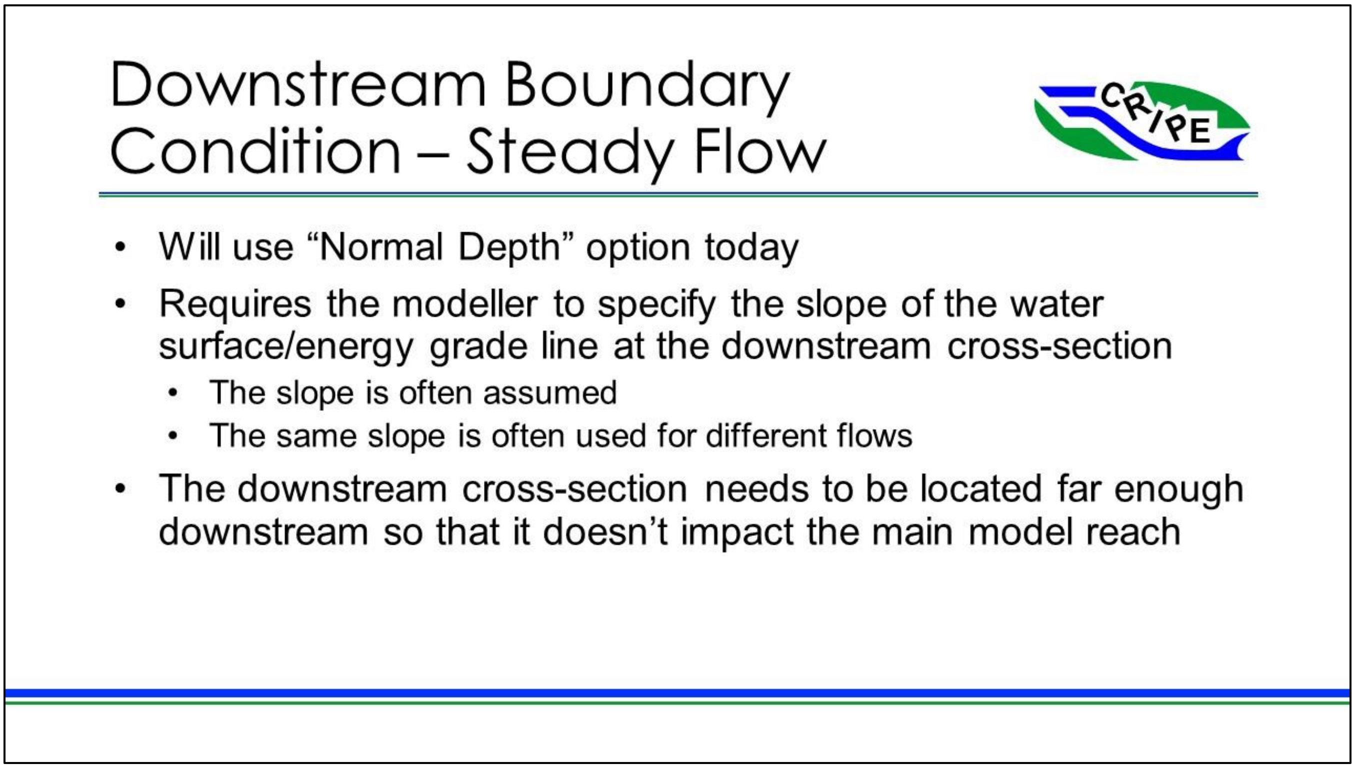


Upstream End



Downstream Boundary Condition – Steady Flow

- This is the starting water level used in the standard step method for subcritical simulations
- HEC-RAS has a few options:
  - Known water surface
  - Critical depth
  - Normal depth
  - Rating curve
- Which one is correct depends on the situation and the data you have



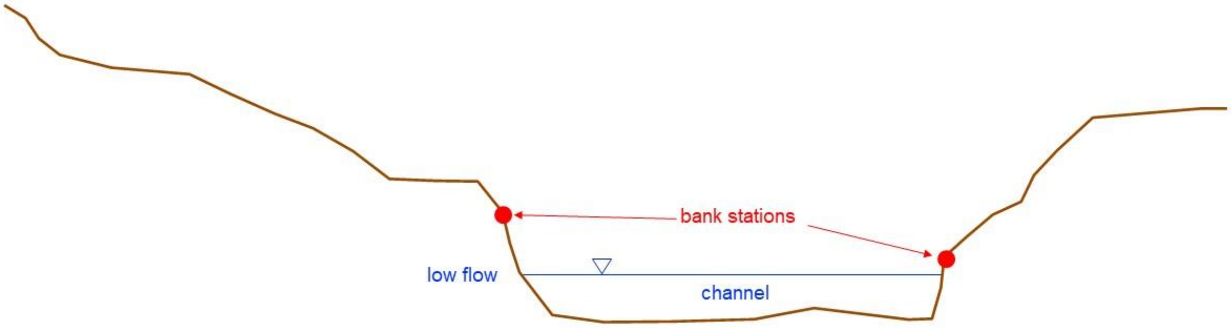
Downstream Boundary Condition – Steady Flow

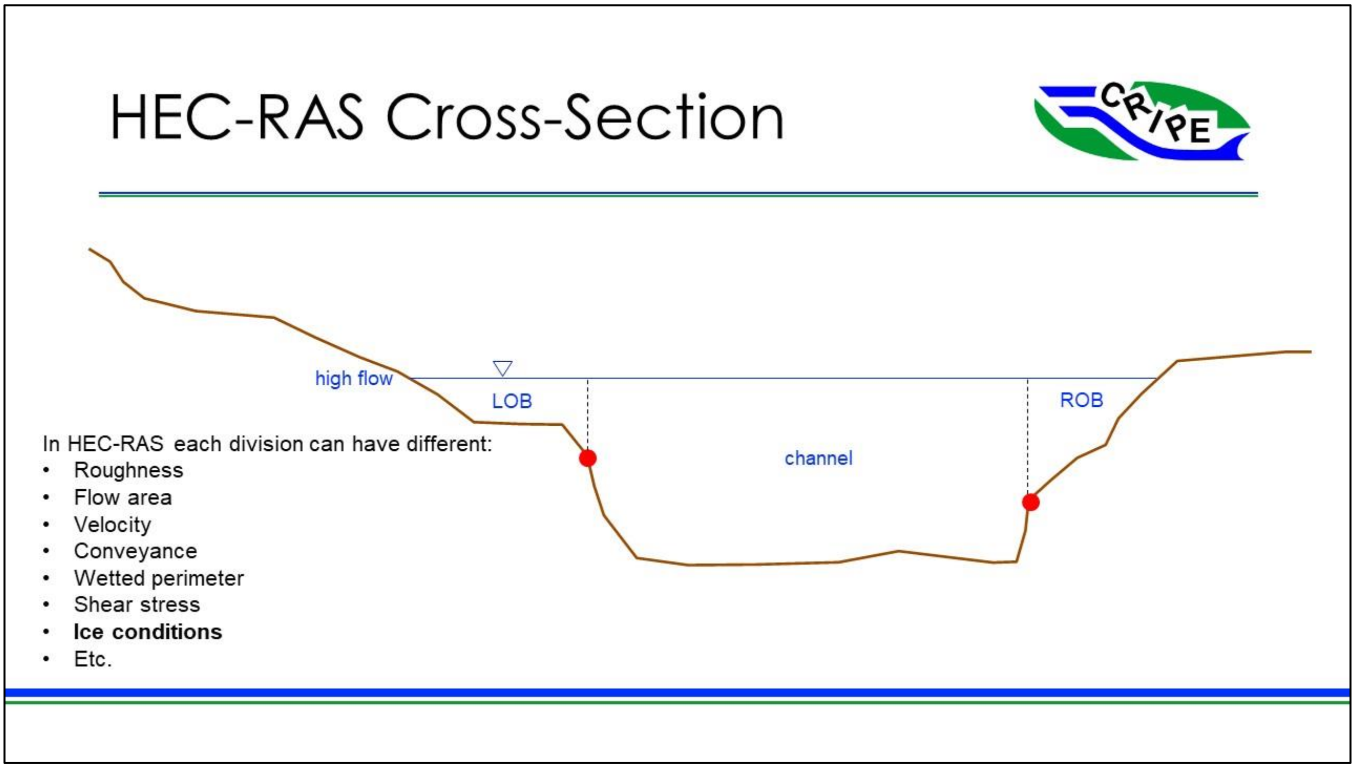
- Will use “Normal Depth” option today
- Requires the modeller to specify the slope of the water surface/energy grade line at the downstream cross-section
  - The slope is often assumed
  - The same slope is often used for different flows
- The downstream cross-section needs to be located far enough downstream so that it doesn’t impact the main model reach

HEC-RAS Cross-Section

- Cross-sections are divided into 3 parts:
  - Channel
  - Left overbank (left side looking downstream) – LOB
  - Right overbank (right side looking downstream) – ROB
- The channel and overbanks are separated by “bank stations”
  - Hydraulic features (changes in conveyance)
  - Geomorphic features (changes in channel/floodplain shape)
  - Roughness features (changes in roughness)
  - Ice features (changes in ice conditions)

HEC-RAS Cross-Section





HEC-RAS Cross-Section

In HEC-RAS each division can have different:

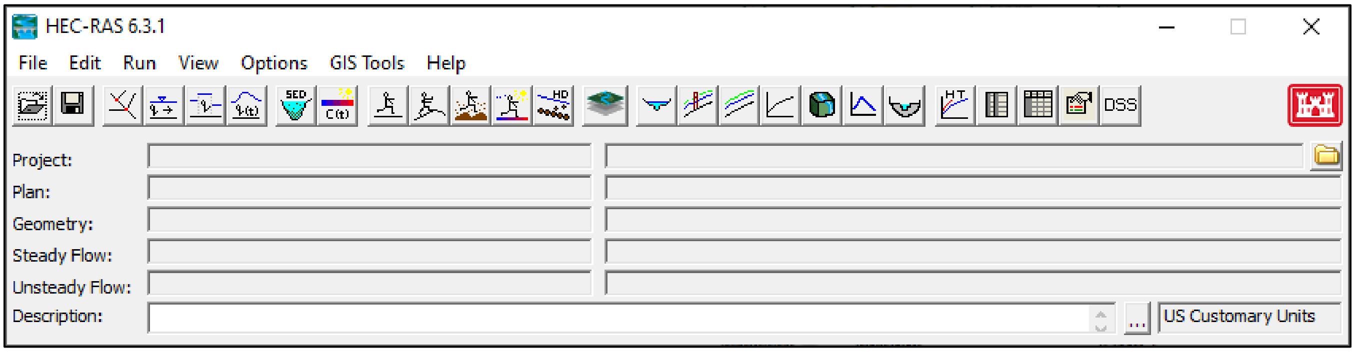
- Roughness
- Flow area
- Velocity
- Conveyance
- Wetted perimeter
- Shear stress
- **Ice conditions**
- Etc.

Task 1A Instructions: Launch HEC-RAS and Get Familiar with the Data and Analysis Windows

Table 1: Model Files Used for HEC-RAS Module 1 - Task 1A and Task 1B

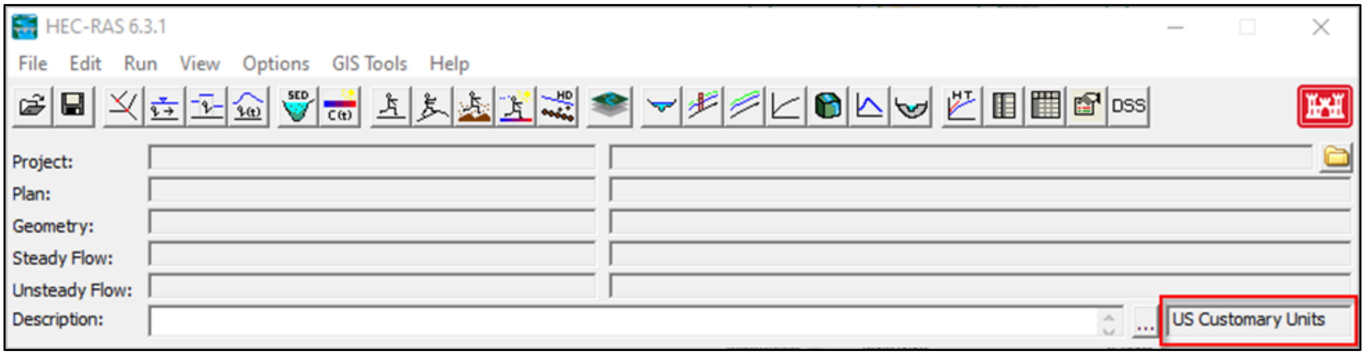
File Type	Filename
Plan	“Module 1: 1990 Flood Calibration”
Geometry	“Module 1: Open Water”
Steady Flow	“Module 1: 1990 Flood Calibration

1. Double click on the HEC-RAS 6.3.1 icon on your desktop . The main interface window will open.



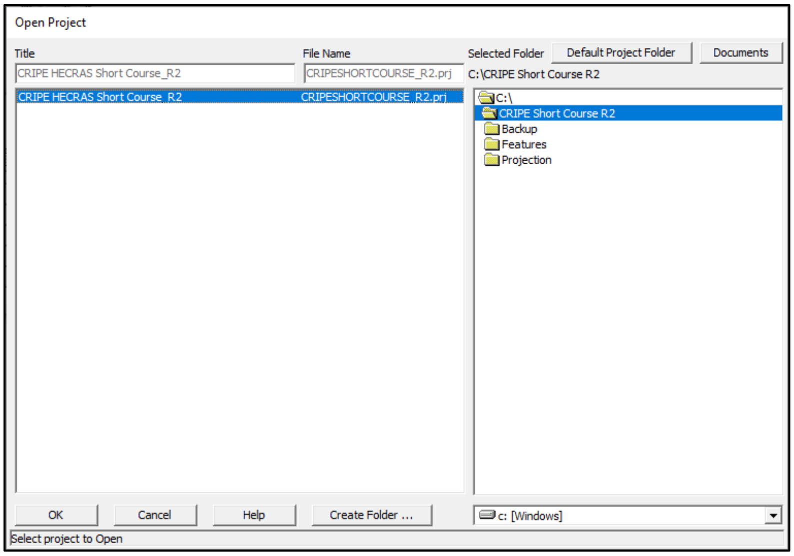
US Customary Units

Notice that the first time you open HEC-RAS the units will be set as ‘US Customary Units’. The use of ‘US Customary Units’ or ‘Metric’ units is a setting in the project file.



US Customary Units

2. Click on in the main interface to open the HEC-RAS project for this course. Browse to the file location: “C:\CRIPE Short Course R2” and is project file called *“***CRIPESHORTCOURSE_R2.prj***”*



Title: CRIPE HECRAS Short Course_R2

File Name: CRIPESHORTCOURSE_R2.prj

Selected Folder: C:\CRIPE Short Course R2

CRIPE HECRAS Short Course_R2	CRIPESHORTCOURSE_R2.prj

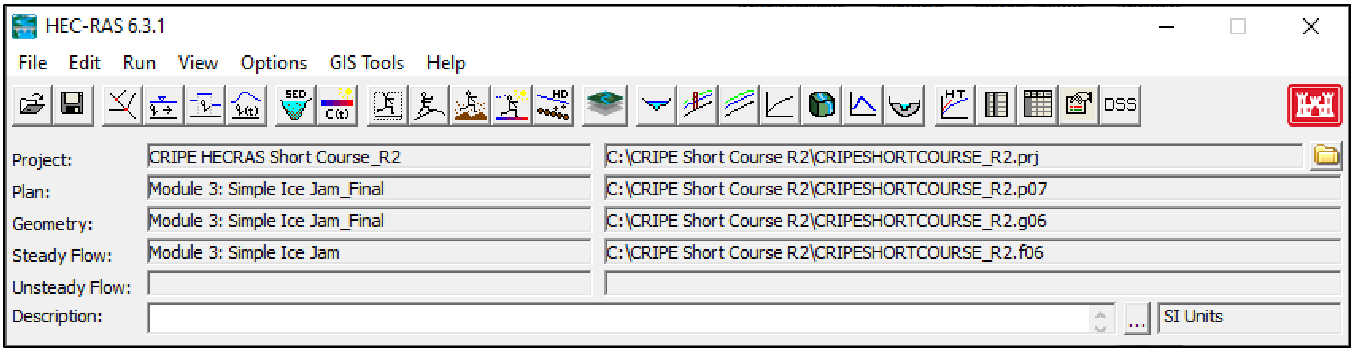
C:\
CRIPE Short Course R2
Backup
Features
Projection

c: [Windows]

Select project to Open

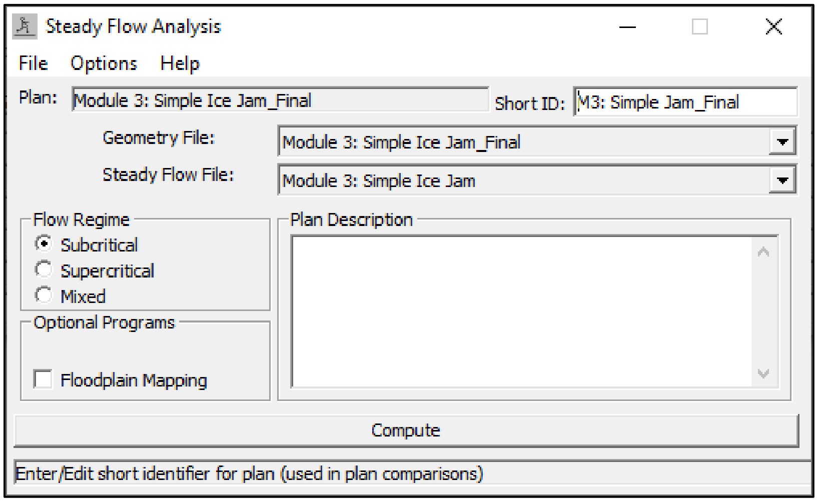
3. Click OK ,

The main interface now shows the **plan**, **geometry**, and **steady flow** files that are currently loaded in the project. The files shown in your main interface may be different from the ones shown here:



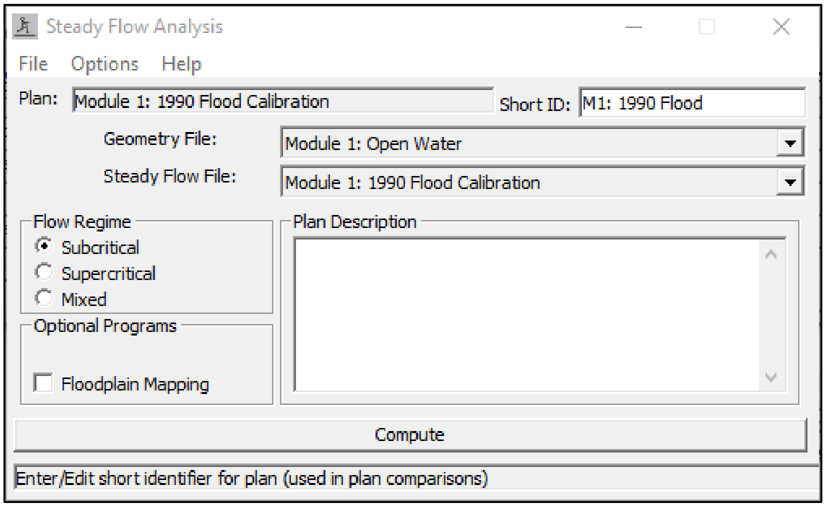
Project: CRIPE HECRAS Short Course_R2 C:\CRIPE Short Course R2\CRIPESHORTCOURSE_R2.prj
Plan: Module 3: Simple Ice Jam_Final C:\CRIPE Short Course R2\CRIPESHORTCOURSE_R2.p07
Geometry: Module 3: Simple Ice Jam_Final C:\CRIPE Short Course R2\CRIPESHORTCOURSE_R2.g06
Steady Flow: Module 3: Simple Ice Jam C:\CRIPE Short Course R2\CRIPESHORTCOURSE_R2.f06
Unsteady Flow:
Description: SI Units

4. Click on in the main interface to open the ‘Steady Flow Analysis’ window:



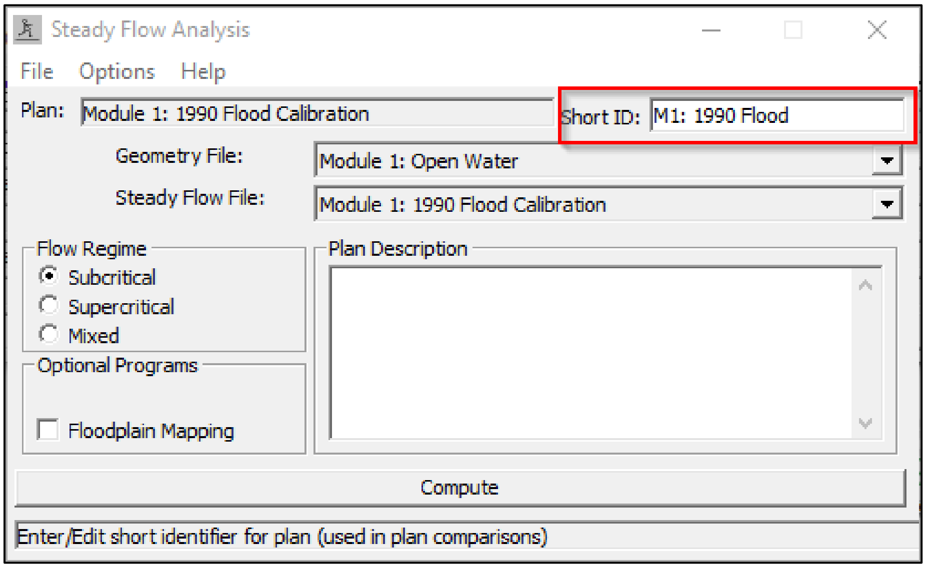
Plan: Module 3: Simple Ice Jam_Final Short ID: M3: Simple Jam_Final
Geometry File: Module 3: Simple Ice Jam_Final
Steady Flow File: Module 3: Simple Ice Jam
Flow Regime
● Subcritical
○ Supercritical
○ Mixed
Optional Programs
☐ Floodplain Mapping
Plan Description
Enter/Edit short identifier for plan (used in plan comparisons)

5. In the ‘Steady Flow Analysis’ window, click File and select the ‘*Open Plan…*’ option. Select the plan file we are using for this Task: “**Module 1: 1990 Flood Calibration**”.



Plan: Module 1: 1990 Flood Calibration Short ID: M1: 1990 Flood
Geometry File: Module 1: Open Water
Steady Flow File: Module 1: 1990 Flood Calibration
Flow Regime
● Subcritical
○ Supercritical
○ Mixed
Optional Programs
☐ Floodplain Mapping
Plan Description
Enter/Edit short identifier for plan (used in plan comparisons)

Now the geometry file and the steady flow files for this Task are loaded. Note that the plan file we opened *“***Module 1: 1990 Flood Calibration***”* links together a geometry file and a steady flow file. The ‘Short ID’ of the plan file (*“***M1: 1990 Flood***”)* is what is used in output results tables and figures in HEC-RAS:



Plan: Module 1: 1990 Flood Calibration

Short ID: M1: 1990 Flood

Geometry File: Module 1: Open Water

Steady Flow File: Module 1: 1990 Flood Calibration

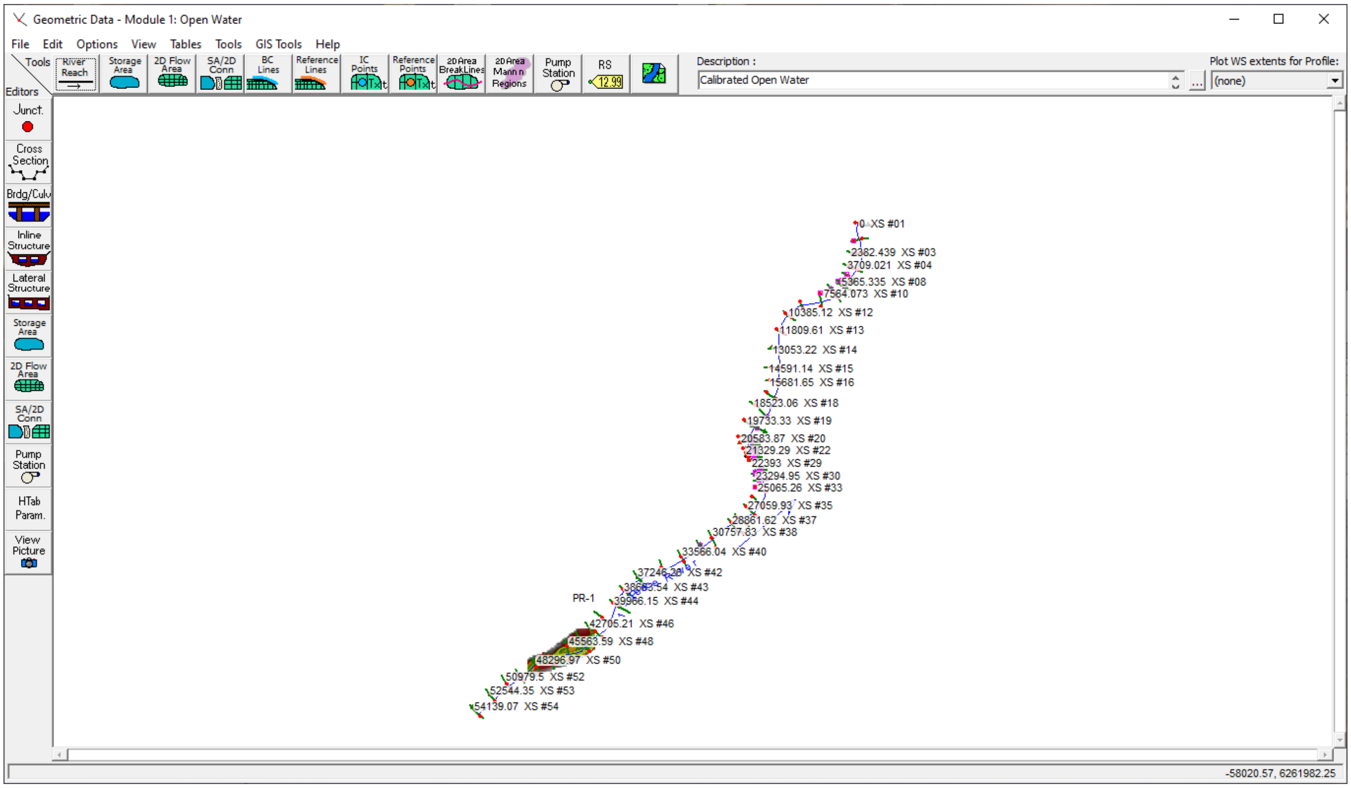
Flow Regime
● Subcritical
○ Supercritical
○ Mixed

Optional Programs
☐ Floodplain Mapping

Enter/Edit short identifier for plan (used in plan comparisons)

6. Close the ‘Steady Flow Analysis’ window by clicking the ×

7. Click on the in the main interface to open the ‘Geometric Data’ window:

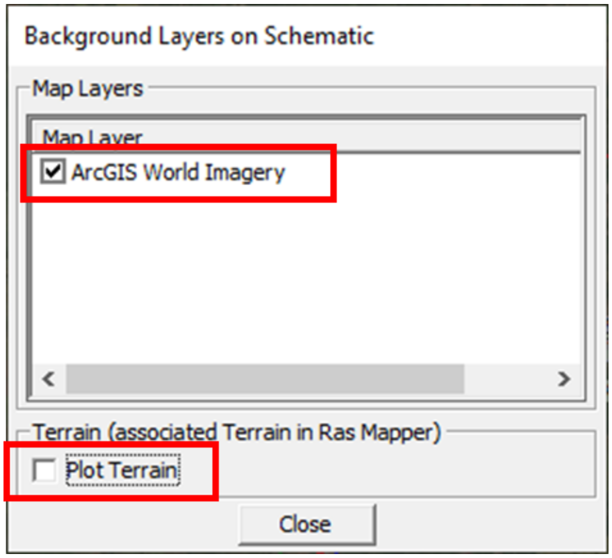


Description : Calibrated Open Water

Plot WS extents for Profile: (none)

8. Click on the icon in the Geometric Data window.

9. Un-check “Plot Terrain” and check “ArcGIS World Imagery” in the pop-up window:



Background Layers on Schematic

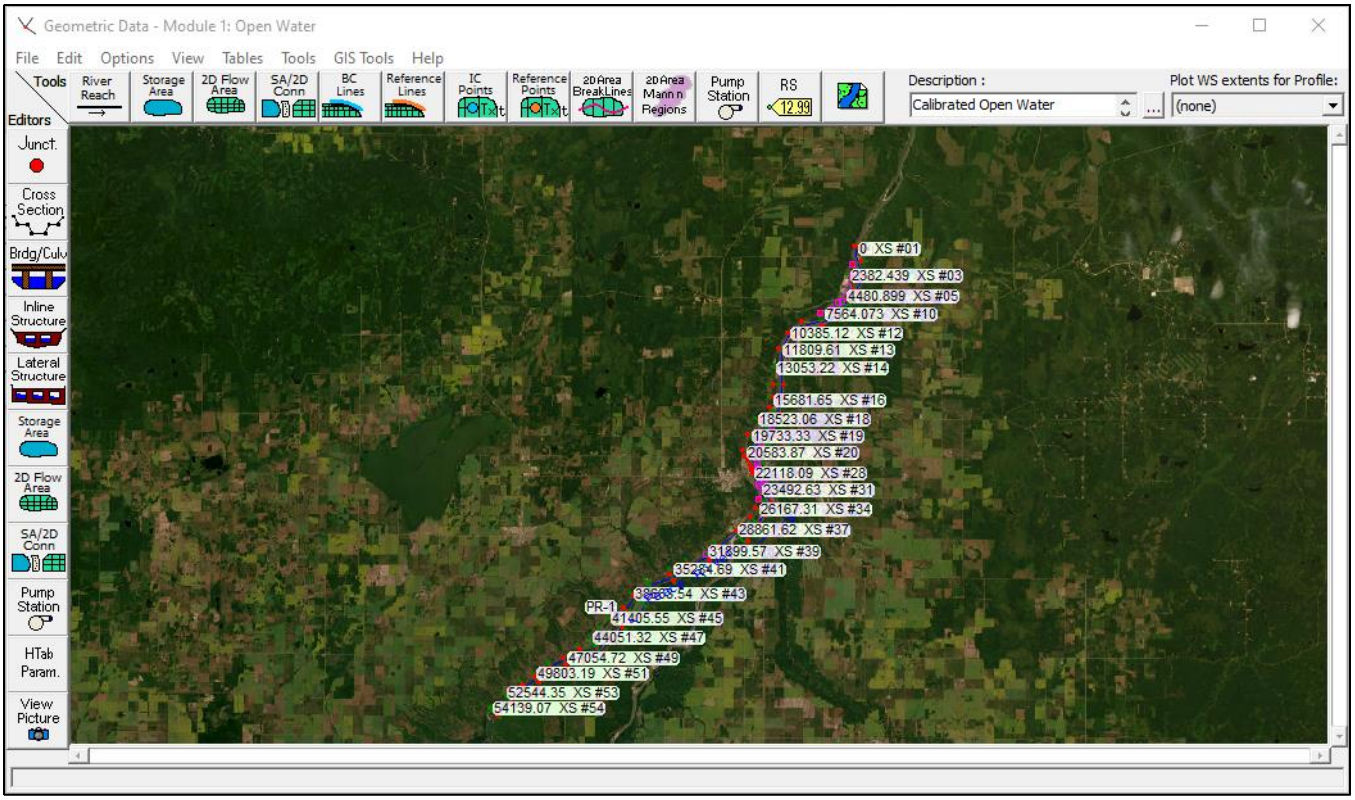
Map Layers

☑ ArcGIS World Imagery

Terrain (associated Terrain in Ras Mapper)

☐ Plot Terrain

10. Click Close.



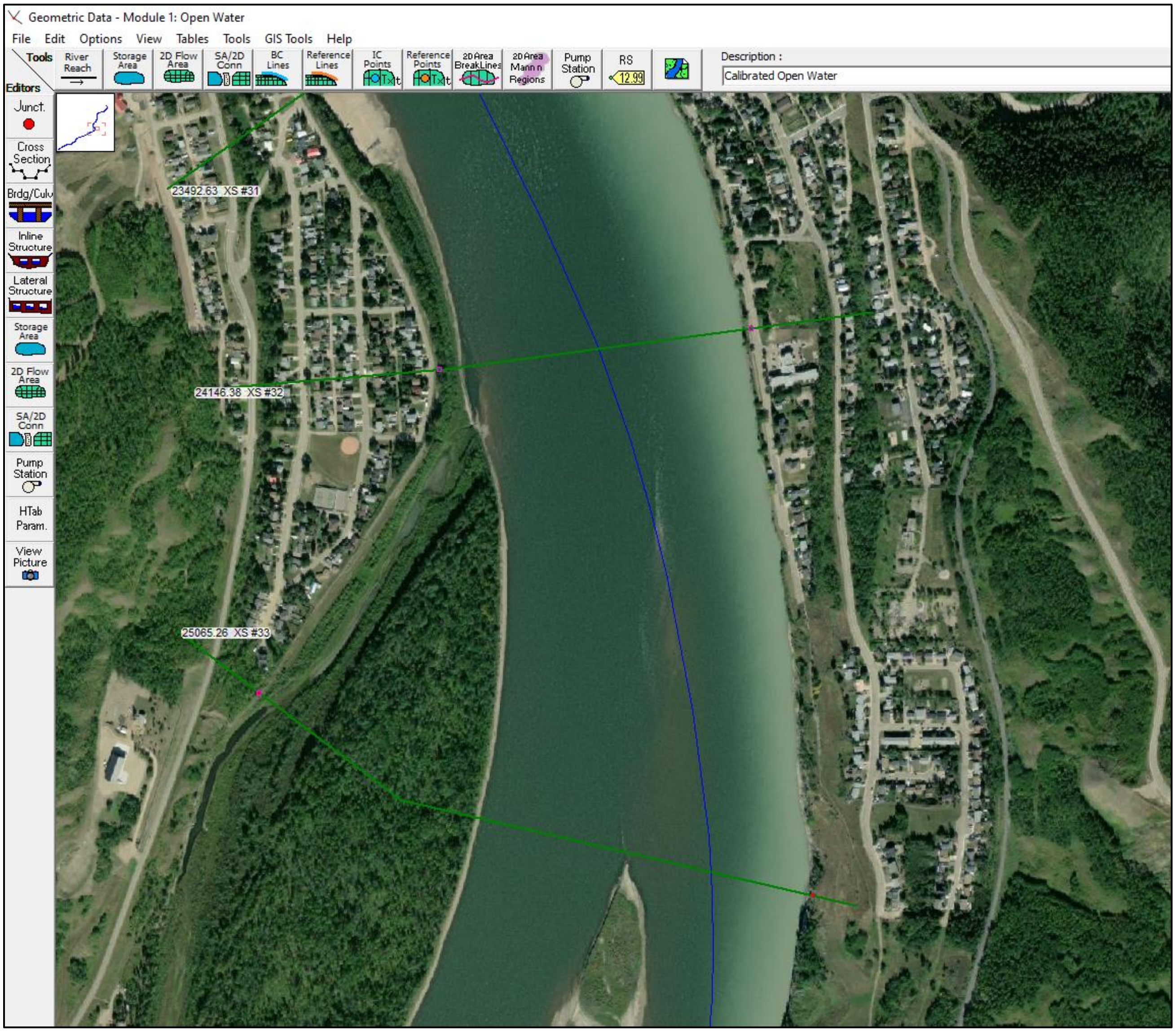
Geometric Data - Module 1: Open Water

Description : Calibrated Open Water

Plot WS extents for Profile: (none)

The ‘Geometric Data’ window shows the model geometry including the river centreline, model cross-section locations, junctions, bank stations, etc.

11. Look around the model domain by zooming in and out and panning. The tools for zooming and panning are in the View menu at top of the program. Alternatively, you can hold down the SHIFT key to pan and scroll to zoom.



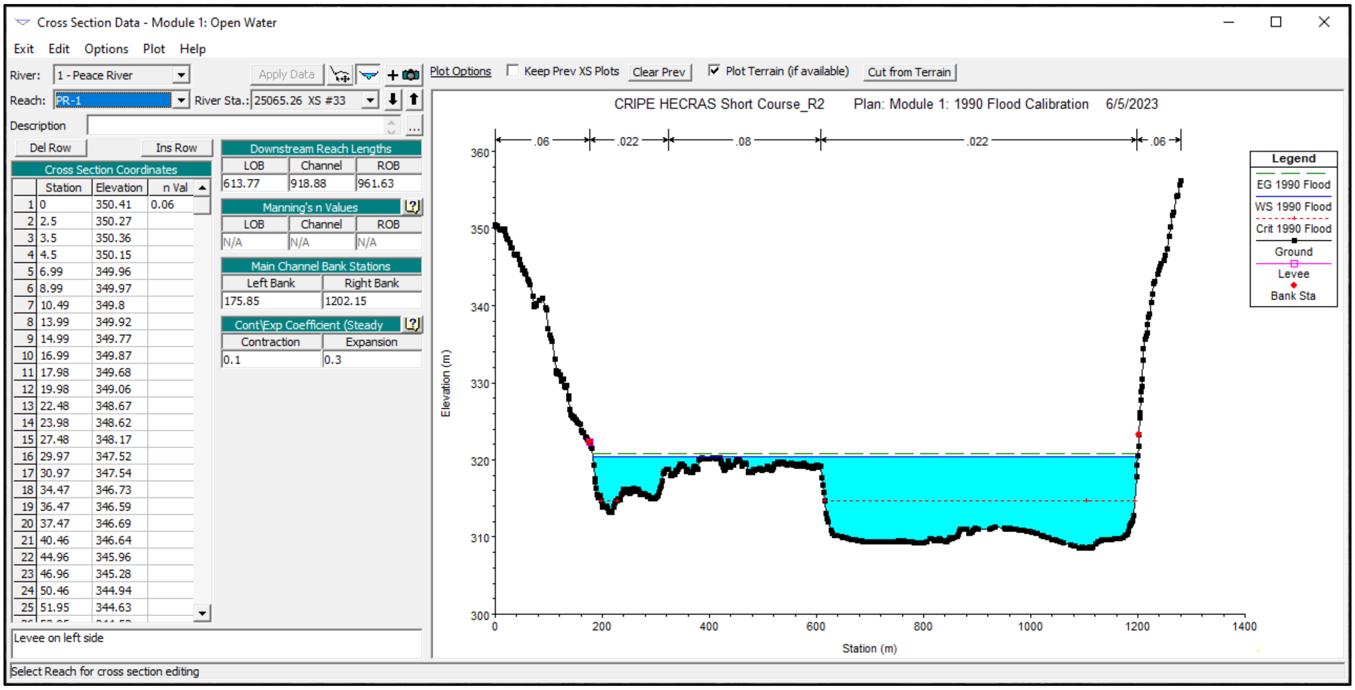
Description : Calibrated Open Water

Note that:

- The channel centreline is shown as a blue line
- The cross-section lines are shown as a green line
- The cross-sections are labeled with their location along the channel centreline (in meters) and a cross-section number (e.g. ‘24146.38 XS #32’)
- Top of bank locations (also called “bank stations”) are shown with red dots
- Levee locations are shown with open pink squares.

- The background image ('Base Map Layer') is supplied by HEC-RAS from a web mapping service, but your own imagery can be added.

12. From the Geometric Data Window click on the Cross Section to open the 'Cross Section Data' window:



River: 1 - Peace River

Reach: PR-1

River Sta.: 25065.26 XS #33

Description:

Cross Section Coordinates

	Station	Elevation	n Val
1	0	350.41	0.06
2	2.5	350.27	
3	3.5	350.36	
4	4.5	350.15	
5	6.99	349.96	
6	8.99	349.97	
7	10.49	349.8	
8	13.99	349.92	
9	14.99	349.77	
10	16.99	349.87	
11	17.98	349.68	
12	19.98	349.06	
13	22.48	348.67	
14	23.98	348.62	
15	27.48	348.17	
16	29.97	347.52	
17	30.97	347.54	
18	34.47	346.73	
19	36.47	346.59	
20	37.47	346.69	
21	40.46	346.64	
22	44.96	345.96	
23	46.96	345.28	
24	50.46	344.94	
25	51.95	344.63	

Downstream Reach Lengths

LOB	Channel	ROB
613.77	918.88	961.63

Manning's n Values

LOB	Channel	ROB
N/A	N/A	N/A

Main Channel Bank Stations

Left Bank	Right Bank
175.85	1202.15

Cont\Exp Coefficient (Steady

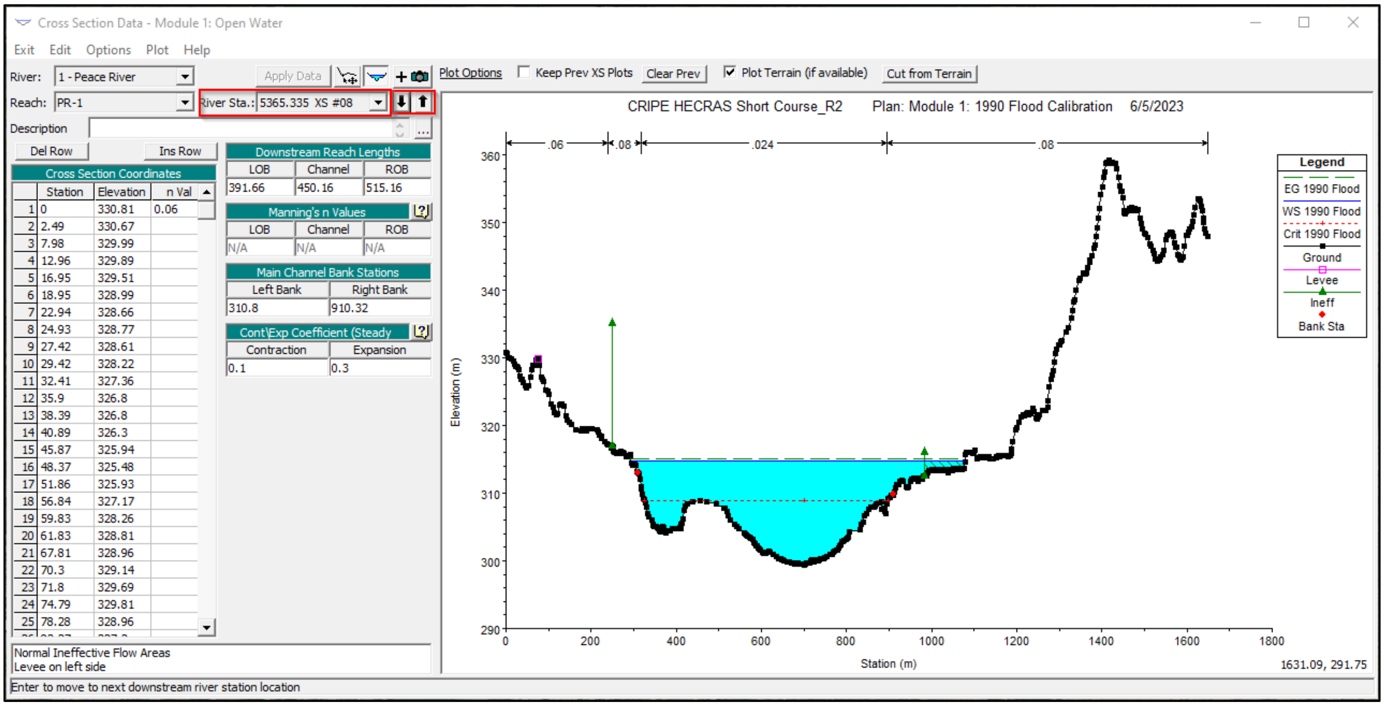
Contraction	Expansion
0.1	0.3

Levee on left side

Select Reach for cross section editing

The 'Cross Section Data' window show the cross-section geometry, the location of the left and right bank stations, the roughness values (Manning's *n*). Because this model has been run before, model results are available, so the water level (dark blue line) and filled in wetted area (cyan fill) are shown.

13. Browse the cross-sections by scrolling using the up and down black arrows, or selecting the cross-section from the dropdown list:



River: 1 - Peace River

Reach: PR-1

River Sta.: 5365.335 XS #08

Description

Cross Section Coordinates

	Station	Elevation	n Val
1	0	330.81	0.06
2	2.49	330.67	
3	7.98	329.99	
4	12.96	329.89	
5	16.95	329.51	
6	18.95	328.99	
7	22.94	328.66	
8	24.93	328.77	
9	27.42	328.61	
10	29.42	328.22	
11	32.41	327.36	
12	35.9	326.8	
13	38.39	326.8	
14	40.89	326.3	
15	45.87	325.94	
16	48.37	325.48	
17	51.86	325.93	
18	56.84	327.17	
19	59.83	328.26	
20	61.83	328.81	
21	67.81	328.96	
22	70.3	329.14	
23	71.8	329.69	
24	74.79	329.81	
25	78.28	328.96	

Downstream Reach Lengths

LOB	Channel	ROB
391.66	450.16	515.16

Manning's n Values

LOB	Channel	ROB
N/A	N/A	N/A

Main Channel Bank Stations

Left Bank	Right Bank
310.8	910.32

Cont\Exp Coefficient (Steady

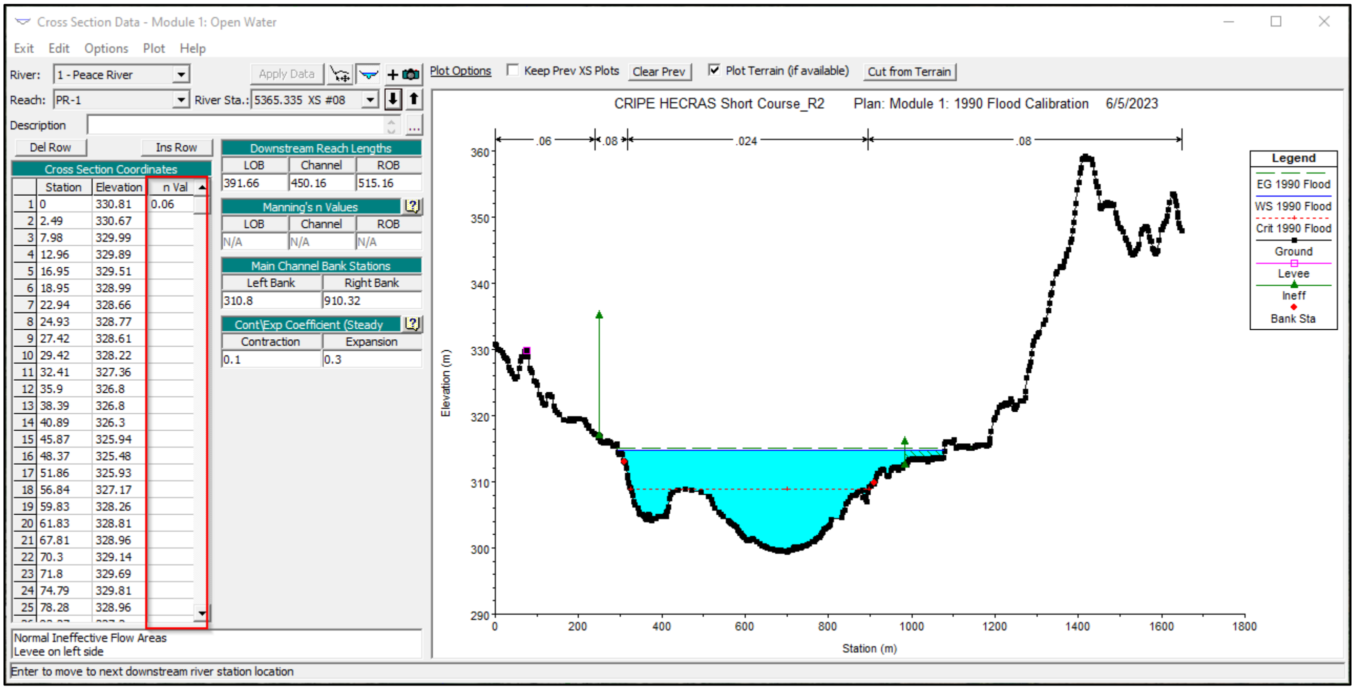
Contraction	Expansion
0.1	0.3

Normal Ineffective Flow Areas
Levee on left side

Enter to move to next downstream river station location

Some cross-sections have additional features such as levees, ineffective flow areas, and bridges. As you view different cross-sections, the cross-section you are currently viewing is highlighted on the plan view in the Geometric Data window.

14. View the Manning's *n* roughness values used for a cross-section in the 'Cross Section Coordinates' table.



River: 1 - Peace River

Reach: PR-1

River Sta.: 5365.335 XS #08

Description

Cross Section Coordinates

	Station	Elevation	n Val
1	0	330.81	0.06
2	2.49	330.67	
3	7.98	329.99	
4	12.96	329.89	
5	16.95	329.51	
6	18.95	328.99	
7	22.94	328.66	
8	24.93	328.77	
9	27.42	328.61	
10	29.42	328.22	
11	32.41	327.36	
12	35.9	326.8	
13	38.39	326.8	
14	40.89	326.3	
15	45.87	325.94	
16	48.37	325.48	
17	51.86	325.93	
18	56.84	327.17	
19	59.83	328.26	
20	61.83	328.81	
21	67.81	328.96	
22	70.3	329.14	
23	71.8	329.69	
24	74.79	329.81	
25	78.28	328.96	

Downstream Reach Lengths

LOB	Channel	ROB
391.66	450.16	515.16

Manning's n Values

LOB	Channel	ROB
N/A	N/A	N/A

Main Channel Bank Stations

Left Bank	Right Bank
310.8	910.32

Cont\Exp Coefficient (Steady

Contraction	Expansion
0.1	0.3

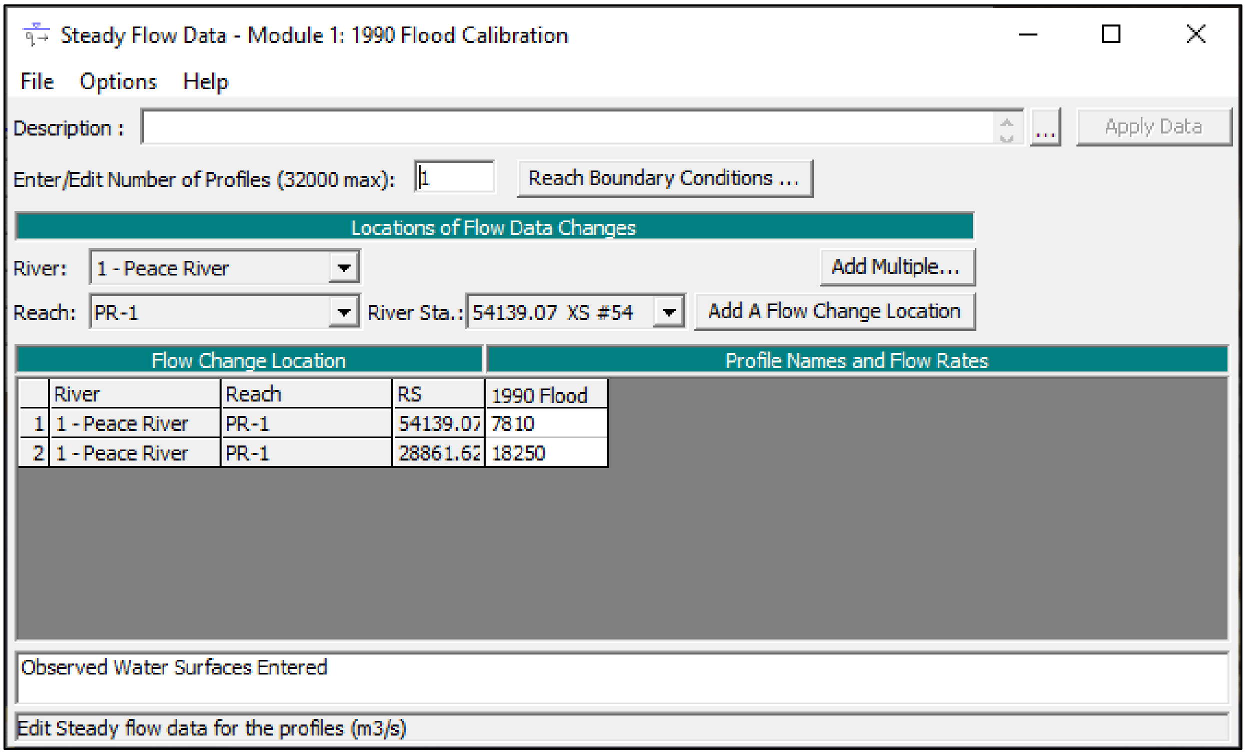
Normal Ineffective Flow Areas
Levee on left side

Enter to move to next downstream river station location

In this open water model, the n-values are varied along the cross-section, by assigning a value at different stations. This is called the “Horizontal Variation Method”. We will change this to the “Standard Method” (where roughness values are assigned only for the channel, left, and right overbanks) before simulating an ice cover.

15. Close the ‘Cross Section Data’ window and the ‘Geometric Data’ window by clicking on the × on each window.

16. In the main interface click on the to open the ‘Steady Flow Data’ window:



Steady Flow Data - Module 1: 1990 Flood Calibration

Enter/Edit Number of Profiles (32000 max): 1

River: 1 - Peace River

Reach: PR-1

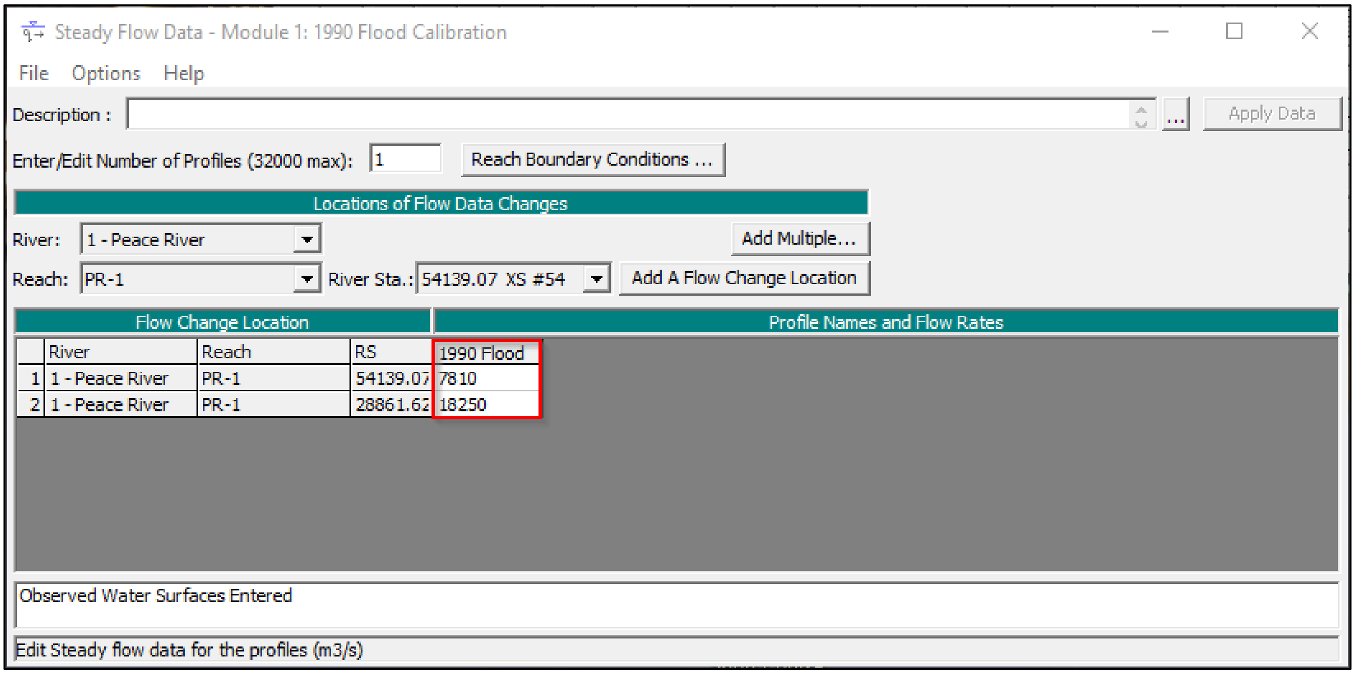
River Sta.: 54139.07 XS #54

	River	Reach	RS	1990 Flood
1	1 - Peace River	PR-1	54139.07	7810
2	1 - Peace River	PR-1	28861.62	18250

Observed Water Surfaces Entered

Edit Steady flow data for the profiles (m3/s)

The ‘Steady Flow Data’ window is where the **Steady Flow** file is edited and viewed. The **Steady Flow** file is where the discharge (and discharge change locations), boundary conditions, observed water level, and rating curves are stored. Each flow file can have multiple “profiles” that can each have different discharges, boundary conditions, and observed water levels. This flow file has just one profile, called “**1990 Flood**”. The flow changes at one location: the cross-section at station 28861.62, where the Smoky River tributary enters the Peace River. At this location for the 1990 Flood, the flow was 7,810 m^3/s upstream of the Smoky River tributary, and 18,250 m^3/s downstream of the Smoky River tributary:



Description :

Enter/Edit Number of Profiles (32000 max): 1

River: 1 - Peace River

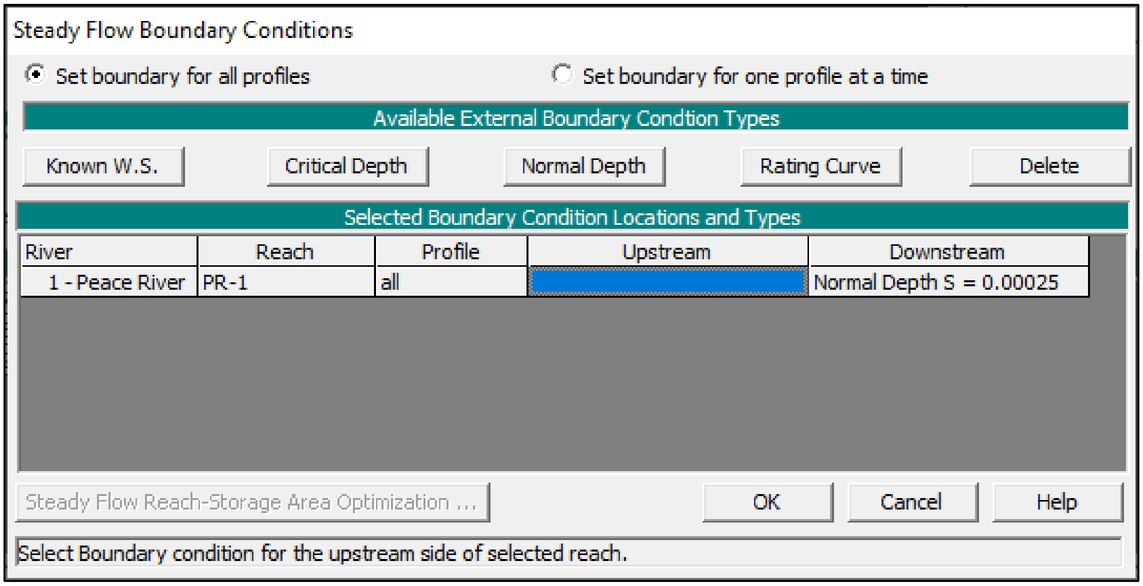
Reach: PR-1 River Sta.: 54139.07 XS #54

	River	Reach	RS	1990 Flood
1	1 - Peace River	PR-1	54139.07	7810
2	1 - Peace River	PR-1	28861.62	18250

Observed Water Surfaces Entered

Edit Steady flow data for the profiles (m3/s)

17. View the boundary conditions by clicking on the Reach Boundary Conditions ... button:



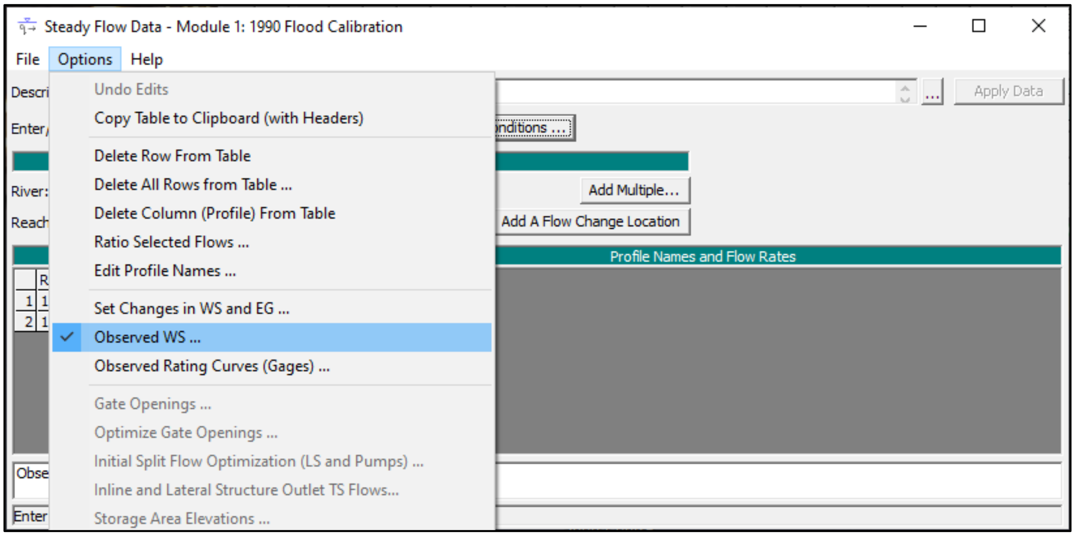
● Set boundary for all profiles ○ Set boundary for one profile at a time

River	Reach	Profile	Upstream	Downstream
1 - Peace River	PR-1	all		Normal Depth S = 0.00025

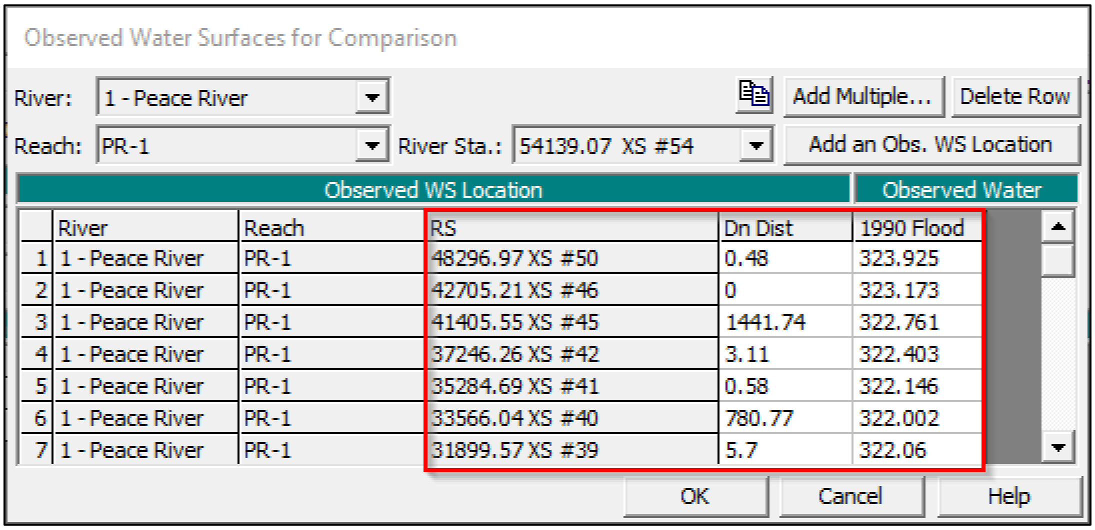
Select Boundary condition for the upstream side of selected reach.

A downstream boundary condition using the “Normal Depth” method will be used for all simulations in this course. Using this method, HEC-RAS will calculate the water level at the most downstream cross-section assuming uniform flow and a water surface and energy grade line slope of 0.00025. This is a reasonable first guess for a downstream section. The location of the downstream boundary condition is chosen to reduce the effect of the boundary condition within the main model reach. It is the role of the modeller and study designer to choose boundary conditions to fit the physical situation and intended use of a model.

18. Close the ‘Steady Flow Boundary Conditions’ window by clicking Cancel .
19. View the observed water surface elevations by clicking Options and selecting ‘*Observed WS…*’ in the ‘Steady Flow Data’ window



20. View the observed water surface elevations that are contained in the **Steady Flow** file.



River: 1 - Peace River
Reach: PR-1
River Sta.: 54139.07 XS #54

	Observed WS Location				Observed Water
	River	Reach	RS	Dn Dist	1990 Flood
1	1 - Peace River	PR-1	48296.97 XS #50	0.48	323.925
2	1 - Peace River	PR-1	42705.21 XS #46	0	323.173
3	1 - Peace River	PR-1	41405.55 XS #45	1441.74	322.761
4	1 - Peace River	PR-1	37246.26 XS #42	3.11	322.403
5	1 - Peace River	PR-1	35284.69 XS #41	0.58	322.146
6	1 - Peace River	PR-1	33566.04 XS #40	780.77	322.002
7	1 - Peace River	PR-1	31899.57 XS #39	5.7	322.06

Each observed water surface has a location and an elevation. The elevation is under the column called ‘1990 Flood’. This is because this profile is from the 1990 Flood, and the name of the profile is ‘1990 Flood’. The location is defined as a cross-section and River Station (RS), and the distance downstream of the cross-section (‘Dn Dist’, in meters), so that the locations of observed water surfaces can be located between cross-sections.

21. Close the ‘Observed Water Surface for Comparison’ window by clicking Cancel .
22. Close the ‘Steady Flow Data’ window by clicking on the × .

Task 1B and 1C: Background Information

Observed Data

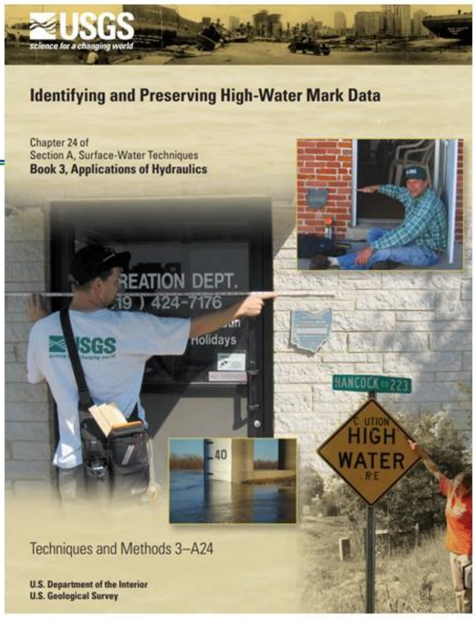
- Used to compare model results to real world
- Used in model calibration
- For ice we could use:
  - Water surface elevation
  - High water mark (evidence of a past peak water surface elevation)
  - Ice thickness
  - Top of ice
  - Bottom of ice

Water Surface Elevations

Surveyed

Gauged

High Water Marks


USGS
science for a changing world

Identifying and Preserving High-Water Mark Data

Chapter 24 of
Section A, Surface-Water Techniques
Book 3, Applications of Hydraulics

Techniques and Methods 3–A24

U.S. Department of the Interior
U.S. Geological Survey

High water mark survey, Peace River at Fort Vermilion, April 2020.
Photo by Stefan Emmer, Alberta Environment and Protected Areas.

Koenig, et al. 2016

Ice Thickness

Measured through the ice

Measuring shear walls on the Peace River

Photo: Faye Hicks, U of A

Photo: BCHydro

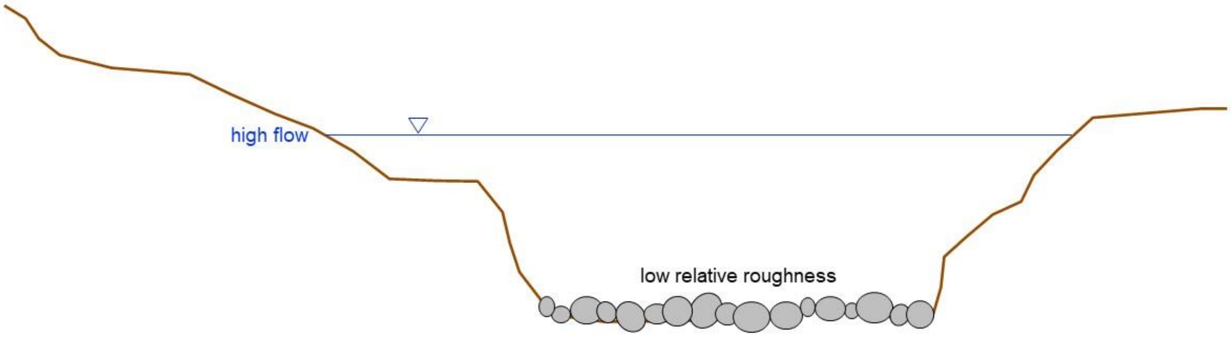
Calibration

- Matching model results to observations
  - Most commonly matching water level
- We know or have assumed:
  - Stream geometry
  - Discharge
- We don’t know:
  - Roughness

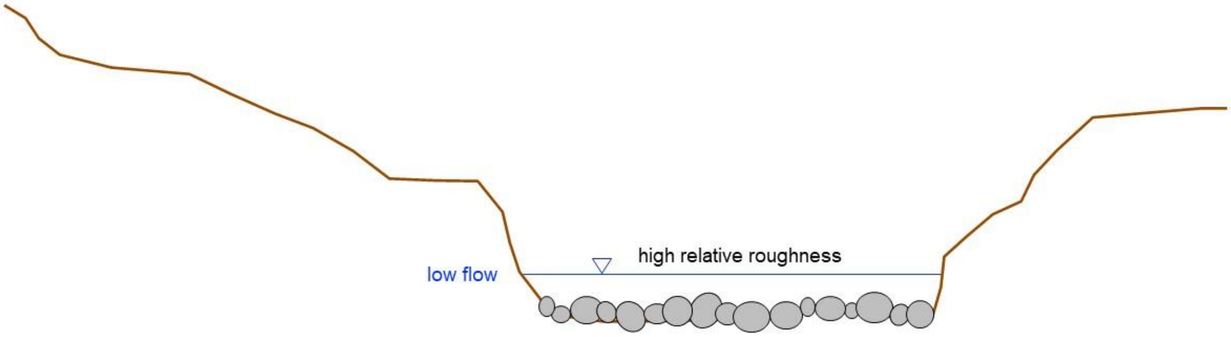
Calibration

- Modelers change roughness to match water levels
- HEC-RAS uses Manning’s “n” values to define the roughness of the channel boundaries
  - Can also input “k” (roughness height), but these are converted by HEC-RAS to “n”
  - Accounts for energy losses in the stream
    - Except for expansion and contraction losses

Relative Roughness – Task 1C

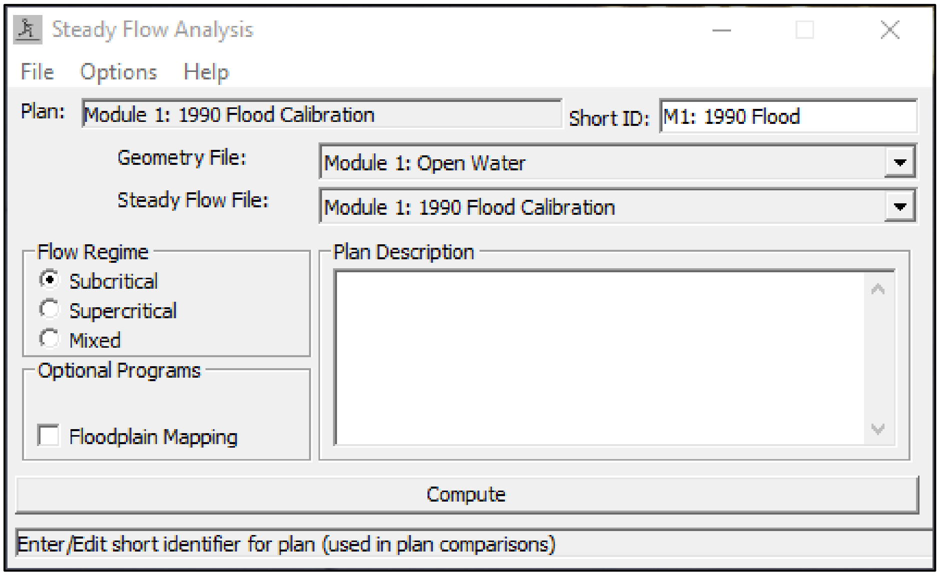


Relative Roughness – Task 1C



Task 1B Instructions: Run the HEC-RAS Model for the 1990 Open Water Event and Check Model Calibration

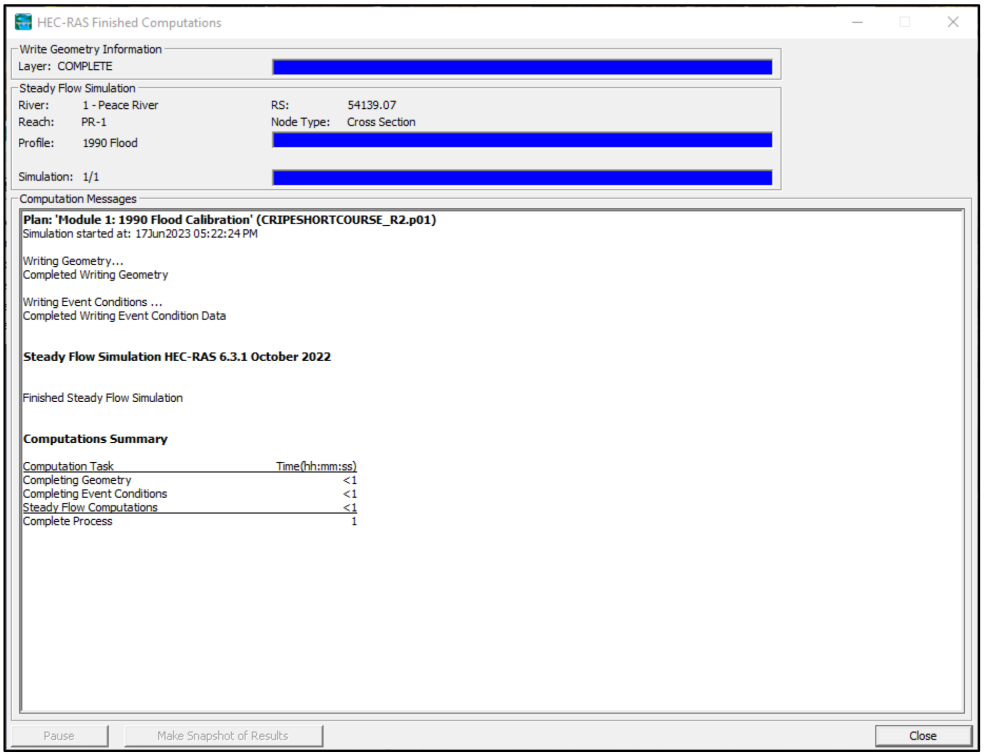
1. From the main interface, open the ‘Steady Flow Analysis’ window by clicking on the :



Plan: Module 1: 1990 Flood Calibration
Short ID: M1: 1990 Flood
Geometry File: Module 1: Open Water
Steady Flow File: Module 1: 1990 Flood Calibration
Flow Regime
● Subcritical
○ Supercritical
○ Mixed
Optional Programs
☐ Floodplain Mapping
Plan Description
Enter/Edit short identifier for plan (used in plan comparisons)

This is the window from where you will run the model. It shows the **Plan** file you are using (“**Module 1: 1990 Flood Calibration**”) and the **Geometry** and **Steady Flow** file information that will be used for the model run.

2. Click Compute to run the model.



Layer: COMPLETE

River: 1 - Peace River
Reach: PR-1
Profile: 1990 Flood
RS: 54139.07
Node Type: Cross Section
Simulation: 1/1

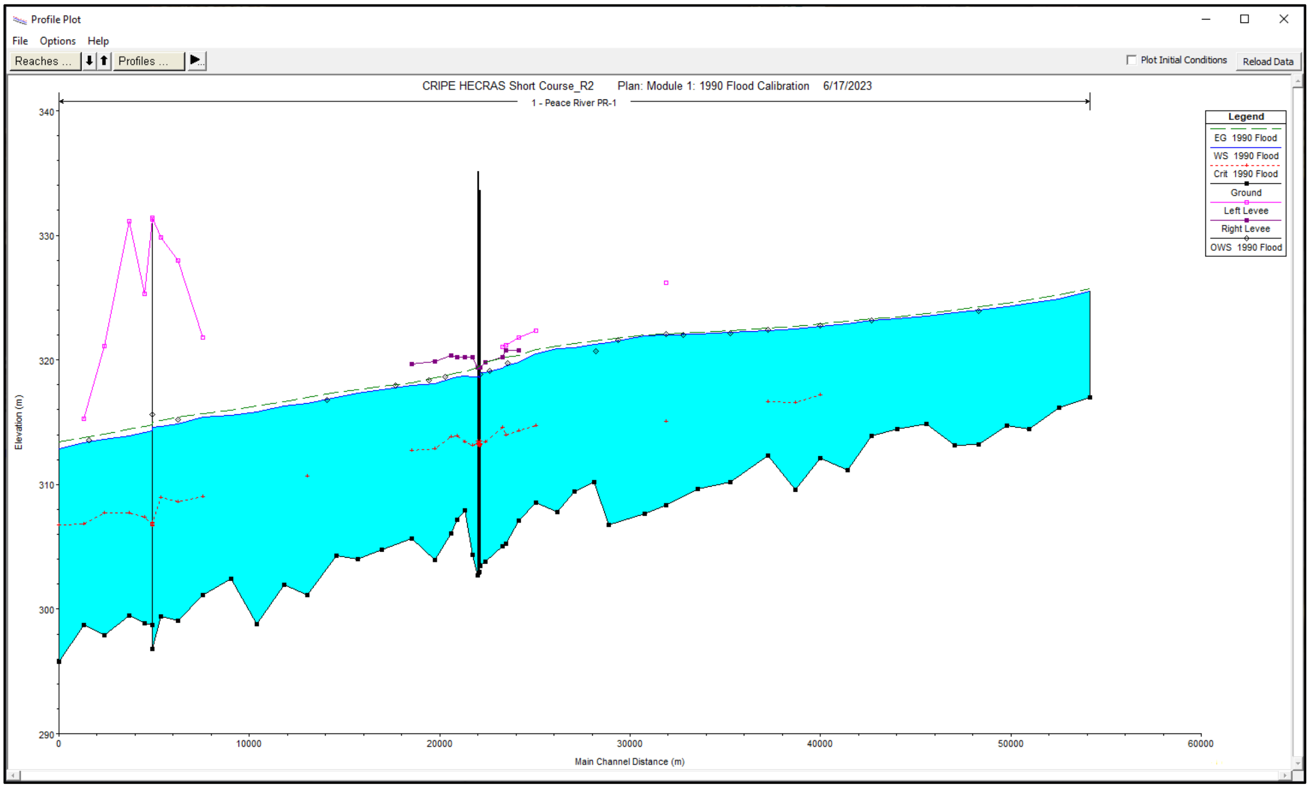
```
Plan: 'Module 1: 1990 Flood Calibration' (CRIPESHORTCOURSE_R2.p01)
Simulation started at: 17Jun2023 05:22:24 PM

Writing Geometry...
Completed Writing Geometry

Writing Event Conditions ...
Completed Writing Event Condition Data


Steady Flow Simulation HEC-RAS 6.3.1 October 2022


Finished Steady Flow Simulation


Computations Summary

Computation Task                 Time(hh:mm:ss)
Completing Geometry                          <1
Completing Event Conditions                  <1
Steady Flow Computations                     <1
Complete Process                              1
```

The ‘HEC-RAS Finished Computations’ window will open while the model runs and shows a summary of the model run information.

3. Click Close to close this summary.

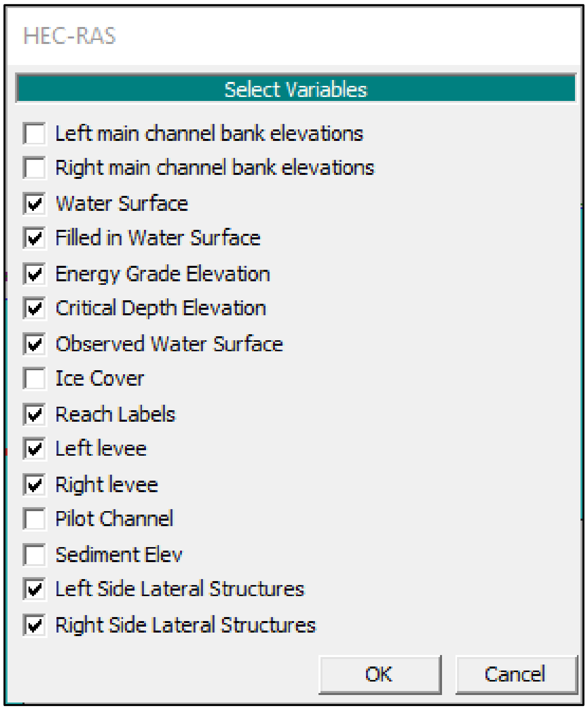
4. Close the ‘Steady Flow Analysis’ window by clicking on the ×.

5. In the main interface, click to view the model run results as a profile plot:



This shows the model results compared to the observed water surface data. This plot could be made a little clearer, as there are several things shown that aren't needed right now. You can control what is shown on this plot.

6. Go to Options and click '*Variables*':



HEC-RAS

Select Variables

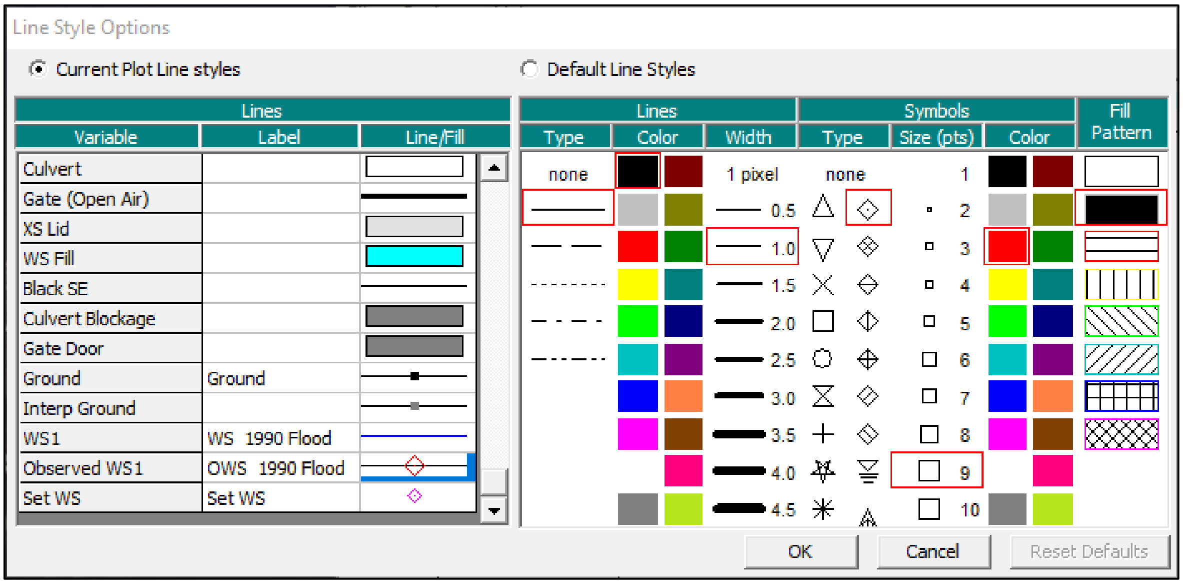
☐ Left main channel bank elevations
☐ Right main channel bank elevations
☑ Water Surface
☑ Filled in Water Surface
☑ Energy Grade Elevation
☑ Critical Depth Elevation
☑ Observed Water Surface
☐ Ice Cover
☑ Reach Labels
☑ Left levee
☑ Right levee
☐ Pilot Channel
☐ Sediment Elev
☑ Left Side Lateral Structures
☑ Right Side Lateral Structures

7. De-select the following options:
    - *Energy Grade Elevation*
    - *Critical Depth Elevation*
    - *Left Levee*
    - *Right Levee*

    Click OK to exit.

Notice that you can turn on the view of an ice cover if we were modelling ice.

8. Go to Options and click on the '*Lines and Symbols …*' option. Change the style options for the '*Observed WS 1'* to be larger and red:

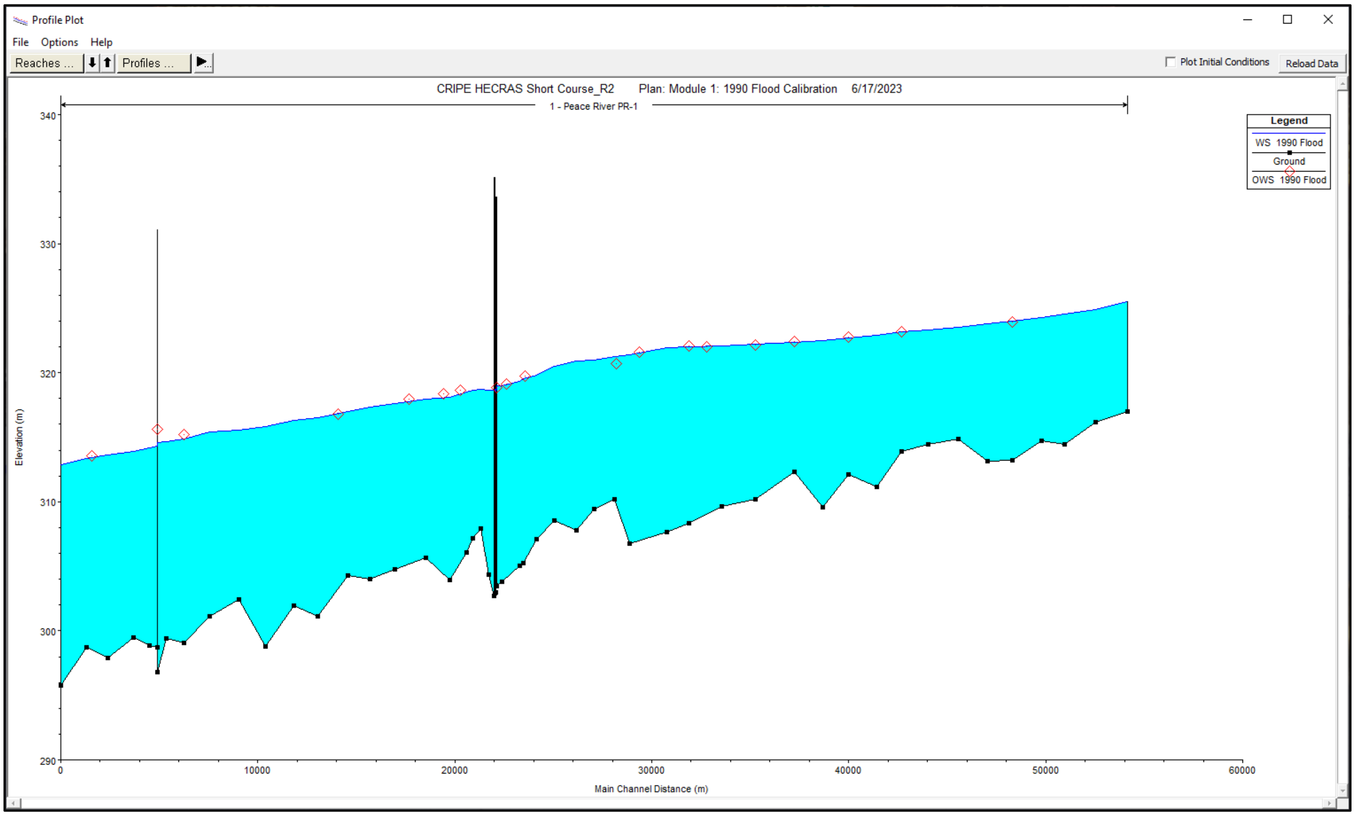


Line Style Options

● Current Plot Line styles ○ Default Line Styles

Variable	Label
Culvert	
Gate (Open Air)	
XS Lid	
WS Fill	
Black SE	
Culvert Blockage	
Gate Door	
Ground	Ground
Interp Ground	
WS1	WS 1990 Flood
Observed WS1	OWS 1990 Flood
Set WS	Set WS

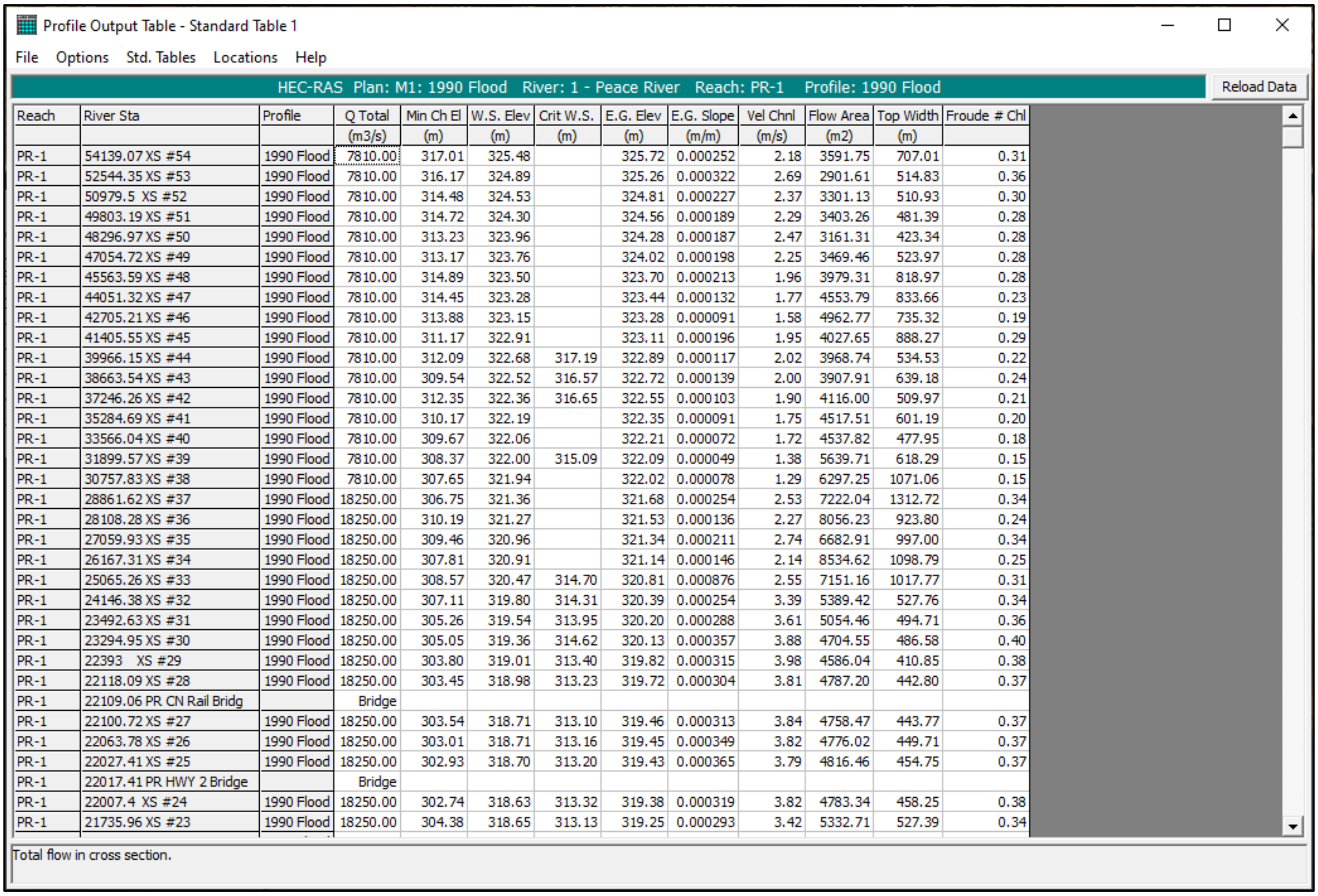
9. Close the 'Line Style Options' window by clicking OK. The observed water surface data now stand out a little better against the model results:



Notice that the modelled water surface (filled in cyan) matches the observed water surface data well. Therefore, the model was well-calibrated to these conditions.

10. Close the ‘Profile Plot’ window by clicking on the ×.

11. Review the model results in a summary table by clicking on the ▦ in the main interface.



HEC-RAS Plan: M1: 1990 Flood River: 1 - Peace River Reach: PR-1 Profile: 1990 Flood

Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
PR-1	54139.07 XS #54	1990 Flood	7810.00	317.01	325.48		325.72	0.000252	2.18	3591.75	707.01	0.31
PR-1	52544.35 XS #53	1990 Flood	7810.00	316.17	324.89		325.26	0.000322	2.69	2901.61	514.83	0.36
PR-1	50979.5 XS #52	1990 Flood	7810.00	314.48	324.53		324.81	0.000227	2.37	3301.13	510.93	0.30
PR-1	49803.19 XS #51	1990 Flood	7810.00	314.72	324.30		324.56	0.000189	2.29	3403.26	481.39	0.28
PR-1	48296.97 XS #50	1990 Flood	7810.00	313.23	323.96		324.28	0.000187	2.47	3161.31	423.34	0.28
PR-1	47054.72 XS #49	1990 Flood	7810.00	313.17	323.76		324.02	0.000198	2.25	3469.46	523.97	0.28
PR-1	45563.59 XS #48	1990 Flood	7810.00	314.89	323.50		323.70	0.000213	1.96	3979.31	818.97	0.28
PR-1	44051.32 XS #47	1990 Flood	7810.00	314.45	323.28		323.44	0.000132	1.77	4553.79	833.66	0.23
PR-1	42705.21 XS #46	1990 Flood	7810.00	313.88	323.15		323.28	0.000091	1.58	4962.77	735.32	0.19
PR-1	41405.55 XS #45	1990 Flood	7810.00	311.17	322.91		323.11	0.000196	1.95	4027.65	888.27	0.29
PR-1	39966.15 XS #44	1990 Flood	7810.00	312.09	322.68	317.19	322.89	0.000117	2.02	3968.74	534.53	0.22
PR-1	38663.54 XS #43	1990 Flood	7810.00	309.54	322.52	316.57	322.72	0.000139	2.00	3907.91	639.18	0.24
PR-1	37246.26 XS #42	1990 Flood	7810.00	312.35	322.36	316.65	322.55	0.000103	1.90	4116.00	509.97	0.21
PR-1	35284.69 XS #41	1990 Flood	7810.00	310.17	322.19		322.35	0.000091	1.75	4517.51	601.19	0.20
PR-1	33566.04 XS #40	1990 Flood	7810.00	309.67	322.06		322.21	0.000072	1.72	4537.82	477.95	0.18
PR-1	31899.57 XS #39	1990 Flood	7810.00	308.37	322.00	315.09	322.09	0.000049	1.38	5639.71	618.29	0.15
PR-1	30757.83 XS #38	1990 Flood	7810.00	307.65	321.94		322.02	0.000078	1.29	6297.25	1071.06	0.15
PR-1	28861.62 XS #37	1990 Flood	18250.00	306.75	321.36		321.68	0.000254	2.53	7222.04	1312.72	0.34
PR-1	28108.28 XS #36	1990 Flood	18250.00	310.19	321.27		321.53	0.000136	2.27	8056.23	923.80	0.24
PR-1	27059.93 XS #35	1990 Flood	18250.00	309.46	320.96		321.34	0.000211	2.74	6682.91	997.00	0.34
PR-1	26167.31 XS #34	1990 Flood	18250.00	307.81	320.91		321.14	0.000146	2.14	8534.62	1098.79	0.25
PR-1	25065.26 XS #33	1990 Flood	18250.00	308.57	320.47	314.70	320.81	0.000876	2.55	7151.16	1017.77	0.31
PR-1	24146.38 XS #32	1990 Flood	18250.00	307.11	319.80	314.31	320.39	0.000254	3.39	5389.42	527.76	0.34
PR-1	23492.63 XS #31	1990 Flood	18250.00	305.26	319.54	313.95	320.20	0.000288	3.61	5054.46	494.71	0.36
PR-1	23294.95 XS #30	1990 Flood	18250.00	305.05	319.36	314.62	320.13	0.000357	3.88	4704.55	486.58	0.40
PR-1	22393 XS #29	1990 Flood	18250.00	303.80	319.01	313.40	319.82	0.000315	3.98	4586.04	410.85	0.38
PR-1	22118.09 XS #28	1990 Flood	18250.00	303.45	318.98	313.23	319.72	0.000304	3.81	4787.20	442.80	0.37
PR-1	22109.06 PR CN Rail Bridg		Bridge									
PR-1	22100.72 XS #27	1990 Flood	18250.00	303.54	318.71	313.10	319.46	0.000313	3.84	4758.47	443.77	0.37
PR-1	22063.78 XS #26	1990 Flood	18250.00	303.01	318.71	313.16	319.45	0.000349	3.82	4776.02	449.71	0.37
PR-1	22027.41 XS #25	1990 Flood	18250.00	302.93	318.70	313.20	319.43	0.000365	3.79	4816.46	454.75	0.37
PR-1	22017.41 PR HWY 2 Bridge		Bridge									
PR-1	22007.4 XS #24	1990 Flood	18250.00	302.74	318.63	313.32	319.38	0.000319	3.82	4783.34	458.25	0.38
PR-1	21735.96 XS #23	1990 Flood	18250.00	304.38	318.65	313.13	319.25	0.000293	3.42	5332.71	527.39	0.34

Total flow in cross section.

This table shows the results of the model run at each cross-section. This table can be exported to a text file or to the clipboard. This is HEC-RAS's standard table, but there are many variables that can be shown in an output table.

12. Go to Options and select '*Define Table …*' to view the different variables that can be added to an output table. Scroll through the list to see the available variables.

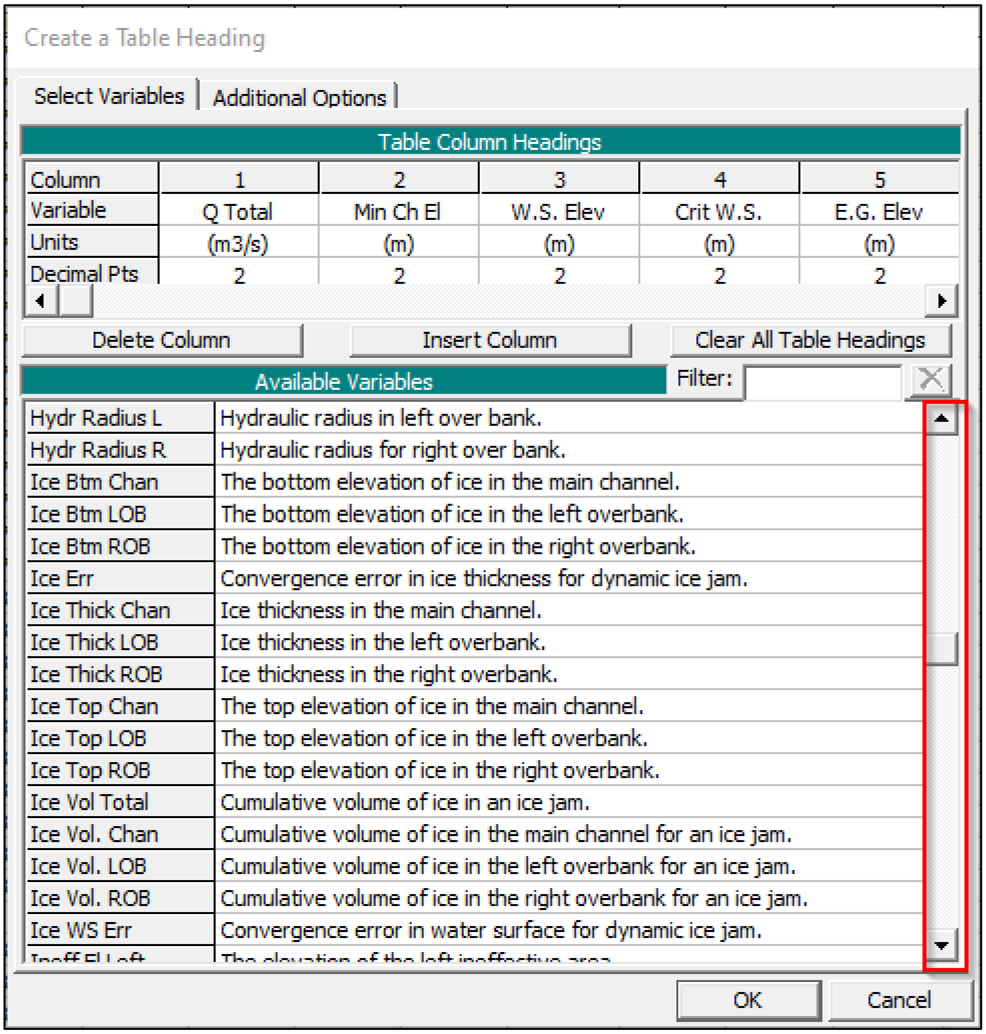


Table Column Headings

Column	1	2	3	4	5
Variable	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev
Units	(m3/s)	(m)	(m)	(m)	(m)
Decimal Pts	2	2	2	2	2

Available Variables

Hydr Radius L	Hydraulic radius in left over bank.
Hydr Radius R	Hydraulic radius for right over bank.
Ice Btm Chan	The bottom elevation of ice in the main channel.
Ice Btm LOB	The bottom elevation of ice in the left overbank.
Ice Btm ROB	The bottom elevation of ice in the right overbank.
Ice Err	Convergence error in ice thickness for dynamic ice jam.
Ice Thick Chan	Ice thickness in the main channel.
Ice Thick LOB	Ice thickness in the left overbank.
Ice Thick ROB	Ice thickness in the right overbank.
Ice Top Chan	The top elevation of ice in the main channel.
Ice Top LOB	The top elevation of ice in the left overbank.
Ice Top ROB	The top elevation of ice in the right overbank.
Ice Vol Total	Cumulative volume of ice in an ice jam.
Ice Vol. Chan	Cumulative volume of ice in the main channel for an ice jam.
Ice Vol. LOB	Cumulative volume of ice in the left overbank for an ice jam.
Ice Vol. ROB	Cumulative volume of ice in the right overbank for an ice jam.
Ice WS Err	Convergence error in water surface for dynamic ice jam.
Ineff El Left	The elevation of the left ineffective area

Notice that there are several ice-cover-related variables available. Each variable has a short name that is displayed in the output table, and a description that is only viewable in this ‘Create Table Heading’ window.

13. Close the ‘Create Table Heading’ window by clicking Cancel .

14. Close the ‘Profile Output’ window by clicking on the × .

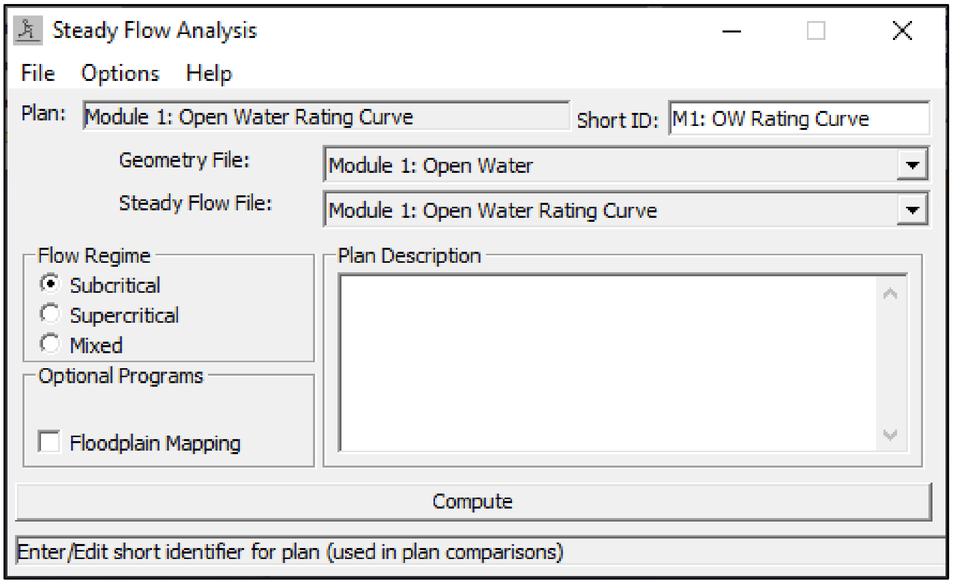
Task 1C Instructions: OPTIONAL Check Open Water Model Calibration Against the Rating Curve

In this task we will check the open water calibration against a series of flows. The model bed roughness calibration worked well for the 1990 flood, but it is important to check the calibration against smaller floods using a rating curve. We will be using a different **Steady Flow** file, so we will also use a different **Plan** file. We will use the same **Geometry** file that we used in Task 1A and Task 1B.

Table 2: Model Files Used for HEC-RAS Module 1 - Task 1C

File Type	Filename
Plan	"Module 1: Open Water Rating Curve"
Geometry	"Module 1: Open Water"
Steady Flow	"Module 1: Open Water Rating Curve"

1. From the main interface, open the 'Steady Flow Analysis' window by clicking on the .
2. Open the new **Plan** file by going to File and select '*Open Plan …*' Choose the "**Module 1: Open Water Rating Curve**" plan file.
3. Click OK
4. In the 'Steady Flow Analysis' window, note that the **Steady Flow** file is now changed to "**Module 1: Open Water Rating Curve**", but we are still using the same **Geometry** file ("**Module 1: Open Water**")



Plan: Module 1: Open Water Rating Curve Short ID: M1: OW Rating Curve

Geometry File: Module 1: Open Water

Steady Flow File: Module 1: Open Water Rating Curve

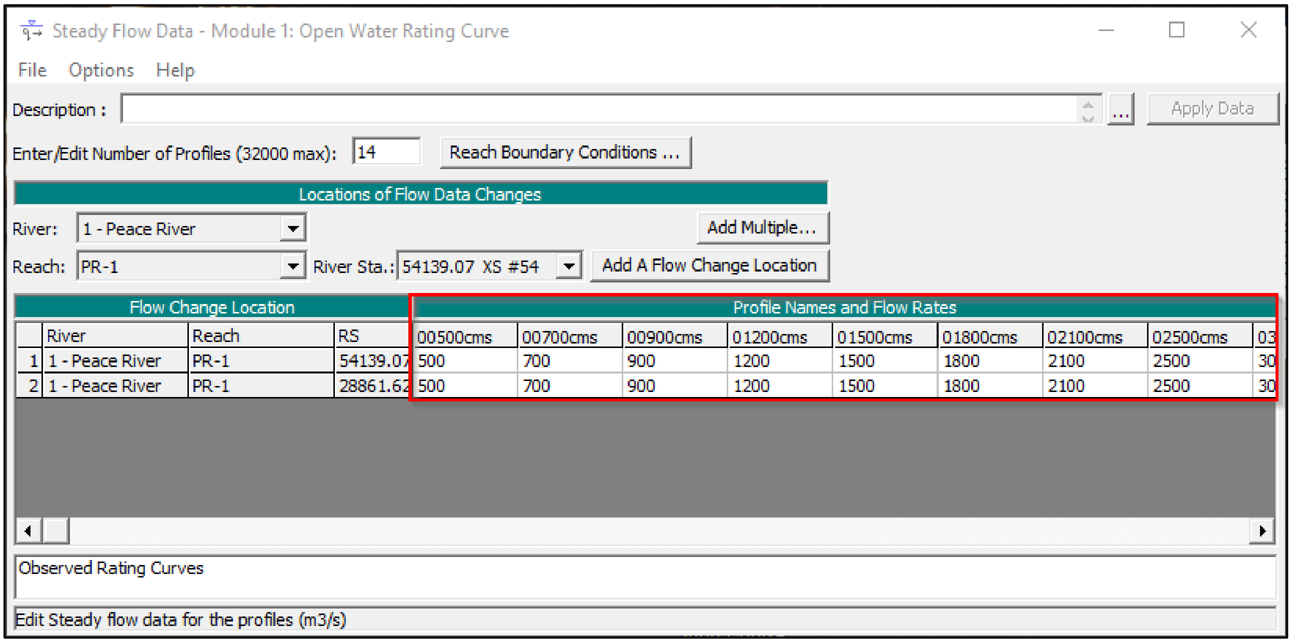
Flow Regime
● Subcritical
○ Supercritical
○ Mixed

Optional Programs
☐ Floodplain Mapping

Plan Description

Enter/Edit short identifier for plan (used in plan comparisons)

5. Close the 'Steady Flow Analysis' window by clicking on the ×.
6. In the main interface, click the to open the 'Steady Flow Data' window:



Description :

Enter/Edit Number of Profiles (32000 max): 14

River: 1 - Peace River

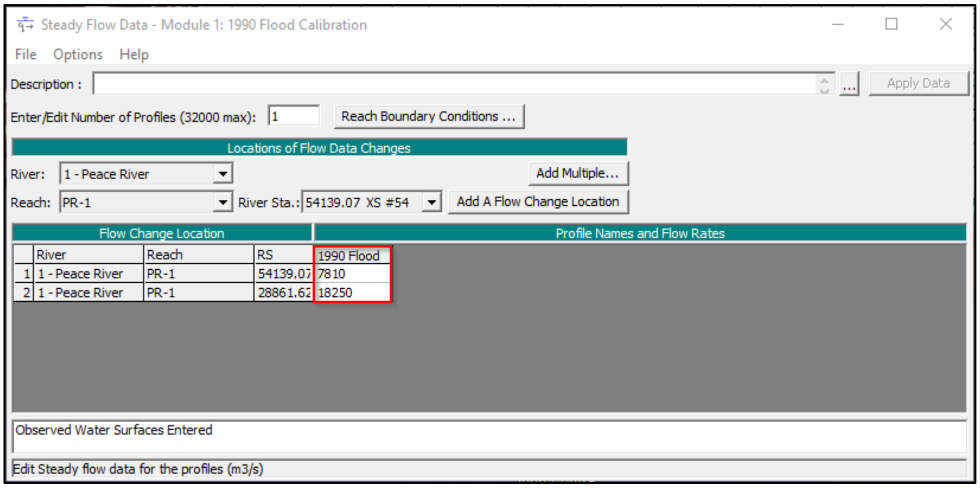
Reach: PR-1 River Sta.: 54139.07 XS #54

	River	Reach	RS	00500cms	00700cms	00900cms	01200cms	01500cms	01800cms	02100cms	02500cms	03
1	1 - Peace River	PR-1	54139.07	500	700	900	1200	1500	1800	2100	2500	30
2	1 - Peace River	PR-1	28861.62	500	700	900	1200	1500	1800	2100	2500	30

Observed Rating Curves

Edit Steady flow data for the profiles (m3/s)

Notice that this **Steady Flow** file (shown above) has many more profiles than did our previous steady flow file (shown below) did:



Description :

Enter/Edit Number of Profiles (32000 max): 1

River: 1 - Peace River

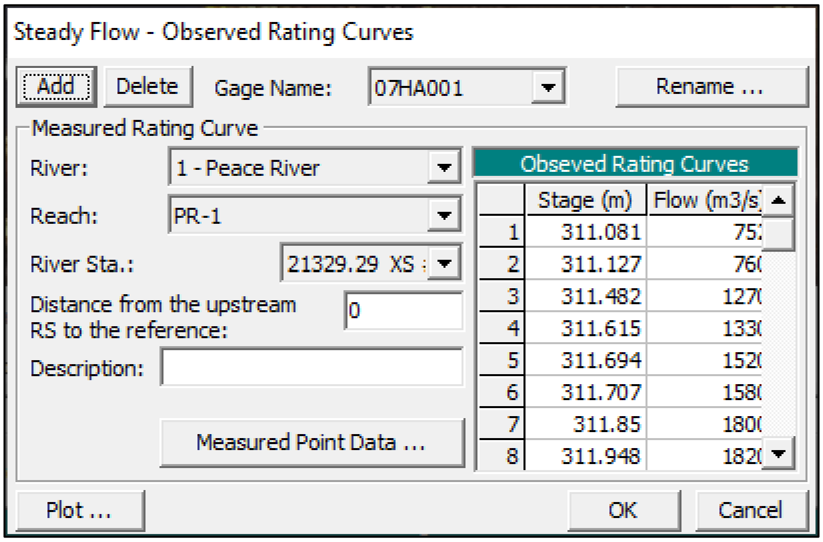
Reach: PR-1 River Sta.: 54139.07 XS #54

	River	Reach	RS	1990 Flood
1	1 - Peace River	PR-1	54139.07	7810
2	1 - Peace River	PR-1	28861.62	18250

Observed Water Surfaces Entered

Edit Steady flow data for the profiles (m3/s)

7. Access the observed rating curve data from the 'Steady Flow Data' window by clicking Options and selecting '*Observed Rating Curves (Gauges) …*'



Steady Flow - Observed Rating Curves

Gage Name: 07HA001

River: 1 - Peace River

Reach: PR-1

River Sta.: 21329.29 XS

Distance from the upstream RS to the reference: 0

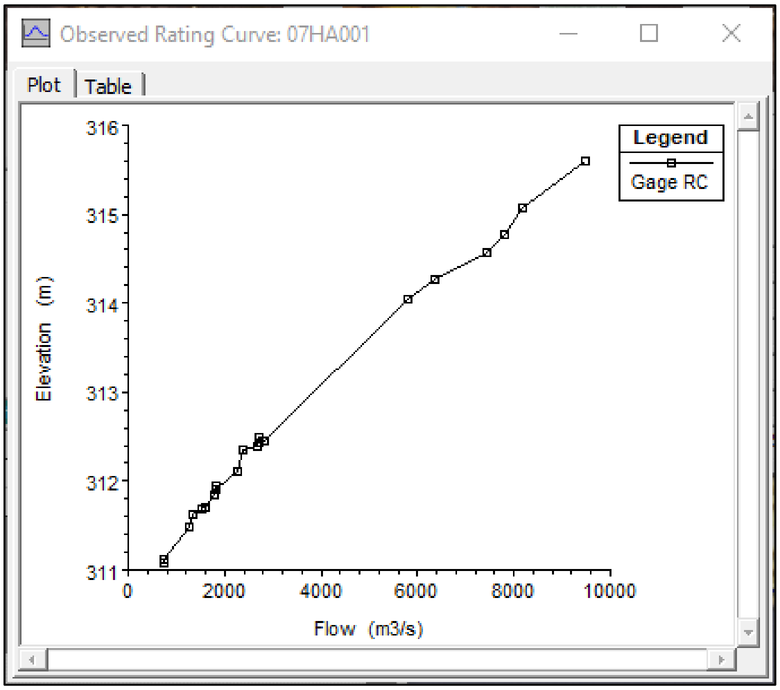
Description:

Obseved Rating Curves

	Stage (m)	Flow (m3/s)
1	311.081	75
2	311.127	76
3	311.482	127
4	311.615	133
5	311.694	152
6	311.707	158
7	311.85	180
8	311.948	182

This rating curve is for the Water Survey of Canada (WSC) gauge “Peace River at Peace River” (#07HA001). The gauge is located at cross-section ‘21329.29 XS#22’. The data shown here is not the interpolated and extrapolated rating curve used by WSC, but only the raw discharge measurements. A range of 14 discharges and their associated water levels have been entered, covering a range of discharge measurements.

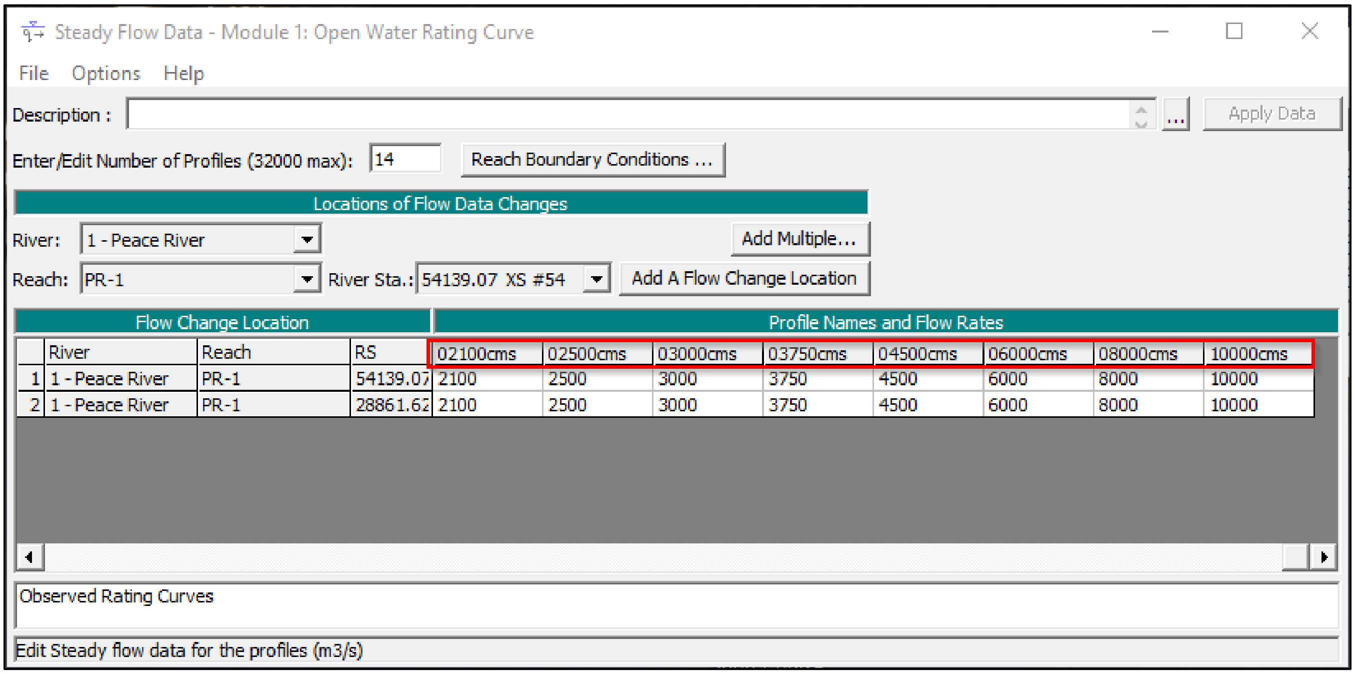
8. Click on Plot … to view the rating curve as a flow-elevation plot:



9. Close the plot by clicking on the ×.

10. Close the ‘Steady Flow – Observed Rating curve’ window by clicking Cancel .

11. Return to the ‘Steady Flow Data’ window:



Description :

Enter/Edit Number of Profiles (32000 max): 14

River: 1 - Peace River

Reach: PR-1

River Sta.: 54139.07 XS #54

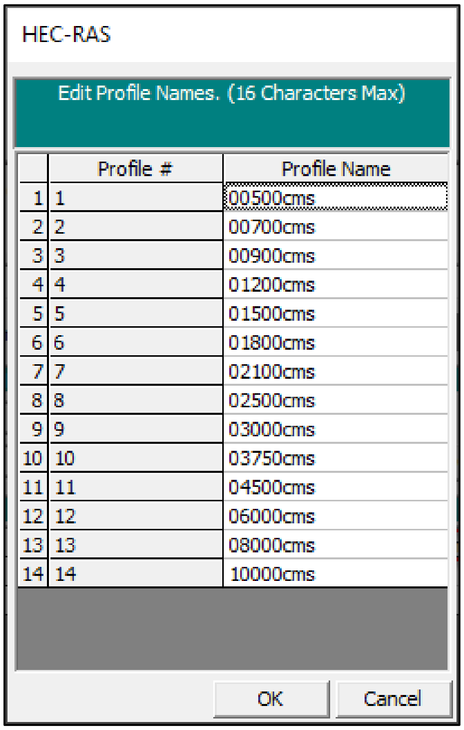
	River	Reach	RS	02100cms	02500cms	03000cms	03750cms	04500cms	06000cms	08000cms	10000cms
1	1 - Peace River	PR-1	54139.07	2100	2500	3000	3750	4500	6000	8000	10000
2	1 - Peace River	PR-1	28861.62	2100	2500	3000	3750	4500	6000	8000	10000

Observed Rating Curves

Edit Steady flow data for the profiles (m3/s)

There are 14 profiles in the **Steady Flow** file. They have been named according to the flow conditions at the WSC gauge. It is helpful to name profiles logically with a description of the flow conditions. This is because it is this name that will be visible in output tables and plots.

12. In the Steady Flow Data window, choose Options and select ‘*Edit Profile Names …*’:



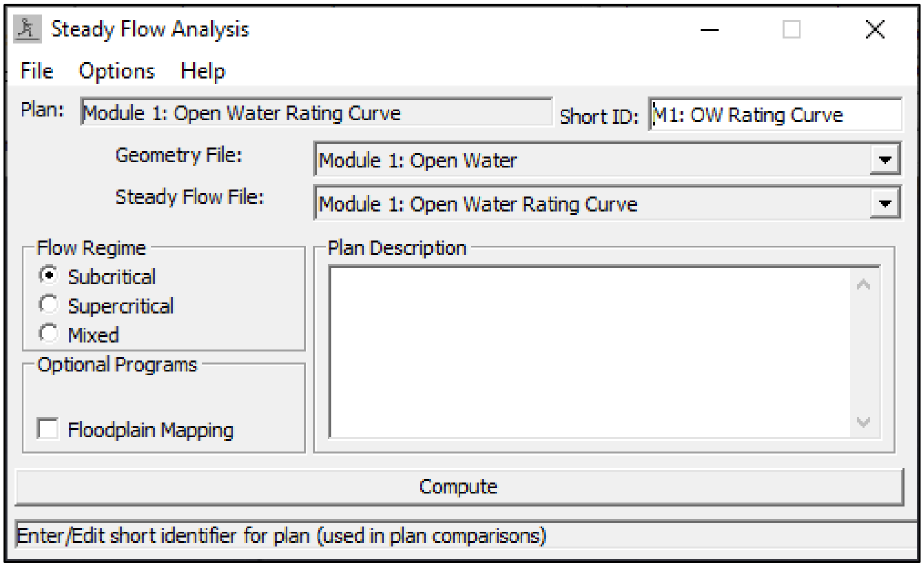
	Profile #	Profile Name
1	1	00500cms
2	2	00700cms
3	3	00900cms
4	4	01200cms
5	5	01500cms
6	6	01800cms
7	7	02100cms
8	8	02500cms
9	9	03000cms
10	10	03750cms
11	11	04500cms
12	12	06000cms
13	13	08000cms
14	14	10000cms

This is the window where profile names are edited.

13. Exit this window by clicking Cancel .

14. Exit the ‘Steady Flow Data’ window by clicking on the × .

15. In the main interface click to open the ‘Steady Flow Analysis’ window. Verify that the correct **Geometry** file and **Steady Flow** file are being used:



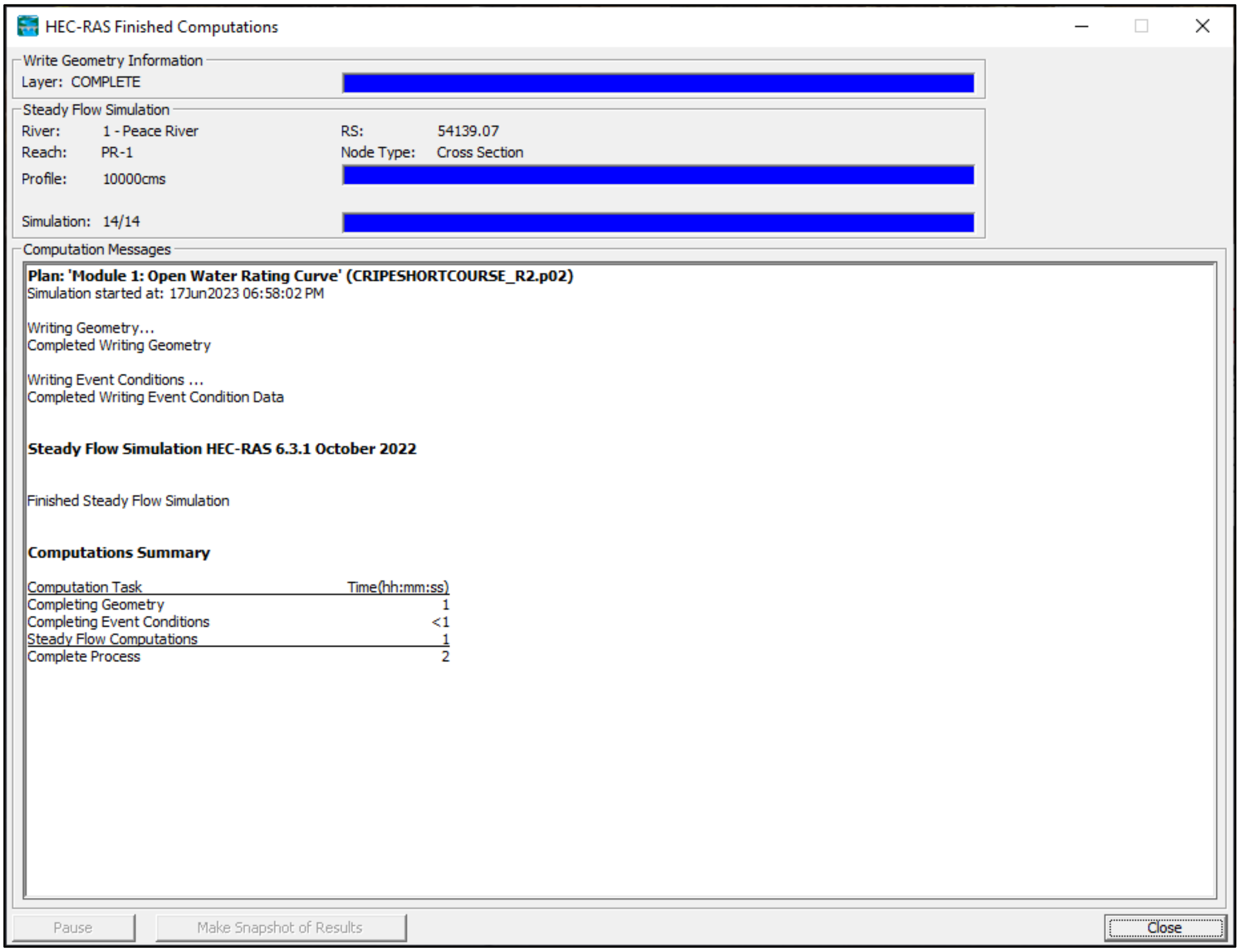
Plan: Module 1: Open Water Rating Curve
Short ID: M1: OW Rating Curve
Geometry File: Module 1: Open Water
Steady Flow File: Module 1: Open Water Rating Curve

Flow Regime
● Subcritical
○ Supercritical
○ Mixed

Optional Programs
☐ Floodplain Mapping

Enter/Edit short identifier for plan (used in plan comparisons)

16. Click Compute to run the model. The HEC-RAS Finished Computations window will appear:



Write Geometry Information
Layer: COMPLETE

Steady Flow Simulation
River: 1 - Peace River RS: 54139.07
Reach: PR-1 Node Type: Cross Section
Profile: 10000cms
Simulation: 14/14

Computation Messages

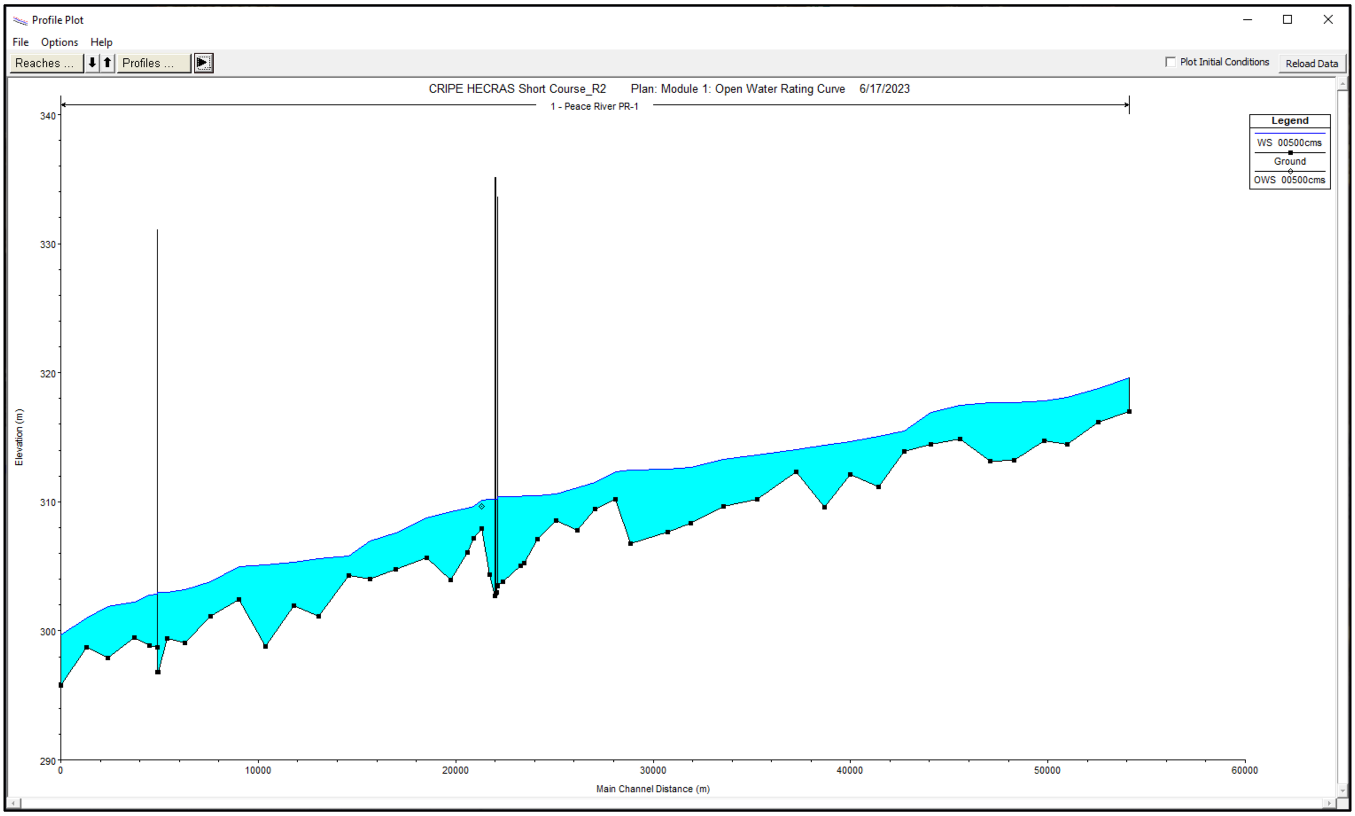
```
Plan: 'Module 1: Open Water Rating Curve' (CRIPESHORTCOURSE_R2.p02)
Simulation started at: 17Jun2023 06:58:02 PM

Writing Geometry...
Completed Writing Geometry

Writing Event Conditions ...
Completed Writing Event Condition Data


Steady Flow Simulation HEC-RAS 6.3.1 October 2022


Finished Steady Flow Simulation


Computations Summary

Computation Task                      Time(hh:mm:ss)
Completing Geometry                                1
Completing Event Conditions                       <1
Steady Flow Computations                           1
Complete Process                                   2
```

Notice that it took a little longer to run the model this time. We are now running 14 different flows for 14 different profiles, instead of the single profile we ran before.

17. Click Close to close this summary.

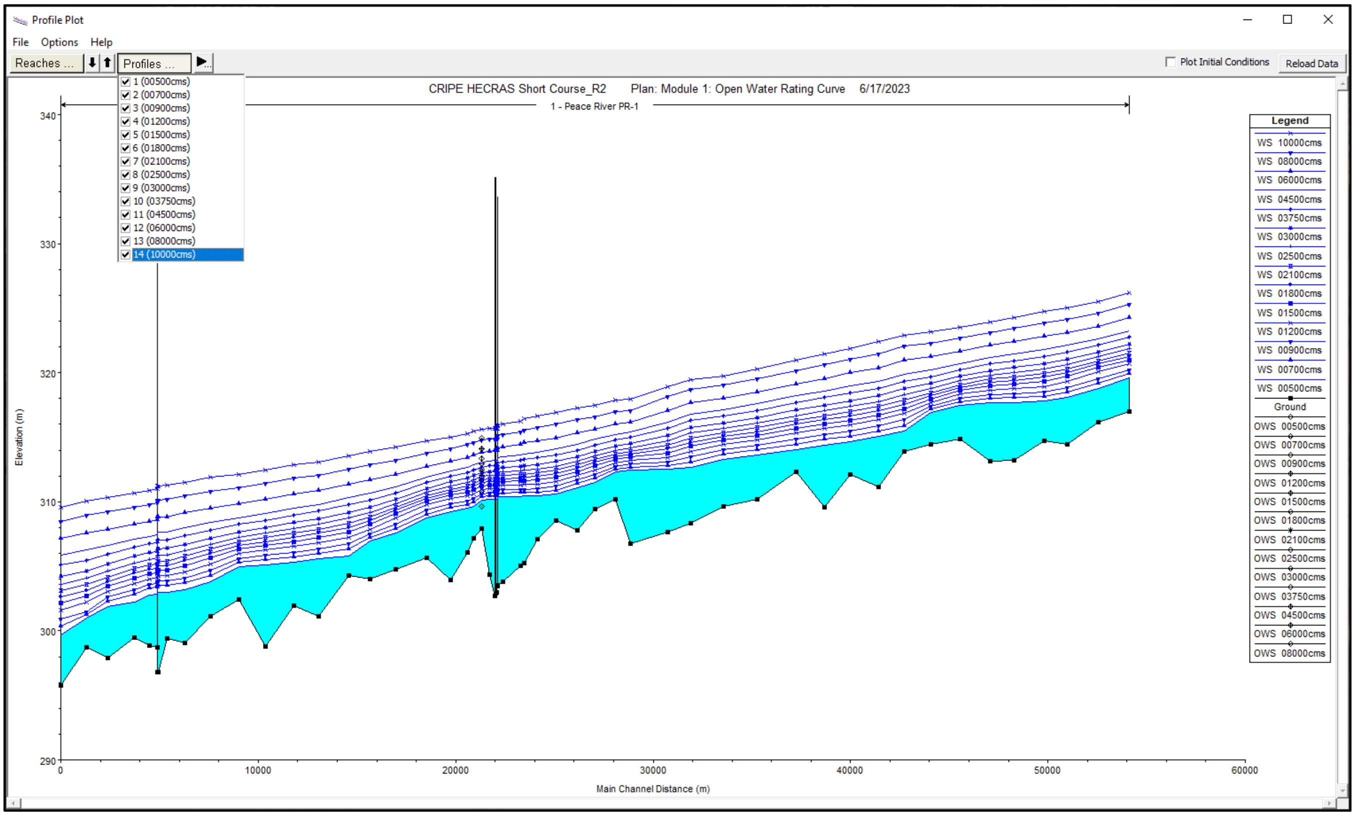
18. Close the ‘Steady Flow Analysis’ window by clicking on the ×.

19. In the main interface, click to view the model run results as a profile plot:



The profile plot shows only one profile. We will need to add the remaining 13 profiles to the plot.

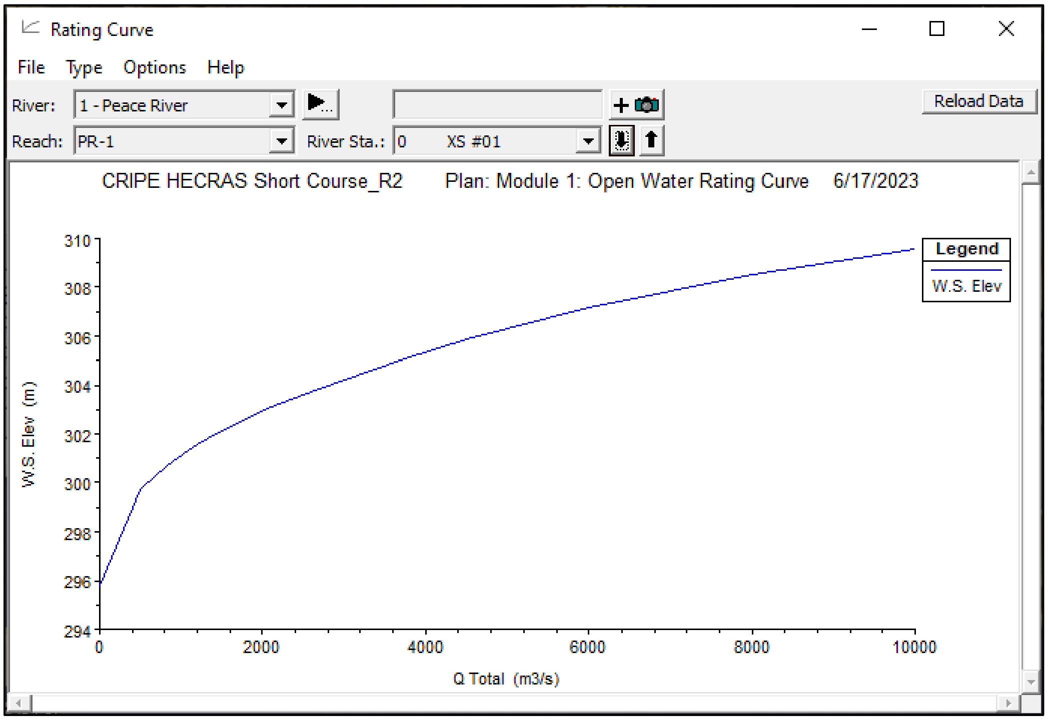
20. Click Profiles ... and check all 14 profiles:



Now the computed water surfaces of all 14 profiles are shown. We don't have observed water surface data for these 14 different flow conditions, so we can use the observed rating curve to understand how well our roughness calibration in the **geometry** file "**Module 1: Open Water**" matches the observed data at the gauge. Note that having properly-named profiles is useful when viewing data in this view.

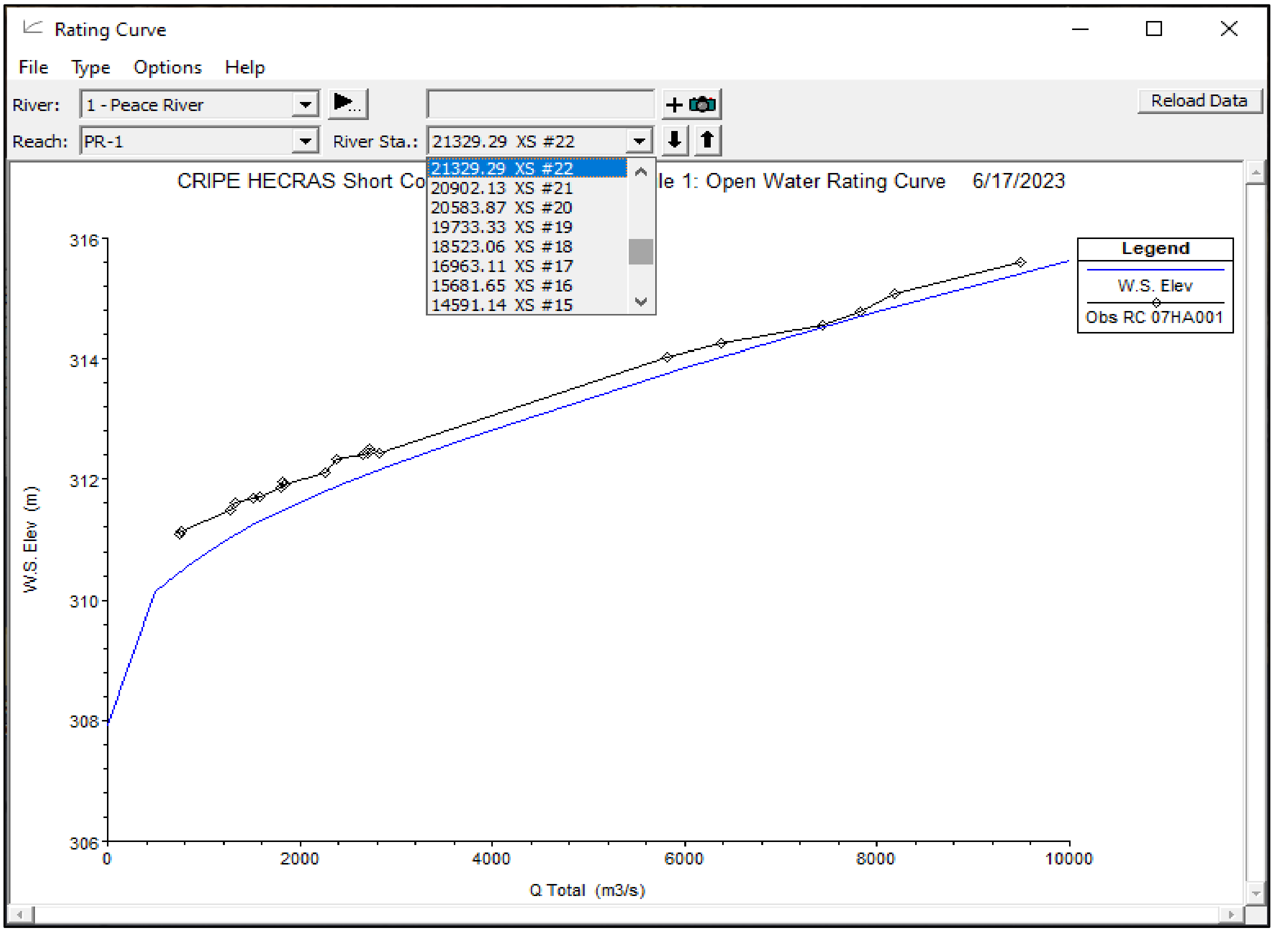
21. Close the 'Profile Plot' window by clicking on the ×.

22. In the main interface, click on the 📈 to open the 'View Rating Curve Results' window:



The window opens to show the computed rating curve at the most downstream cross-section (0 XS#01). A rating curve can be viewed at any cross-section. However, only the cross-section at the gauge has an observed rating curve.

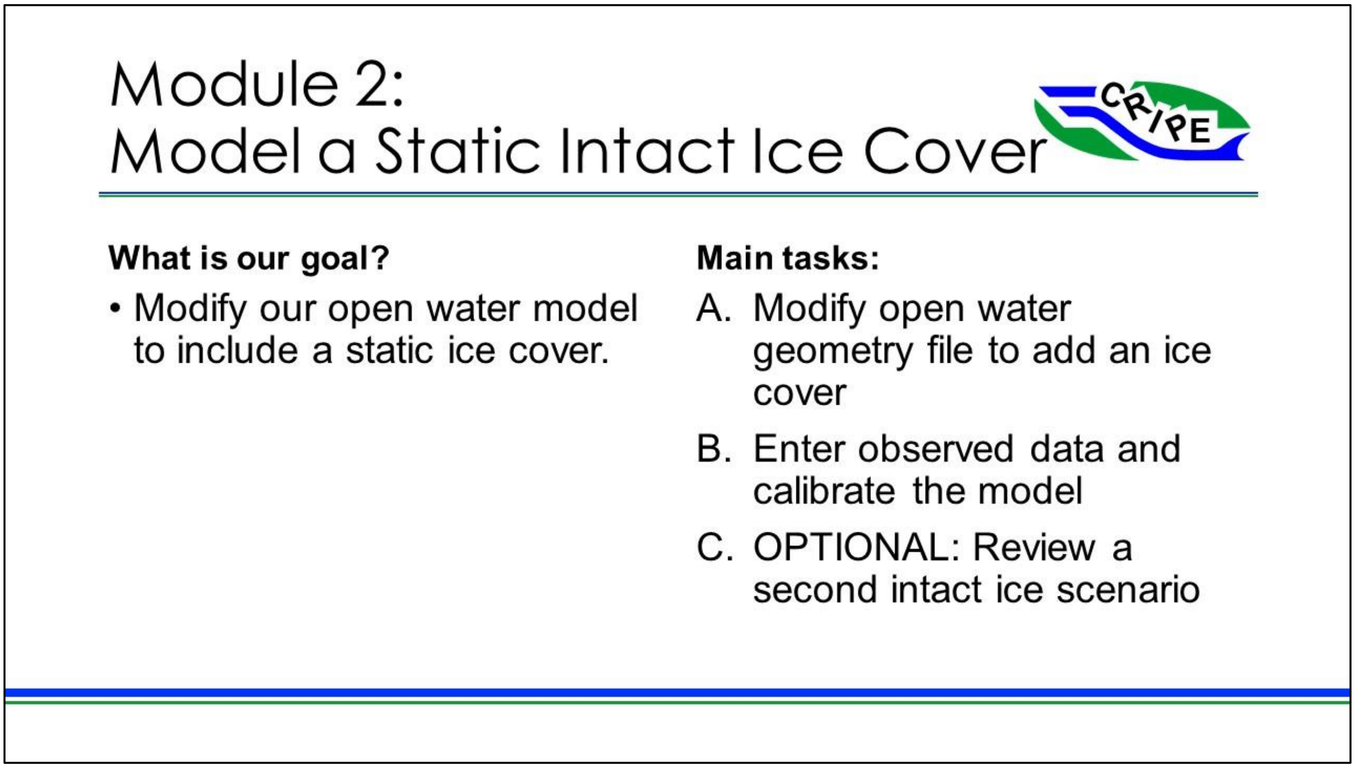
23. Navigate using the black up and down arrows or the dropdown menu to the computed rating curve at cross-section ‘*21329.29 XS #22*’ where the gauge is located:



Notice that the simulated rating curve is below the measured data. This is because in the **geometry** file used here ("**Module 1: Open Water**") the roughness at each cross-section does not vary with discharge. In the real world, bed roughness varies with discharge according to the "relative roughness" principle. In the example shown above, the roughness was calibrated for a discharge of 18,250 m^3/s (the magnitude of the 1990 discharge at the gauge). However, all the flows shown above are less than 18,250 m^3/s. This means that the roughness used by the model is too low for these lower water levels, making the computed flow travel faster, and thus have a lower water level than observed. HEC-RAS has tools to allow a modeller to vary bed roughness by discharge.

However, for our river ice modelling exercise, we will keep the bed roughness the same as the 1990 flood for all modules. This is partly for simplicity, but also because when modelling river ice, it is the composite roughness that is important.

Module 2: Modelling a Static Intact Ice Cover



Module 2: Model a Static Intact Ice Cover

What is our goal?

- Modify our open water model to include a static ice cover.

Main tasks:

A. Modify open water geometry file to add an ice cover

B. Enter observed data and calibrate the model

C. OPTIONAL: Review a second intact ice scenario

Intact Ice Scenario

Peace River at the Town of Peace River

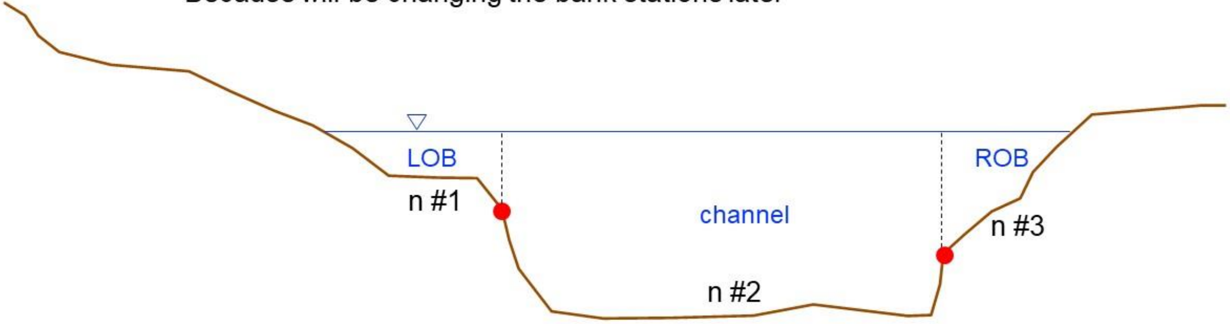
Photo from WSC, via AEPA

Intact Ice Scenario

- Need to adapt our open water model for an ice-covered scenario
- This is a real scenario from January 31, 2003:
  - Measured ice thicknesses
  - Measured water levels
  - Measured discharge
- Unknown ice roughnesses
- Will use calibrated bed roughnesses from open water model

Intact Ice Scenario

1. Simplify the bed roughnesses
2. Make channel and overbank roughnesses equal
   - Because will be changing the bank stations later



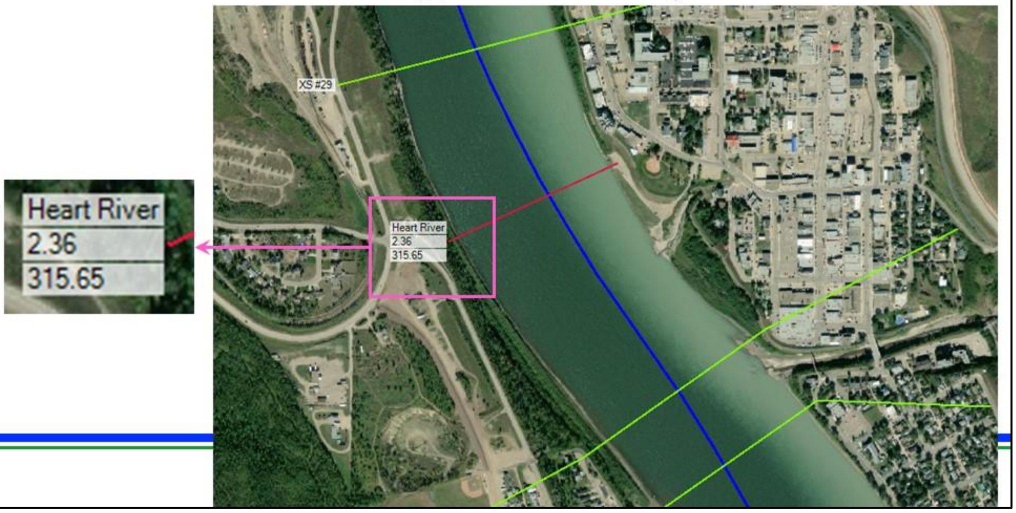
Observed Data

- The observed data are in a RAS Mapper feature layer

Observation Location Name

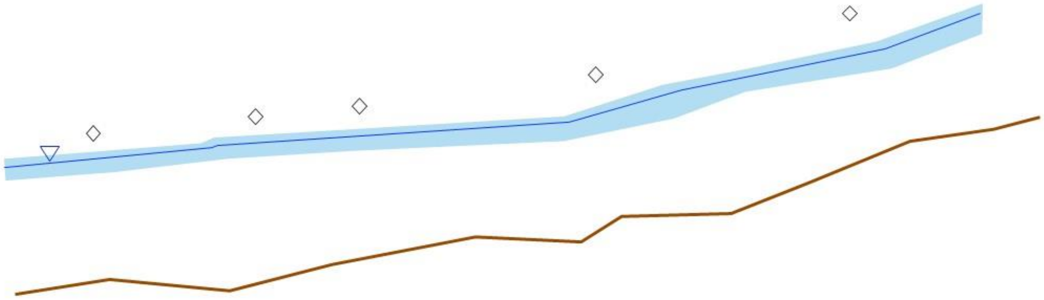
Ice Thickness, m

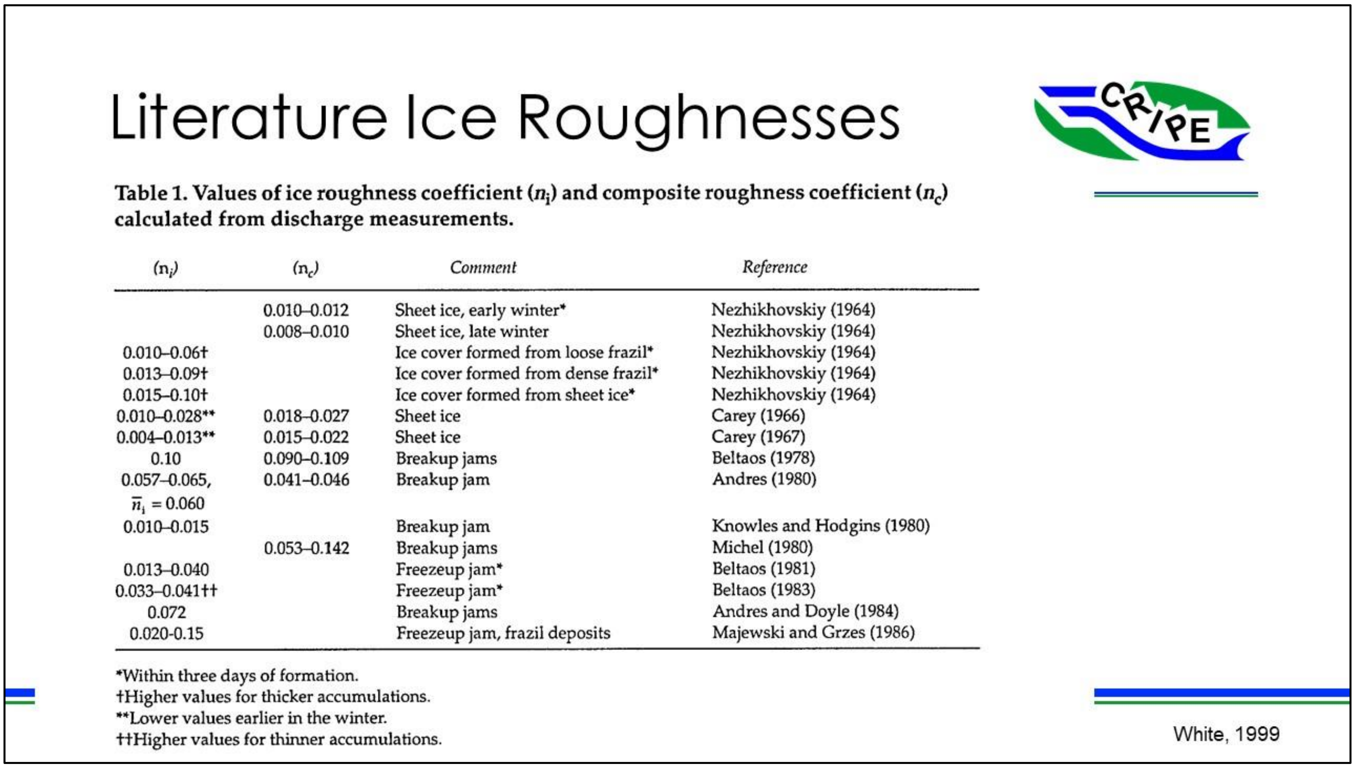
Observed water surface elevation, m



Calibration Procedure

- Initial guess of ice cover roughness - use 0.024





Literature Ice Roughnesses

Table 1. Values of ice roughness coefficient (n_i) and composite roughness coefficient (n_c) calculated from discharge measurements.

(n_i)	(n_c)	*Comment*	*Reference*
	0.010–0.012	Sheet ice, early winter*	Nezhikhovskiy (1964)
	0.008–0.010	Sheet ice, late winter	Nezhikhovskiy (1964)
0.010–0.06†		Ice cover formed from loose frazil*	Nezhikhovskiy (1964)
0.013–0.09†		Ice cover formed from dense frazil*	Nezhikhovskiy (1964)
0.015–0.10†		Ice cover formed from sheet ice*	Nezhikhovskiy (1964)
0.010–0.028**	0.018–0.027	Sheet ice	Carey (1966)
0.004–0.013**	0.015–0.022	Sheet ice	Carey (1967)
0.10	0.090–0.109	Breakup jams	Beltaos (1978)
0.057–0.065, $\bar{n}_i = 0.060$	0.041–0.046	Breakup jam	Andres (1980)
0.010–0.015		Breakup jam	Knowles and Hodgins (1980)
	0.053–0.142	Breakup jams	Michel (1980)
0.013–0.040		Freezeup jam*	Beltaos (1981)
0.033–0.041††		Freezeup jam*	Beltaos (1983)
0.072		Breakup jams	Andres and Doyle (1984)
0.020-0.15		Freezeup jam, frazil deposits	Majewski and Grzes (1986)

*Within three days of formation.
†Higher values for thicker accumulations.
**Lower values earlier in the winter.
††Higher values for thinner accumulations.

White, 1999

Literature Ice Roughnesses

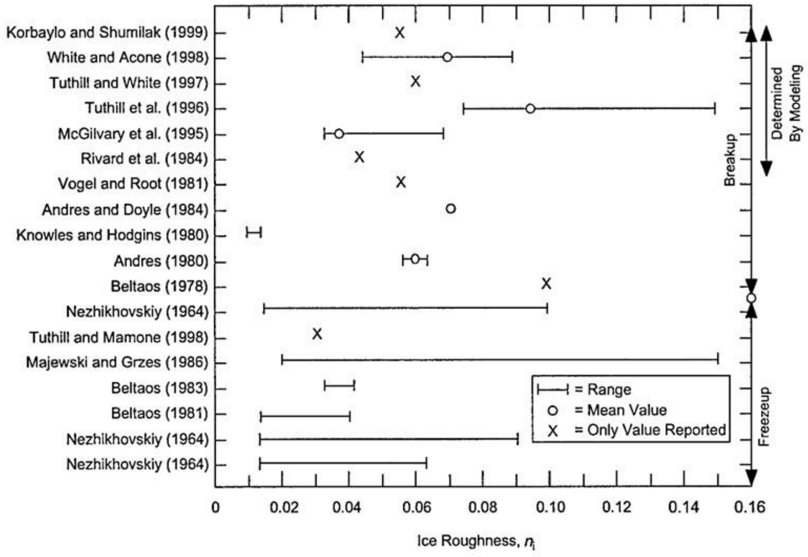


Figure 6. Reported values of ice roughness.

White, 1999

Literature Ice Roughnesses

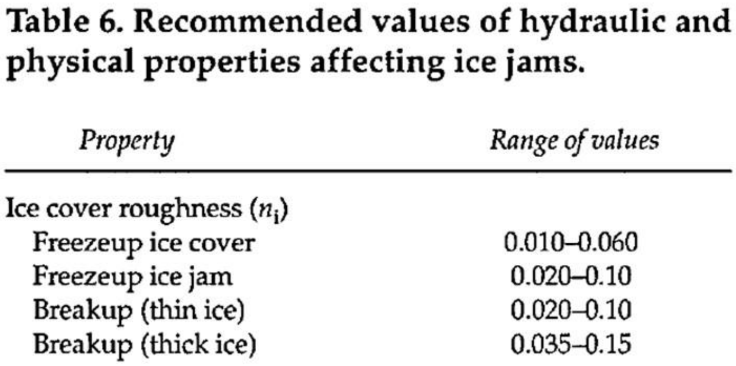


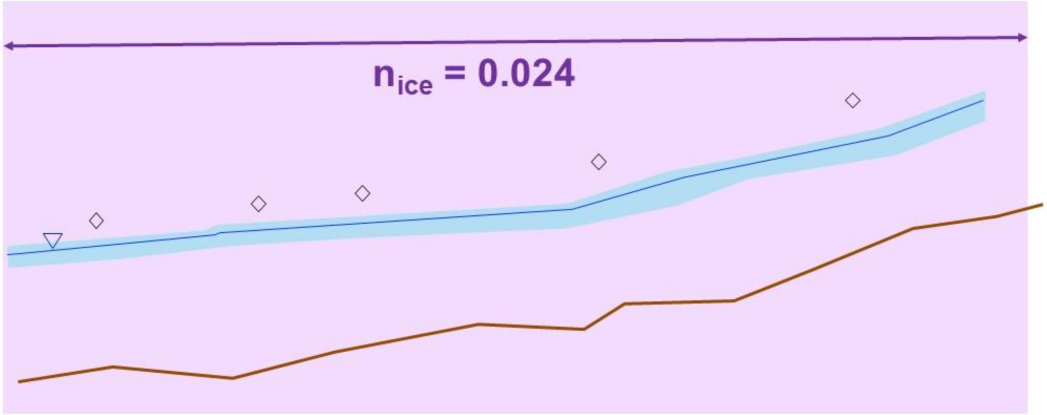
Table 6. Recommended values of hydraulic and physical properties affecting ice jams.

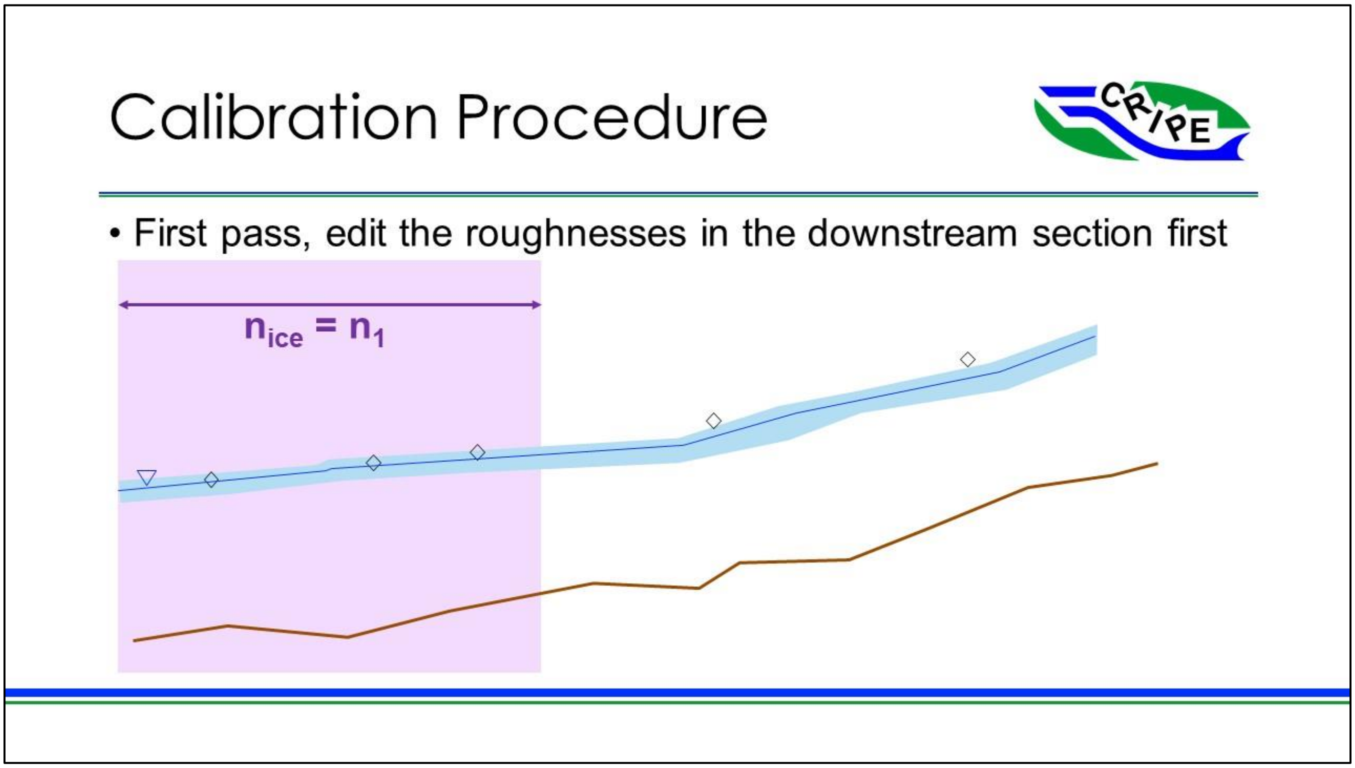
Property	*Range of values*
Ice cover roughness (n_i)	
Freezeup ice cover	0.010–0.060
Freezeup ice jam	0.020–0.10
Breakup (thin ice)	0.020–0.10
Breakup (thick ice)	0.035–0.15

White, 1999

Calibration Procedure

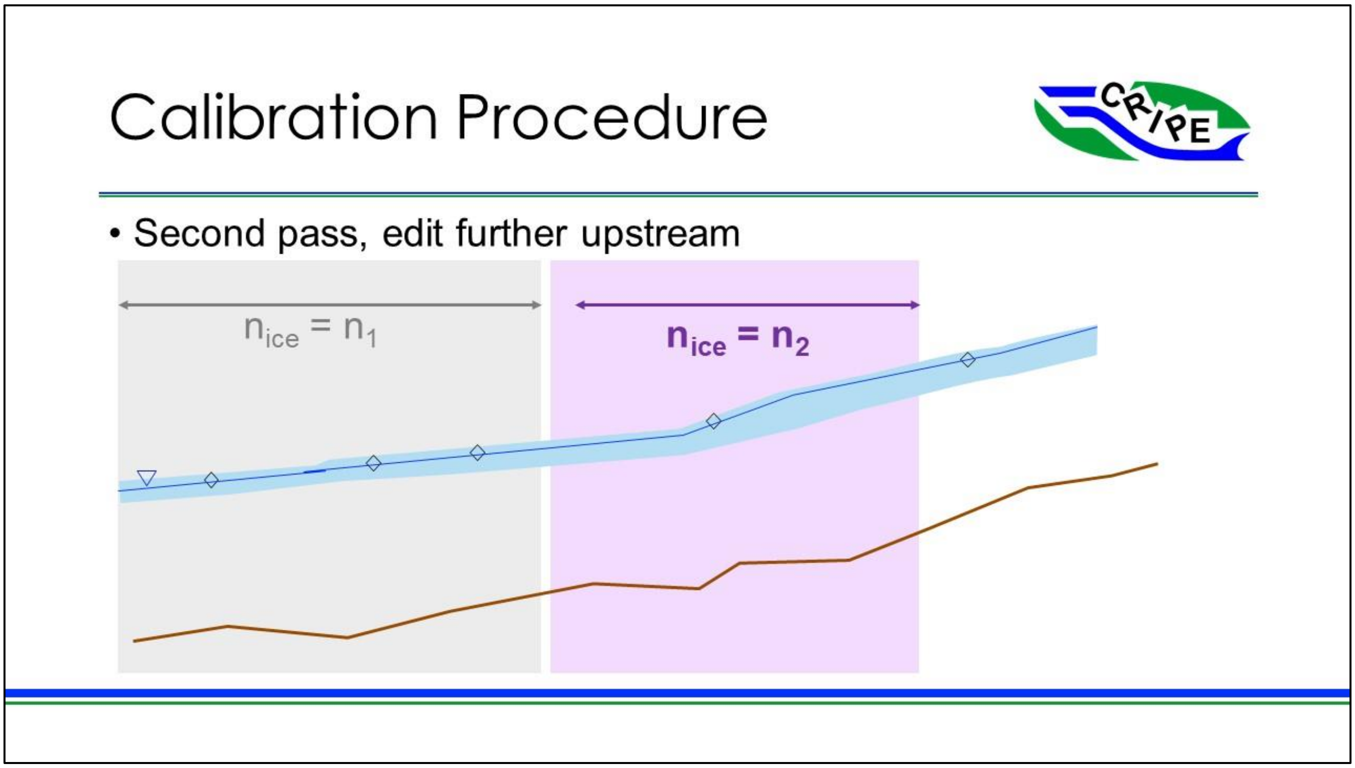
- Initial guess of ice cover roughness - use 0.024





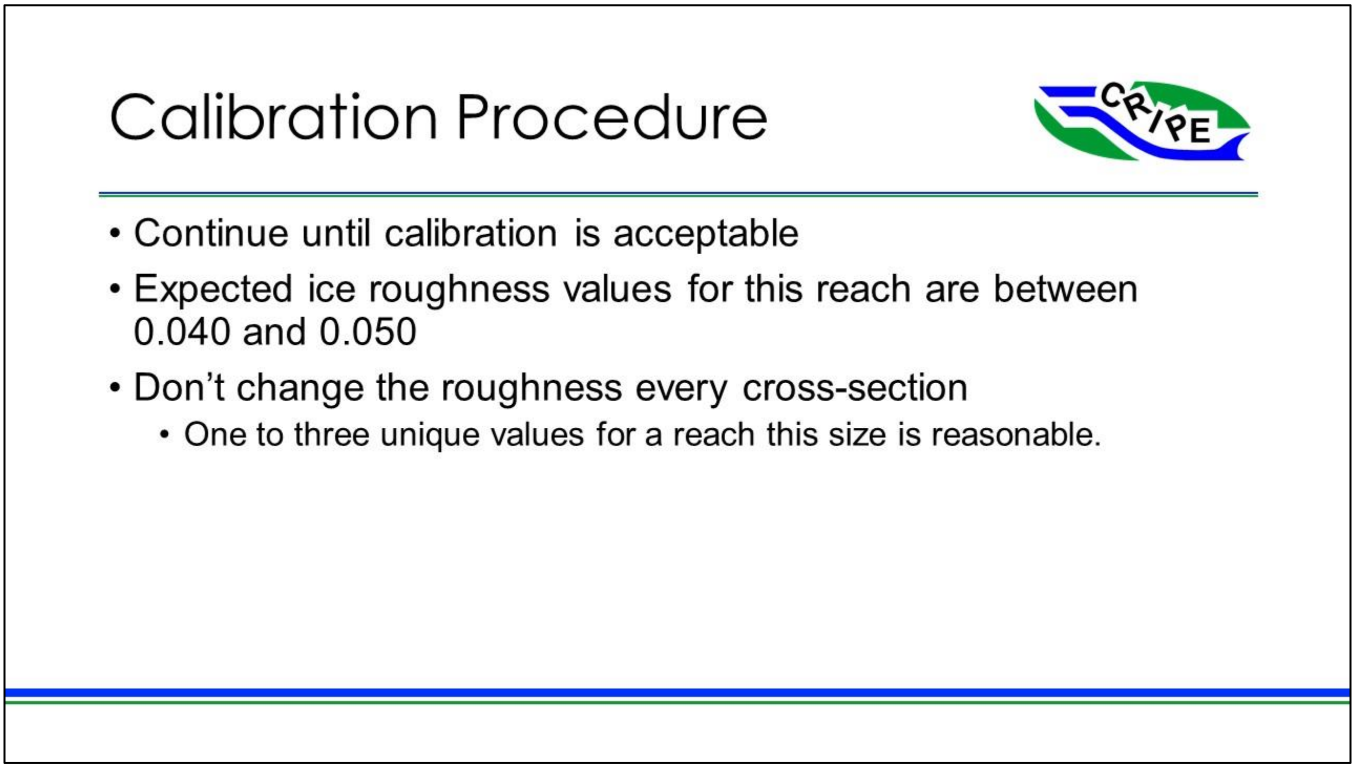
Calibration Procedure

- First pass, edit the roughnesses in the downstream section first



Calibration Procedure

- Second pass, edit further upstream



Calibration Procedure

- Continue until calibration is acceptable
- Expected ice roughness values for this reach are between 0.040 and 0.050
- Don’t change the roughness every cross-section
  - One to three unique values for a reach this size is reasonable.

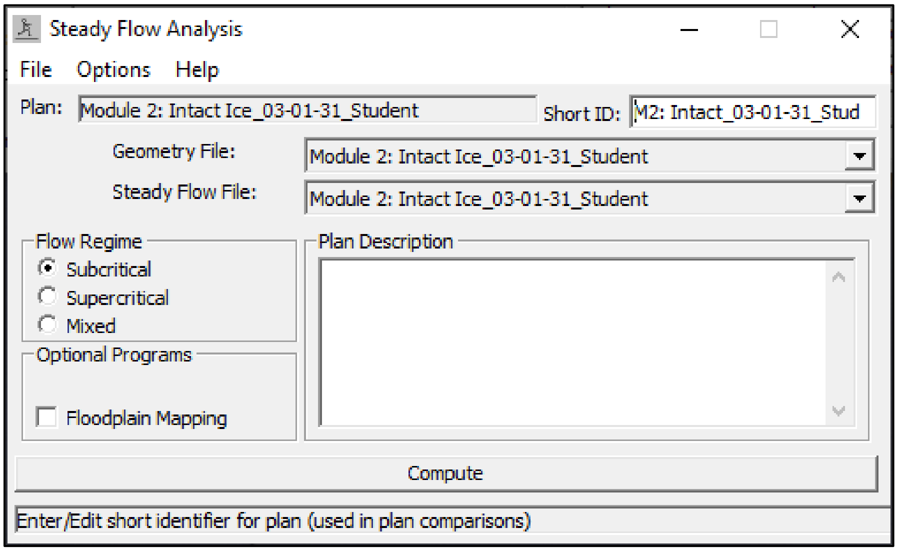
Task 2A Instructions: Modify Open Water Geometry File to Add and Intact Ice Cover

Table 3: Model Files Used for HEC-RAS Module 2 - Task 2A

File Type	Filename
Plan	“Module 2: Intact Ice_03_01_31_Student”
Geometry	“Module 2: Intact Ice_03_01_31_Student”
Steady Flow	“Module 2: Intact Ice_03_01_31_Student”

The geometry file above is a copy of the open water geometry file used in Module 1. We will be modifying this file to simulate the intact ice cover using ice measurements done around January 31, 2003

1. In the main interface click to open the ‘Steady Flow Analysis’ window.
2. Go to File and select the ‘*Open Plan…*’ option. Open the plan file for this task “**Module 2: Intact Ice_03_01_31_Student**”. Click OK
3. Verify that the correct **Steady Flow** and **Geometry** files have been loaded:



Plan: Module 2: Intact Ice_03-01-31_Student
Short ID: M2: Intact_03-01-31_Stud
Geometry File: Module 2: Intact Ice_03-01-31_Student
Steady Flow File: Module 2: Intact Ice_03-01-31_Student

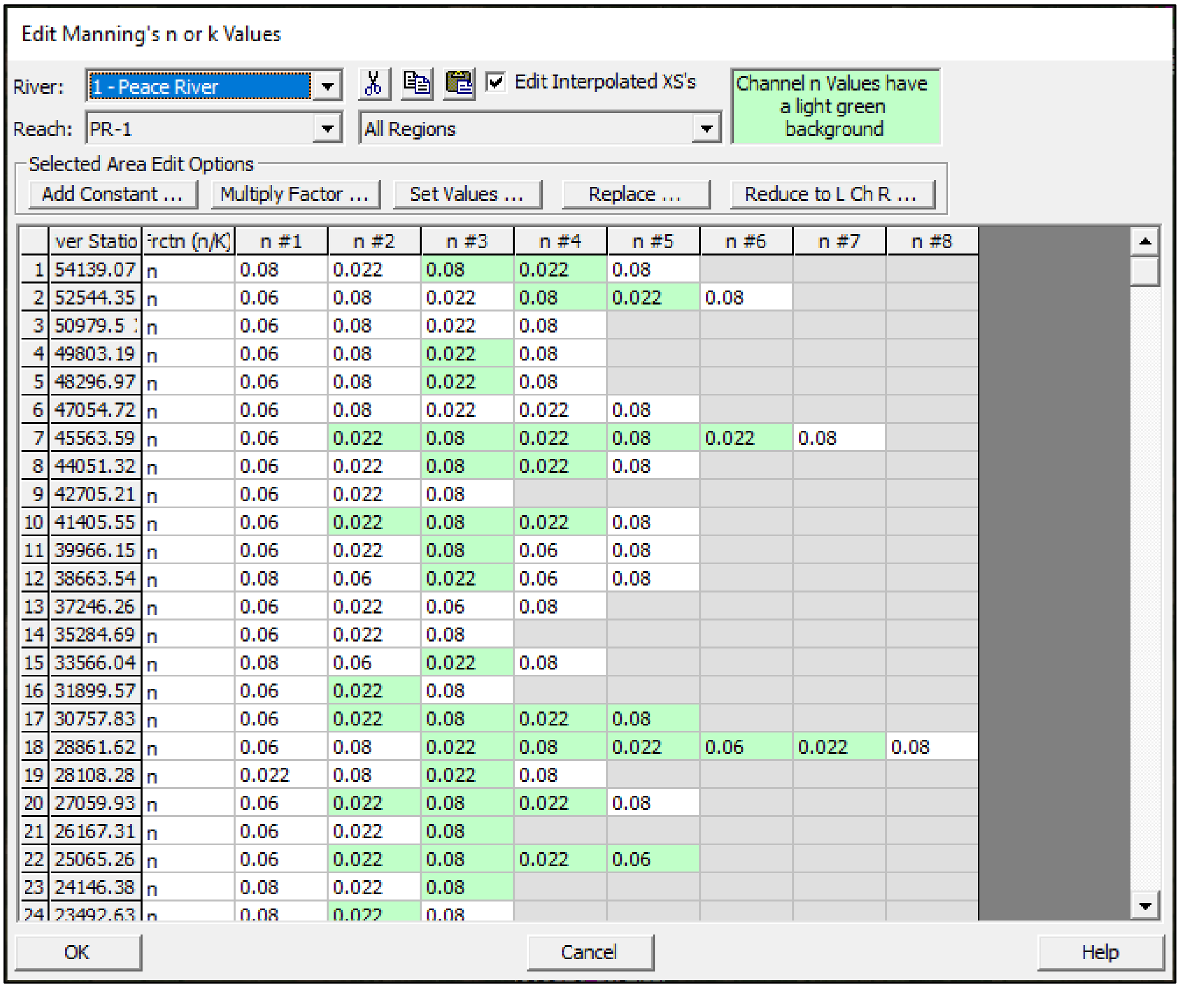
Flow Regime
● Subcritical
○ Supercritical
○ Mixed

Optional Programs
☐ Floodplain Mapping

Plan Description

Enter/Edit short identifier for plan (used in plan comparisons)

4. Close the ‘Steady Flow Analysis’ window by clicking on the ×.
5. Click on the in the main interface to open the ‘Geometric Data’ window:
6. Click on Tables and select ‘*Manning’s n or k Values (Horizontally Varied) …*’



River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

All Regions

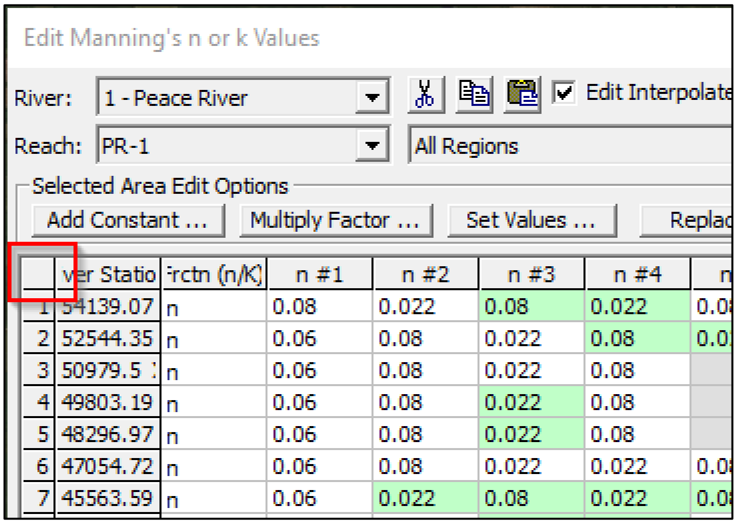
Channel n Values have a light green background

	ver Statio	rctn (n/K)	n #1	n #2	n #3	n #4	n #5	n #6	n #7	n #8
1	54139.07	n	0.08	0.022	0.08	0.022	0.08			
2	52544.35	n	0.06	0.08	0.022	0.08	0.022	0.08		
3	50979.5	n	0.06	0.08	0.022	0.08				
4	49803.19	n	0.06	0.08	0.022	0.08				
5	48296.97	n	0.06	0.08	0.022	0.08				
6	47054.72	n	0.06	0.08	0.022	0.022	0.08			
7	45563.59	n	0.06	0.022	0.08	0.022	0.08	0.022	0.08	
8	44051.32	n	0.06	0.022	0.08	0.022	0.08			
9	42705.21	n	0.06	0.022	0.08					
10	41405.55	n	0.06	0.022	0.08	0.022	0.08			
11	39966.15	n	0.06	0.022	0.08	0.06	0.08			
12	38663.54	n	0.08	0.06	0.022	0.06	0.08			
13	37246.26	n	0.06	0.022	0.06	0.08				
14	35284.69	n	0.06	0.022	0.08					
15	33566.04	n	0.08	0.06	0.022	0.08				
16	31899.57	n	0.06	0.022	0.08					
17	30757.83	n	0.06	0.022	0.08	0.022	0.08			
18	28861.62	n	0.06	0.08	0.022	0.08	0.022	0.06	0.022	0.08
19	28108.28	n	0.022	0.08	0.022	0.08				
20	27059.93	n	0.06	0.022	0.08	0.022	0.08			
21	26167.31	n	0.06	0.022	0.08					
22	25065.26	n	0.06	0.022	0.08	0.022	0.06			
23	24146.38	n	0.08	0.022	0.08					
24	23492.63	n	0.08	0.022	0.08					

This table is another way to view the roughness values for each cross-section, instead of viewing them in the Cross Section viewer as we did in the previous module. The reason why the bed roughness is varied across the channel in this geometry file, is because islands and bars (which are included in the channel in this model) have a rougher bed than the normally-wetted channel.

For our ice jam model we must simplify the Manning's *n* roughness values into just 3 values for each cross-section: one for each of the Left Overbank, Channel, and Right Overbank.

7. Select all the cross-section by clicking the rectangle at the top left of the table:



Edit Manning's n or k Values

River: 1 - Peace River

Reach: PR-1

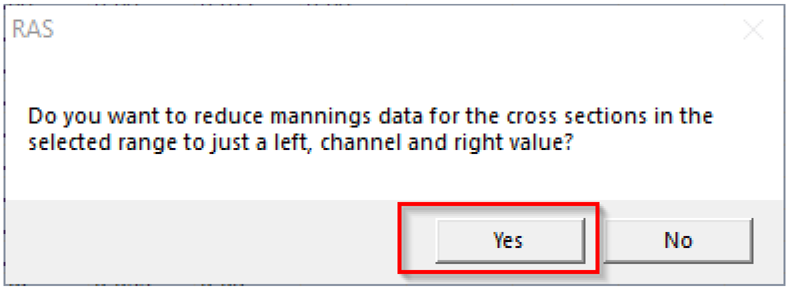
☑ Edit Interpolate

All Regions

Selected Area Edit Options

	ver Statio	Frctn (n/K)	n #1	n #2	n #3	n #4	n
1	54139.07	n	0.08	0.022	0.08	0.022	0.0
2	52544.35	n	0.06	0.08	0.022	0.08	0.0
3	50979.5	n	0.06	0.08	0.022	0.08	
4	49803.19	n	0.06	0.08	0.022	0.08	
5	48296.97	n	0.06	0.08	0.022	0.08	
6	47054.72	n	0.06	0.08	0.022	0.022	0.0
7	45563.59	n	0.06	0.022	0.08	0.022	0.0

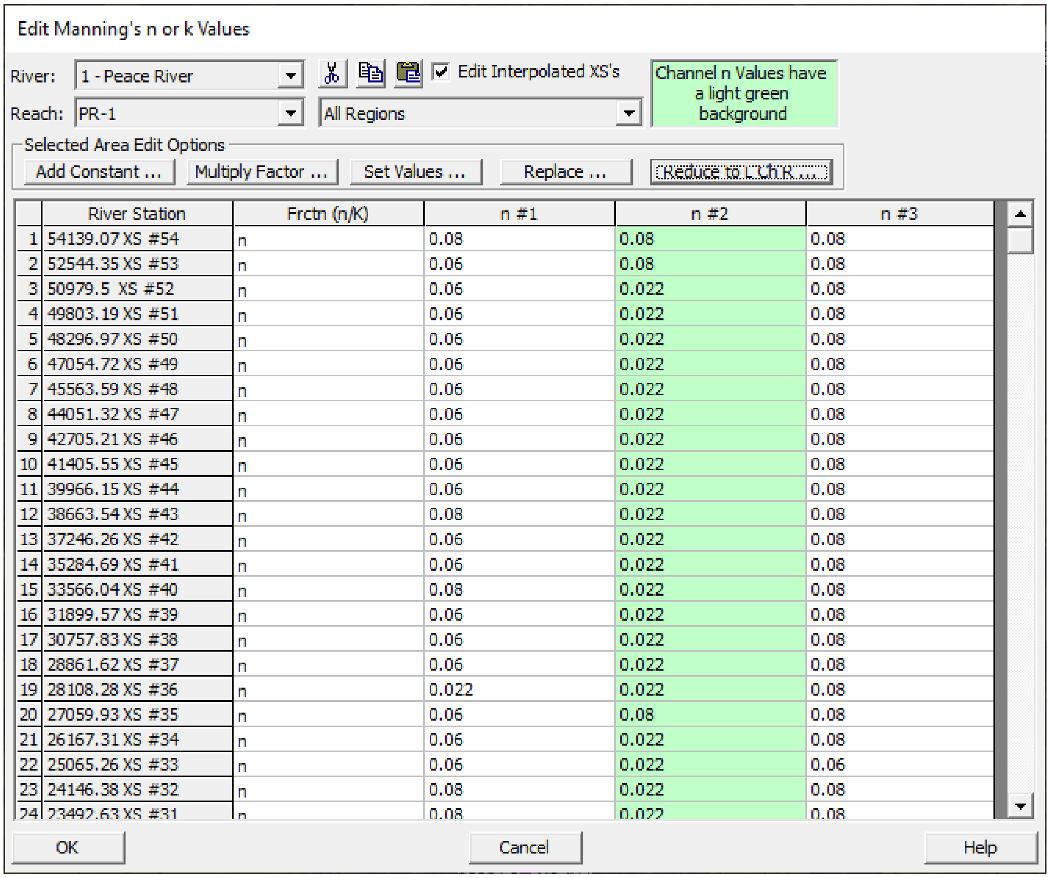
8. Select the button Reduce to L Ch R ... and choose '*Yes*':



RAS

Do you want to reduce mannings data for the cross sections in the selected range to just a left, channel and right value?

The table of roughnesses will now be reduced to 3 roughness values per cross-section:



Edit Manning's n or k Values

River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

All Regions

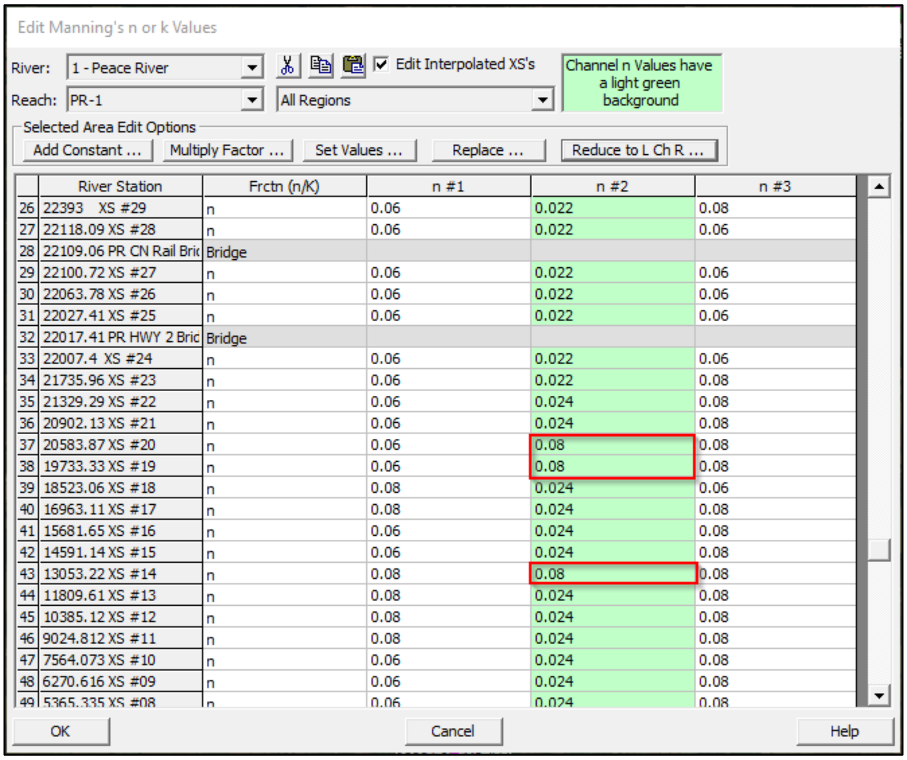
Channel n Values have a light green background

Selected Area Edit Options

	River Station	Frctn (n/K)	n #1	n #2	n #3
1	54139.07 XS #54	n	0.08	0.08	0.08
2	52544.35 XS #53	n	0.06	0.08	0.08
3	50979.5 XS #52	n	0.06	0.022	0.08
4	49803.19 XS #51	n	0.06	0.022	0.08
5	48296.97 XS #50	n	0.06	0.022	0.08
6	47054.72 XS #49	n	0.06	0.022	0.08
7	45563.59 XS #48	n	0.06	0.022	0.08
8	44051.32 XS #47	n	0.06	0.022	0.08
9	42705.21 XS #46	n	0.06	0.022	0.08
10	41405.55 XS #45	n	0.06	0.022	0.08
11	39966.15 XS #44	n	0.06	0.022	0.08
12	38663.54 XS #43	n	0.08	0.022	0.08
13	37246.26 XS #42	n	0.06	0.022	0.08
14	35284.69 XS #41	n	0.06	0.022	0.08
15	33566.04 XS #40	n	0.08	0.022	0.08
16	31899.57 XS #39	n	0.06	0.022	0.08
17	30757.83 XS #38	n	0.06	0.022	0.08
18	28861.62 XS #37	n	0.06	0.022	0.08
19	28108.28 XS #36	n	0.022	0.022	0.08
20	27059.93 XS #35	n	0.06	0.08	0.08
21	26167.31 XS #34	n	0.06	0.022	0.08
22	25065.26 XS #33	n	0.06	0.022	0.06
23	24146.38 XS #32	n	0.08	0.022	0.08
24	23492.63 XS #31	n	0.08	0.022	0.08

The channel roughness values are highlighted with a light green background.

9. Scroll through the table. Notice some anomalously high values for channel roughness in the table:



Edit Manning's n or k Values

River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

All Regions

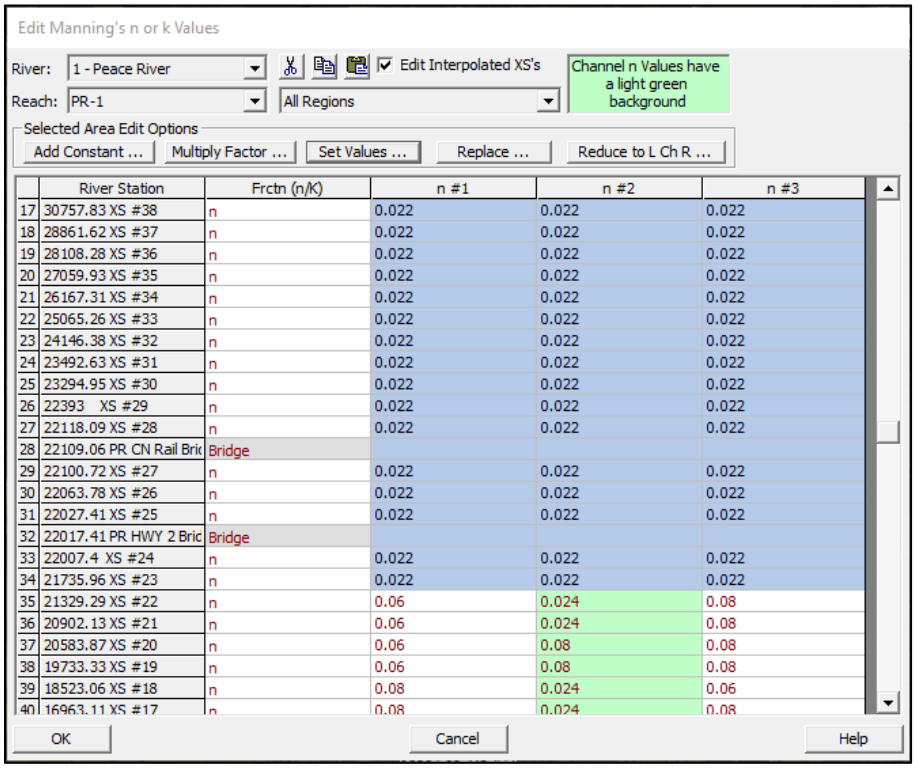
Channel n Values have a light green background

	River Station	Frctn (n/K)	n #1	n #2	n #3
26	22393 XS #29	n	0.06	0.022	0.08
27	22118.09 XS #28	n	0.06	0.022	0.06
28	22109.06 PR CN Rail Bri	Bridge			
29	22100.72 XS #27	n	0.06	0.022	0.06
30	22063.78 XS #26	n	0.06	0.022	0.06
31	22027.41 XS #25	n	0.06	0.022	0.06
32	22017.41 PR HWY 2 Bric	Bridge			
33	22007.4 XS #24	n	0.06	0.022	0.06
34	21735.96 XS #23	n	0.06	0.022	0.08
35	21329.29 XS #22	n	0.06	0.024	0.08
36	20902.13 XS #21	n	0.06	0.024	0.08
37	20583.87 XS #20	n	0.06	0.08	0.08
38	19733.33 XS #19	n	0.06	0.08	0.08
39	18523.06 XS #18	n	0.08	0.024	0.06
40	16963.11 XS #17	n	0.08	0.024	0.08
41	15681.65 XS #16	n	0.06	0.024	0.08
42	14591.14 XS #15	n	0.06	0.024	0.08
43	13053.22 XS #14	n	0.08	0.08	0.08
44	11809.61 XS #13	n	0.08	0.024	0.08
45	10385.12 XS #12	n	0.08	0.024	0.08
46	9024.812 XS #11	n	0.08	0.024	0.08
47	7564.073 XS #10	n	0.06	0.024	0.08
48	6270.616 XS #09	n	0.06	0.024	0.08
49	5365.335 XS #08	n	0.06	0.024	0.08

Upon review of the table, several channel roughness are quite high. This is where HEC-RAS has automatically used the value assigned for rough island areas to the channel.

For this course, we will use channel roughnesses in the channel and in the overbank areas. This will be consistent with the approach we will use in Module 4, when we modify the bank stations.

10. Correct the channel roughness values and also give the overbanks the same values as the channel. Select all 3 '*n*' columns and all rows from '*XS #54*' to '*XS #23*'. To select multiple values, click and drag. Once selected, click Set Values ... . Use enter a value of *0.022* and click OK :

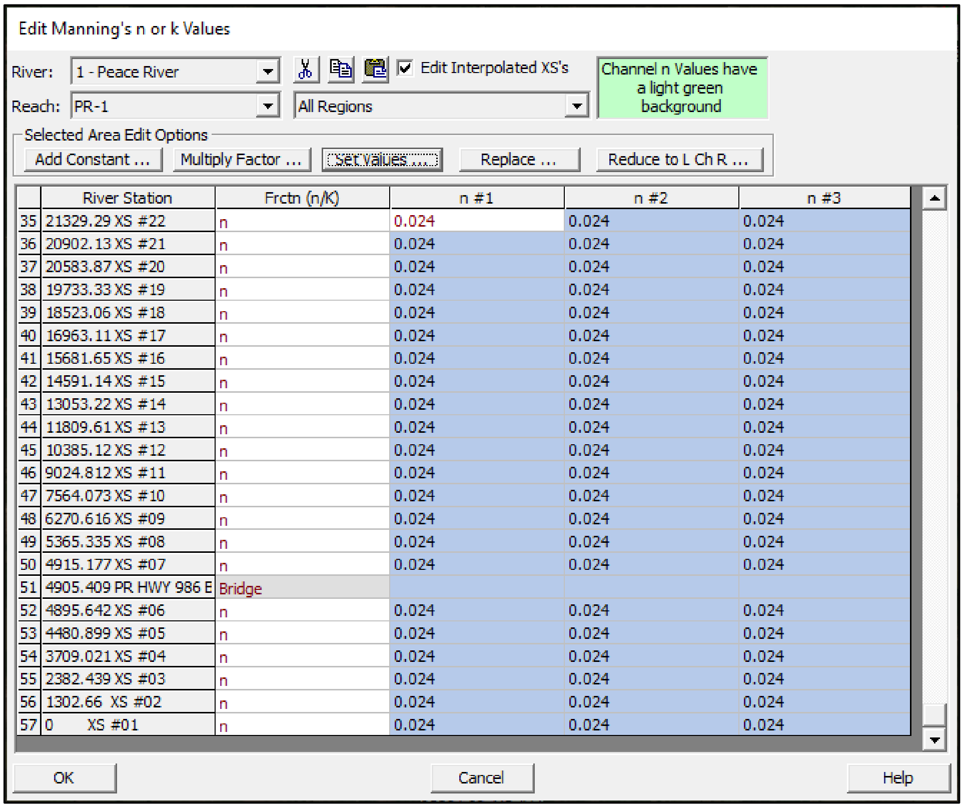


	River Station	Frctn (n/K)	n #1	n #2	n #3
17	30757.83 XS #38	n	0.022	0.022	0.022
18	28861.62 XS #37	n	0.022	0.022	0.022
19	28108.28 XS #36	n	0.022	0.022	0.022
20	27059.93 XS #35	n	0.022	0.022	0.022
21	26167.31 XS #34	n	0.022	0.022	0.022
22	25065.26 XS #33	n	0.022	0.022	0.022
23	24146.38 XS #32	n	0.022	0.022	0.022
24	23492.63 XS #31	n	0.022	0.022	0.022
25	23294.95 XS #30	n	0.022	0.022	0.022
26	22393 XS #29	n	0.022	0.022	0.022
27	22118.09 XS #28	n	0.022	0.022	0.022
28	22109.06 PR CN Rail Bric	Bridge			
29	22100.72 XS #27	n	0.022	0.022	0.022
30	22063.78 XS #26	n	0.022	0.022	0.022
31	22027.41 XS #25	n	0.022	0.022	0.022
32	22017.41 PR HWY 2 Bric	Bridge			
33	22007.4 XS #24	n	0.022	0.022	0.022
34	21735.96 XS #23	n	0.022	0.022	0.022
35	21329.29 XS #22	n	0.06	0.024	0.08
36	20902.13 XS #21	n	0.06	0.024	0.08
37	20583.87 XS #20	n	0.06	0.08	0.08
38	19733.33 XS #19	n	0.06	0.08	0.08
39	18523.06 XS #18	n	0.08	0.024	0.06
40	16963.11 XS #17	n	0.08	0.024	0.08

The first part of the table has been updated. The red values indicated that the table has been edited but not yet saved.

The calibrated roughness values transitioned from n = 0.022 to n = 0.024 between cross-sections “XS #22” and “XS #23”. We will change the remainder of the x-sections to have a roughness of 0.024.

11. Select the remainder of the table (from ‘*XS #22*’ to ‘*XS #01*’) and click Set Values ... . Use enter a value of *0.024* and click OK :

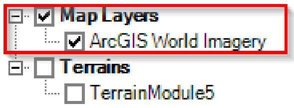


River: 1 - Peace River
Reach: PR-1
All Regions

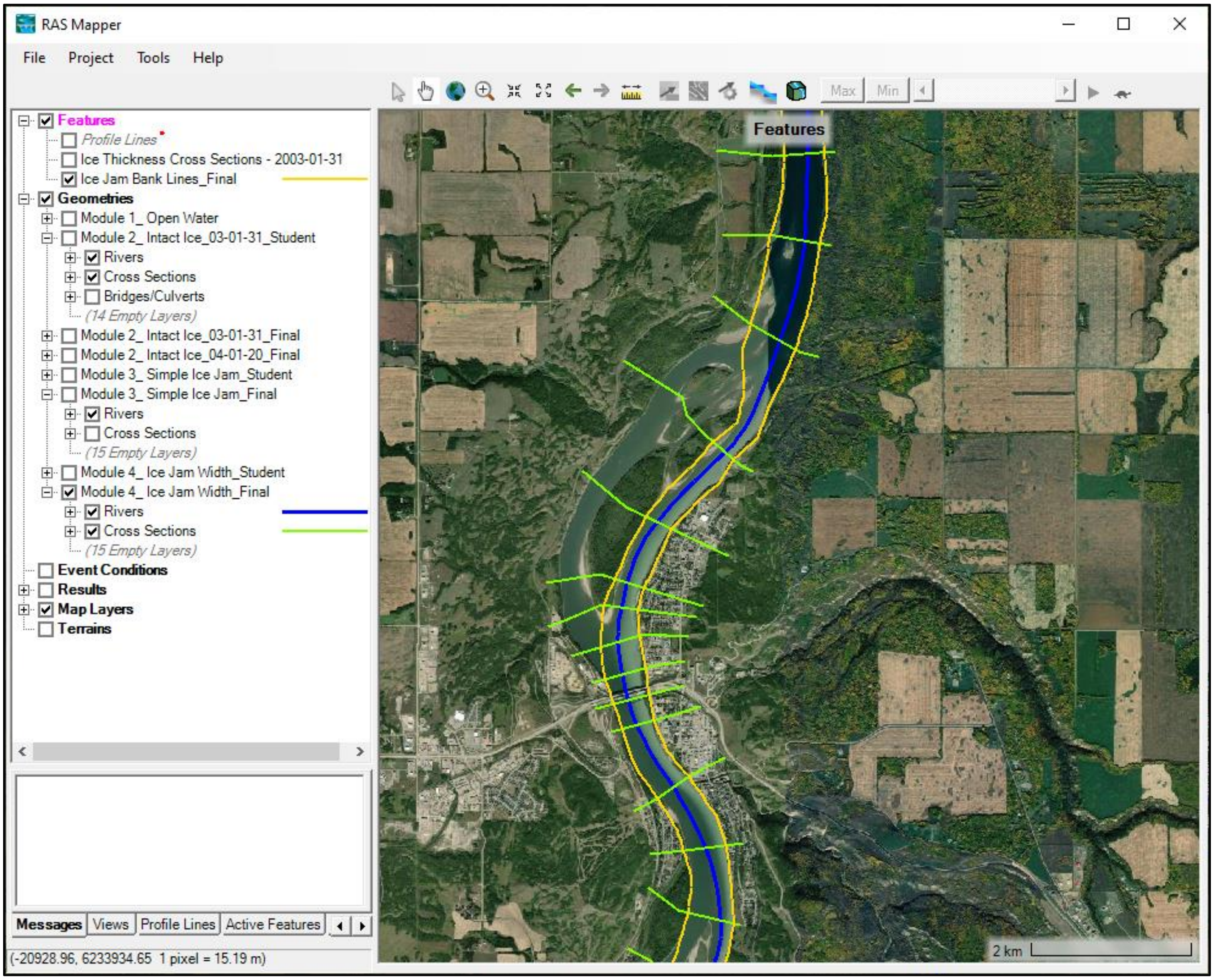
	River Station	Frctn (n/K)	n #1	n #2	n #3
35	21329.29 XS #22	n	0.024	0.024	0.024
36	20902.13 XS #21	n	0.024	0.024	0.024
37	20583.87 XS #20	n	0.024	0.024	0.024
38	19733.33 XS #19	n	0.024	0.024	0.024
39	18523.06 XS #18	n	0.024	0.024	0.024
40	16963.11 XS #17	n	0.024	0.024	0.024
41	15681.65 XS #16	n	0.024	0.024	0.024
42	14591.14 XS #15	n	0.024	0.024	0.024
43	13053.22 XS #14	n	0.024	0.024	0.024
44	11809.61 XS #13	n	0.024	0.024	0.024
45	10385.12 XS #12	n	0.024	0.024	0.024
46	9024.812 XS #11	n	0.024	0.024	0.024
47	7564.073 XS #10	n	0.024	0.024	0.024
48	6270.616 XS #09	n	0.024	0.024	0.024
49	5365.335 XS #08	n	0.024	0.024	0.024
50	4915.177 XS #07	n	0.024	0.024	0.024
51	4905.409 PR HWY 986 E	Bridge			
52	4895.642 XS #06	n	0.024	0.024	0.024
53	4480.899 XS #05	n	0.024	0.024	0.024
54	3709.021 XS #04	n	0.024	0.024	0.024
55	2382.439 XS #03	n	0.024	0.024	0.024
56	1302.66 XS #02	n	0.024	0.024	0.024
57	0 XS #01	n	0.024	0.024	0.024

The table has now been updated with channel roughness values in the channel and both overbanks. Remember that these values were calibrated during the calibration of the open water model, and represent bed roughness values.

12. Click OK in the 'Edit Manning's n or k Values' window.
13. In the 'Geometric Data' window save the geometry file by choosing File and selecting '*Save Geometry Data'*. DO NOT CLOSE THE GEOMETRY WINDOW.
14. In the main interface window, open the 'RAS Mapper' window, while keeping the geometry data window open.
15. Make sure *"ArcGIS World Imagery*" is checked on under *"Map Layers":*

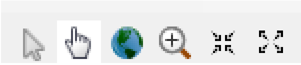


☑ **Map Layers**
  ☑ ArcGIS World Imagery
☐ **Terrains**
  ☐ TerrainModule5

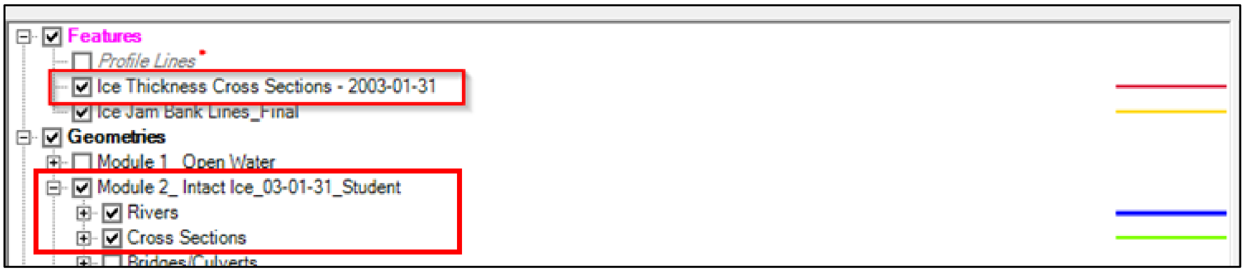


‘RAS Mapper’ is a tool that allows the modeller to see data that is spatially referenced. This includes model geometry (if it is georeferenced), imagery, and additional data that may be relevant to your model.

In the pane on the left, different features can be turned on and off by clicking the check boxes next to the features. You can zoom and pan using the tools at the top of the window:



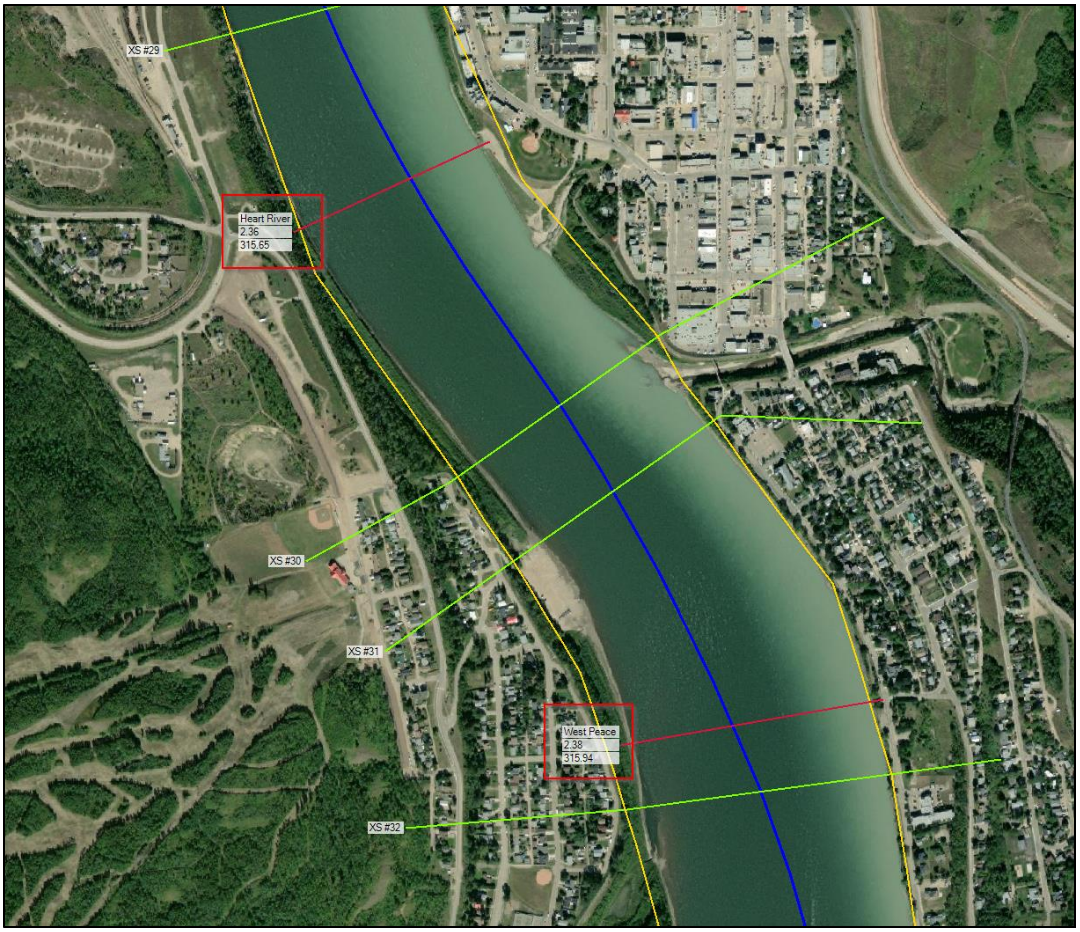
16. Check the boxes beside ‘*Ice Thickness Cross Sections – 2003-01-31*’ and ‘*Module 2_Intact Ice_03-01-31_Student*’ to turn them on in the viewer. Uncheck any other module geometries that may already be selected.



- ☑ Features
  - ☐ Profile Lines*
  - ☑ Ice Thickness Cross Sections - 2003-01-31
  - ☑ Ice Jam Bank Lines_Final
- ☑ Geometries
  - ☐ Module 1_ Open Water
  - ☑ Module 2_ Intact Ice_03-01-31_Student
    - ☑ Rivers
    - ☑ Cross Sections
    - ☐ Bridges/Culverts

This will allow you to view the locations of several cross-sections where ice thicknesses and water levels were measured on January 31, 2003. These were saved in a shapefile and then added to 'RAS mapper'.

17. Zoom into the area near XS #30 to view the ice thickness cross-sections. XS #30 is near the middle of the model domain.



The red lines are the locations where ice-thicknesses were measured across the channel. Notice that the ice thickness locations do not correspond exactly with the locations of the model cross-sections. The labels for these cross-sections contains the measured ice thickness (top number) and the water level (bottom number), both in meters. These thickness values have been averaged across the channel, and the thermal ice and slush ice portions have been added together. In reality, ice thickness can vary significantly across the channel. Here is an example of the original ice thickness data:

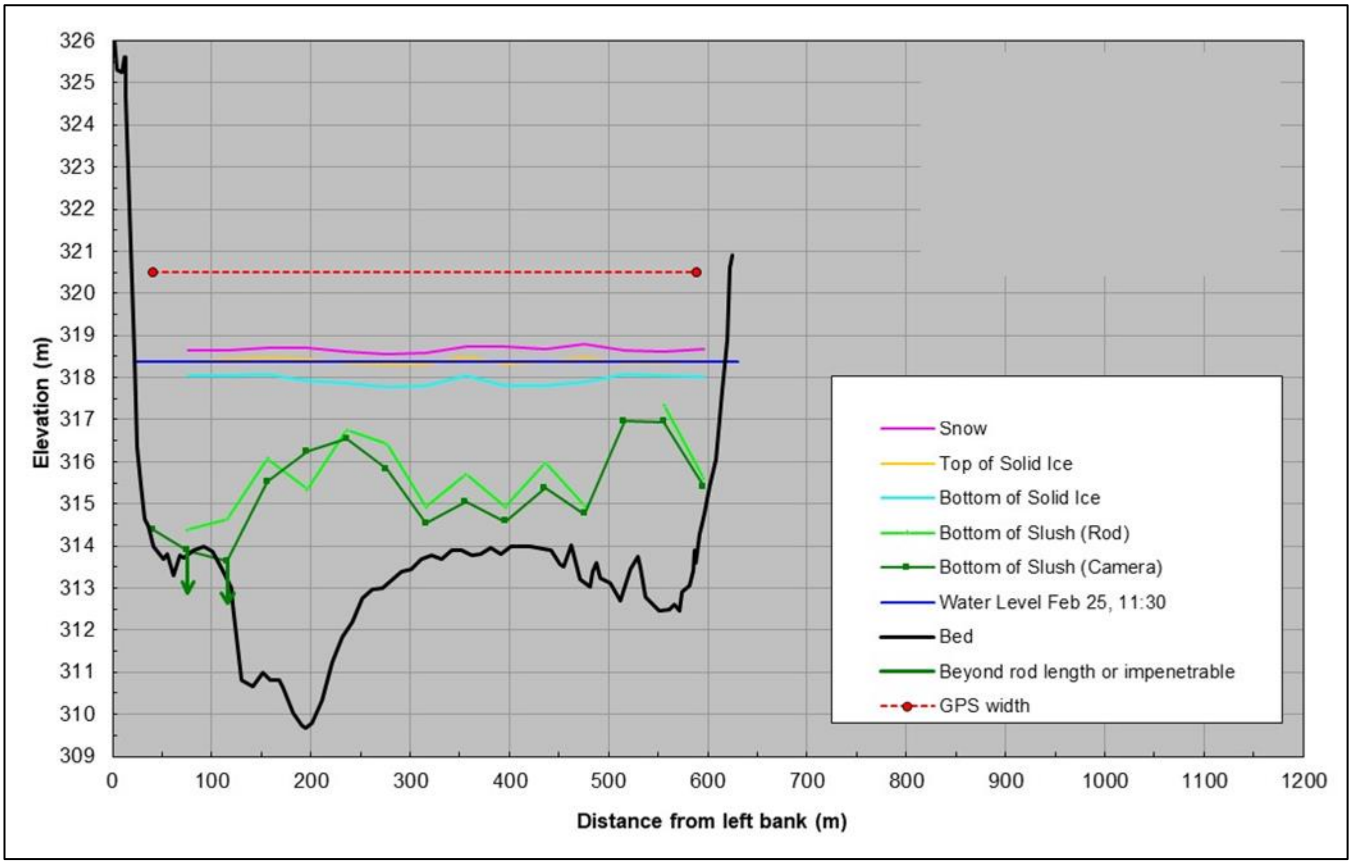


Figure 1: Example of the measured ice thickness data from the Mackenzie Cairn site (modified from Trillium Engineering and Hydrographics Inc., 2004)

Next, we will enter the ice thickness data from ‘RAS mapper’ into the geometry file containing our cross-sections.

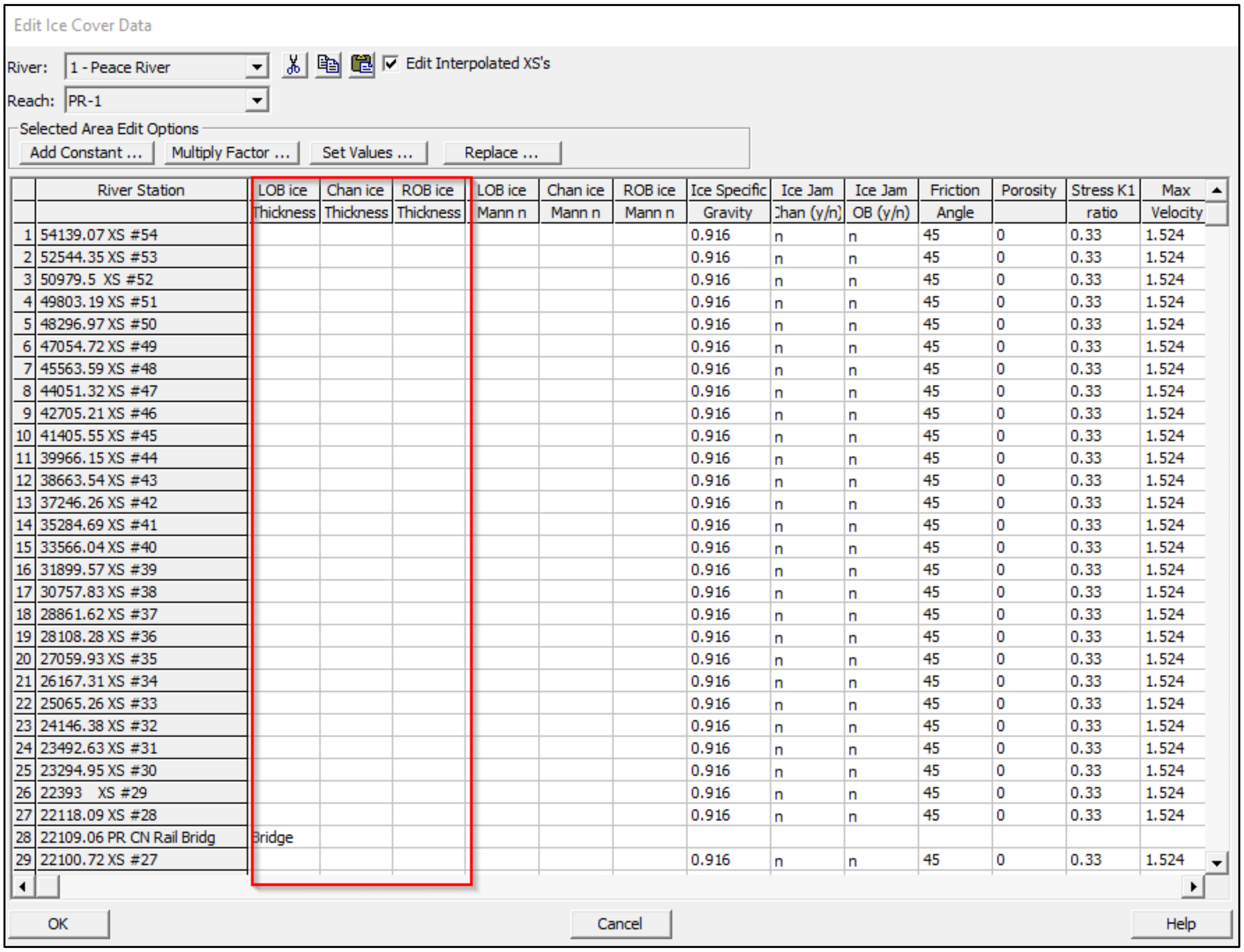
18. Use the ice thickness information in ‘RAS Mapper’ to complete yellow blanks in the following table to help you keep track of the thicknesses that you will enter into the model geometry in the next steps.

    For cross-sections between the measurements, please estimate the ice thickness using nearby measured values. Upstream and downstream of the area where ice thickness measurements were taken, adopt a thickness of *2.4* m.

Table 4: Ice Thicknesses for Adoption in the Model for Task 2A

Location	Measured Ice Thickness, m	Adopted Ice Thickness, m
XS #54 to XS #40	none	2.4
XS #39 McLeod Cairn	3.05	3.05
XS #38 to XS #37	none	
XS #36 Sawchuck's	2.52	2.52
XS #35 to XS #32	none	
Between XS #32 and XS #31 West Peace	2.38	NA
XS #31 to XS #30	none	
Between XS #30 and XS #29 Heart River	2.36	NA
XS #29 to XS #23	none	
XS #22 WSC Gauge	1.66	1.66
XS #21	none	
XS #20 Beweley Island	1.5	1.5
XS #19 to XS #01	none	2.4

19. Go back to the ‘Geometric Data’ window to enter the ice cover thickness data you filled in the above table. Go to Tables and click ‘*Ice Cover …*’.



River: 1 - Peace River

Reach: PR-1

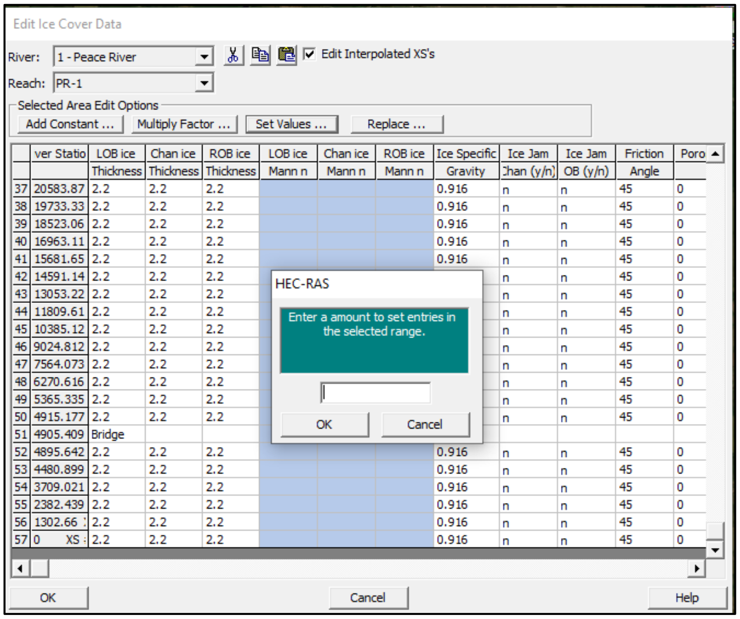
☑ Edit Interpolated XS's

	River Station	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam Chan (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity
1	54139.07 XS #54							0.916	n	n	45	0	0.33	1.524
2	52544.35 XS #53							0.916	n	n	45	0	0.33	1.524
3	50979.5 XS #52							0.916	n	n	45	0	0.33	1.524
4	49803.19 XS #51							0.916	n	n	45	0	0.33	1.524
5	48296.97 XS #50							0.916	n	n	45	0	0.33	1.524
6	47054.72 XS #49							0.916	n	n	45	0	0.33	1.524
7	45563.59 XS #48							0.916	n	n	45	0	0.33	1.524
8	44051.32 XS #47							0.916	n	n	45	0	0.33	1.524
9	42705.21 XS #46							0.916	n	n	45	0	0.33	1.524
10	41405.55 XS #45							0.916	n	n	45	0	0.33	1.524
11	39966.15 XS #44							0.916	n	n	45	0	0.33	1.524
12	38663.54 XS #43							0.916	n	n	45	0	0.33	1.524
13	37246.26 XS #42							0.916	n	n	45	0	0.33	1.524
14	35284.69 XS #41							0.916	n	n	45	0	0.33	1.524
15	33566.04 XS #40							0.916	n	n	45	0	0.33	1.524
16	31899.57 XS #39							0.916	n	n	45	0	0.33	1.524
17	30757.83 XS #38							0.916	n	n	45	0	0.33	1.524
18	28861.62 XS #37							0.916	n	n	45	0	0.33	1.524
19	28108.28 XS #36							0.916	n	n	45	0	0.33	1.524
20	27059.93 XS #35							0.916	n	n	45	0	0.33	1.524
21	26167.31 XS #34							0.916	n	n	45	0	0.33	1.524
22	25065.26 XS #33							0.916	n	n	45	0	0.33	1.524
23	24146.38 XS #32							0.916	n	n	45	0	0.33	1.524
24	23492.63 XS #31							0.916	n	n	45	0	0.33	1.524
25	23294.95 XS #30							0.916	n	n	45	0	0.33	1.524
26	22393 XS #29							0.916	n	n	45	0	0.33	1.524
27	22118.09 XS #28							0.916	n	n	45	0	0.33	1.524
28	22109.06 PR CN Rail Bridg	Bridge												
29	22100.72 XS #27							0.916	n	n	45	0	0.33	1.524

20. Enter the ice thickness data in the table for the Left Overbank (LOB), Channel, and Right Overbank (ROB) columns, give all three columns the same ice thickness for each cross-section.

    To fill in multiple boxes at once, highlight the boxes and choose Set Values … , enter the value and then click OK .

22. Set the ice roughness values for all cross-sections and the LOB, Channel, ROB to an initial value. Select all the rows, and the three columns and choose Set Values ... . Enter a value of *0.024*. A single roughness value similar to the bed roughness is a reasonable first estimate because these values will be edited during calibration:



River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

	ver Statio	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam Chan (y/n)	Ice Jam OB (y/n)	Friction Angle	Poro
37	20583.87	2.2	2.2	2.2				0.916	n	n	45	0
38	19733.33	2.2	2.2	2.2				0.916	n	n	45	0
39	18523.06	2.2	2.2	2.2				0.916	n	n	45	0
40	16963.11	2.2	2.2	2.2				0.916	n	n	45	0
41	15681.65	2.2	2.2	2.2				0.916	n	n	45	0
42	14591.14	2.2	2.2	2.2					n	n	45	0
43	13053.22	2.2	2.2	2.2					n	n	45	0
44	11809.61	2.2	2.2	2.2					n	n	45	0
45	10385.12	2.2	2.2	2.2					n	n	45	0
46	9024.812	2.2	2.2	2.2					n	n	45	0
47	7564.073	2.2	2.2	2.2					n	n	45	0
48	6270.616	2.2	2.2	2.2					n	n	45	0
49	5365.335	2.2	2.2	2.2					n	n	45	0
50	4915.177	2.2	2.2	2.2					n	n	45	0
51	4905.409	Bridge										
52	4895.642	2.2	2.2	2.2				0.916	n	n	45	0
53	4480.899	2.2	2.2	2.2				0.916	n	n	45	0
54	3709.021	2.2	2.2	2.2				0.916	n	n	45	0
55	2382.439	2.2	2.2	2.2				0.916	n	n	45	0
56	1302.66 :	2.2	2.2	2.2				0.916	n	n	45	0
57	0 XS :	2.2	2.2	2.2				0.916	n	n	45	0

HEC-RAS

Enter a amount to set entries in the selected range.

Note that you can expand the first column in this table (click and drag the border) to see the entire river station and cross-section number.

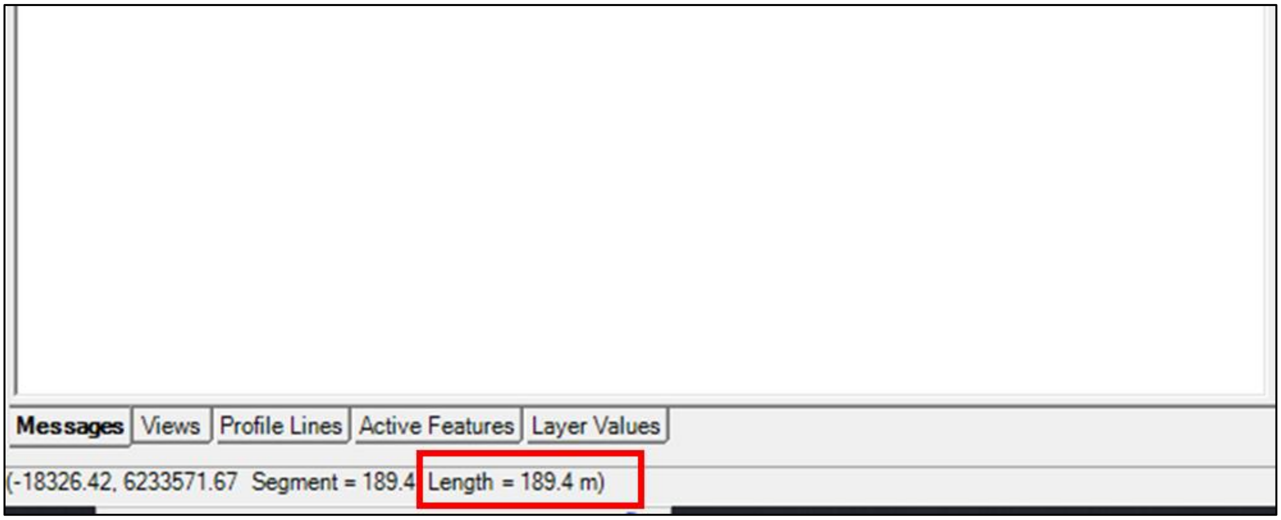
23. Click OK in the ‘Edit Ice Cover Data’ window.

24. Save the geometry file by going to File and select ‘*Save Geometry Data’*. Close the ‘Geometric Data’ window clicking on the ×.

Task 2B Instructions: Enter the Observed Water Surface Calibration Data and Run the Model

In this task we will enter the observed water surface data for the January 31, 2003 ice cover. The observed data is stored in the RAS Mapper feature called "**Ice Thickness Cross Section – 2003-01-31**". However, the observation locations and the model cross-sections do not necessarily line up. We will record the water surface elevation and the distance downstream from a cross-section.

1. In the main interface window, open the 'RAS Mapper' window.
2. From the information in the 'RAS Mapper' window, complete the following table to record the location and elevation of the observed water surface elevation. For locations where the measurement was not recorded on a model cross-section, use *RAS Mapper's measure tool* to determine the distance from model cross-section downstream to observation location. Measure along the centreline. Double click to end your line, or view the length in the box in the bottom left of the window. To exit the measure tool, click on the *arrow tool* .

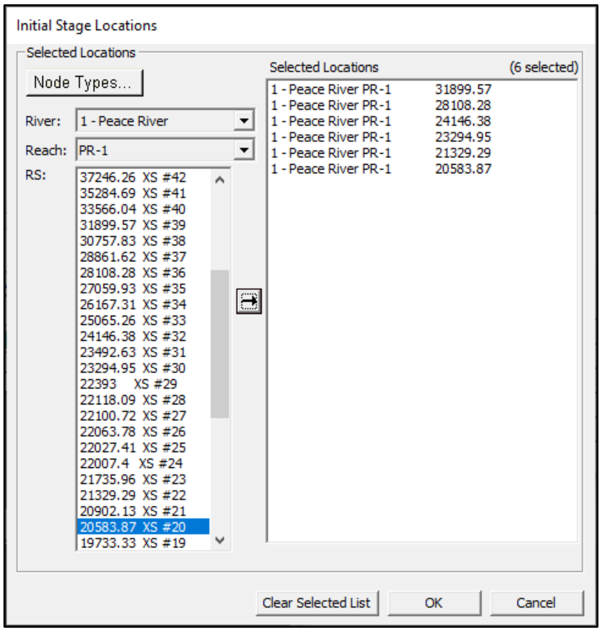


(-18326.42, 6233571.67 Segment = 189.4 Length = 189.4 m)

Table 5: Observed Water Surface Elevations, January 31, 2003

Observation Location Name	Next Closest Model XS in Upstream Direction	Distance from Closest Model XS to Observation Location, m	Observed Water Surface Elevation, m
McLeod Cairn	XS #39 31899.57	0	319.26
Sawchuck’s	XS #36 28108.28	0	318.23
West Peace	XS #32 24146.38		
Heart River	XS #30 23294.95		
WSC Gauge	XS #22 21329.29	0	
Beweley Island	XS #20 20583.87	0	315.03

3. Close ‘RAS Mapper’ by clicking on the ×.
4. In the main interface, click the to open the ‘Steady Flow Data’ window.
5. Choose Options and select ‘*Observed WS*’. Then click Add Multiple... . Add the 6 cross-sections from the above table, selecting each cross-section and clicking → to add to the selection. Click OK .



Initial Stage Locations

Selected Locations

River: 1 - Peace River

Reach: PR-1

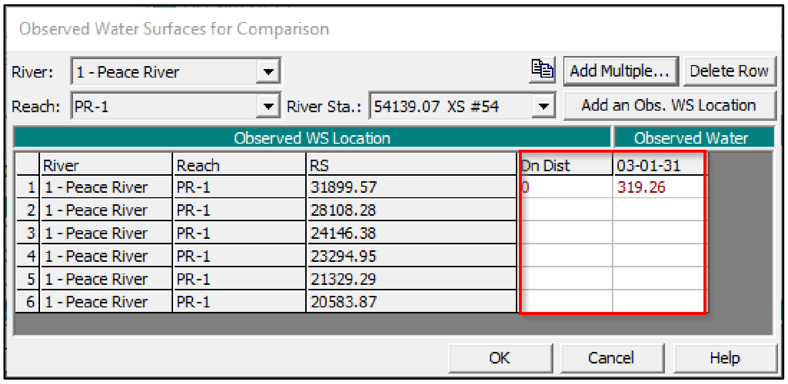
RS:

37246.26 XS #42
35284.69 XS #41
33566.04 XS #40
31899.57 XS #39
30757.83 XS #38
28861.62 XS #37
28108.28 XS #36
27059.93 XS #35
26167.31 XS #34
25065.26 XS #33
24146.38 XS #32
23492.63 XS #31
23294.95 XS #30
22393 XS #29
22118.09 XS #28
22100.72 XS #27
22063.78 XS #26
22027.41 XS #25
22007.4 XS #24
21735.96 XS #23
21329.29 XS #22
20902.13 XS #21
20583.87 XS #20
19733.33 XS #19

Selected Locations (6 selected)

1 - Peace River PR-1	31899.57
1 - Peace River PR-1	28108.28
1 - Peace River PR-1	24146.38
1 - Peace River PR-1	23294.95
1 - Peace River PR-1	21329.29
1 - Peace River PR-1	20583.87

6. Fill in the table in the 'Observed Water Surfaces for Comparison' window using the data in your table.



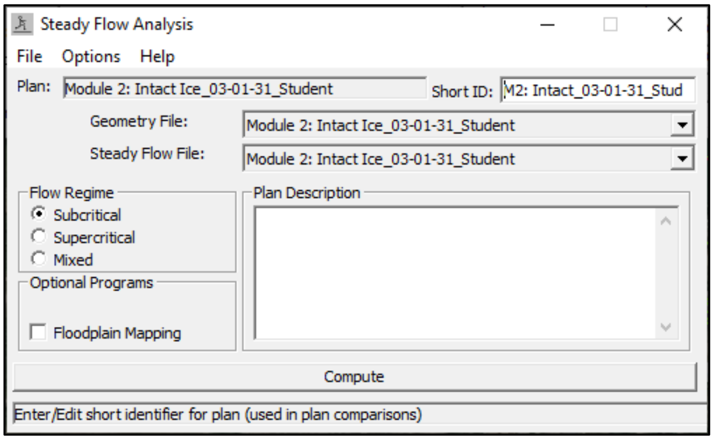
Observed Water Surfaces for Comparison

River: 1 - Peace River

Reach: PR-1 River Sta.: 54139.07 XS #54

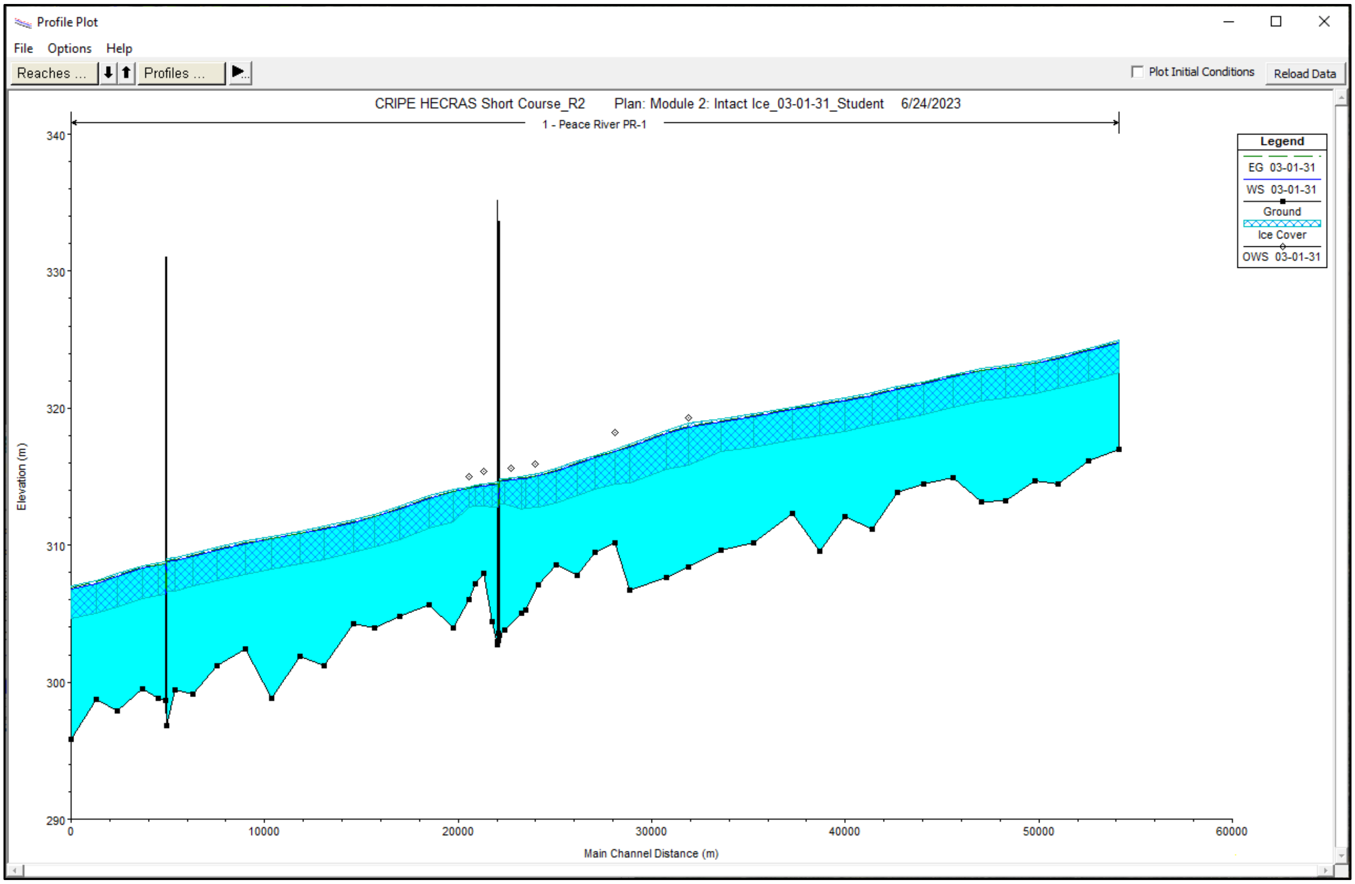
	Observed WS Location			Observed Water	
	River	Reach	RS	Dn Dist	03-01-31
1	1 - Peace River	PR-1	31899.57	0	319.26
2	1 - Peace River	PR-1	28108.28		
3	1 - Peace River	PR-1	24146.38		
4	1 - Peace River	PR-1	23294.95		
5	1 - Peace River	PR-1	21329.29		
6	1 - Peace River	PR-1	20583.87		

7. Click OK in the 'Observed Water Surfaces for Comparison' window.
8. Save your **Steady Flow** file by choosing File and select '*Save Flow Data*' in the 'Steady Flow Data' window.
9. Close the 'Steady Flow Data' window by clicking on the ×.
10. In the main interface click to open the 'Steady Flow Analysis' window.
11. Verify the correct **Geometry** file and **Steady Flow** file are queued and click Compute. Close the 'HEC-RAS Finished Computation' window if there are no errors. Close the 'Steady Flow Analysis' window by clicking on the ×.



Plan: Module 2: Intact Ice_03-01-31_Student
Short ID: M2: Intact_03-01-31_Stud
Geometry File: Module 2: Intact Ice_03-01-31_Student
Steady Flow File: Module 2: Intact Ice_03-01-31_Student
Flow Regime
● Subcritical
○ Supercritical
○ Mixed
Plan Description
Optional Programs
☐ Floodplain Mapping
Enter/Edit short identifier for plan (used in plan comparisons)

12. In the main interface, click to view the model run results as a profile plot. Turn on the view of the ice cover by choosing Options and select ‘*Variables*’ and clicking the check box next to ‘*Ice Cover*’. Click OK.



The computed water surface (dark blue line) falls below the observed water surface (diamonds). Now we must calibrate our ice roughness values to make the computed water surface match the observed surface. Because our computed water surface is too low, we must *increase* the ice roughness. This will result in a slower and deeper computed flow.

13. Click on the in the main interface to open the 'Geometric Data' window.
14. Go to Tables and select '*Ice Cover …*'
15. Edit the ice roughness values so that they are a higher value. You will then <u>iteratively</u> change the ice roughness, run the model, view the results, until the computed water surface matches the observed water surface reasonably well. The general steps are:
    - In the 'Geometric Data' window, go to Tables and select '*Ice Cover …*' Edit the ice roughnesses in the table. At all cross-sections, give the LOB, Channel, and ROB the same roughness.
    - Save the Geometric Data: Go to File and click '*Save Geometry Data*'.
    - In the main interface click to open the 'Steady Flow Analysis' window, click '*compute'.*
    - View a 'Profile Plot' of the results by clicking in the main interface. Or click Reload Data if the 'Profile Plot' window is already open. Compare model results to observations. If adjustments are needed, go back to step a) and change the roughnesses.
    - Repeat until a good agreement between the computer water surface and the observed water surface elevation points is achieved.
16. Some general guidelines for roughness calibrations are:
    - Start with a single roughness value for the entire reach that matches the most downstream observed water surfaces
    - Once the downstream observed water surfaces are matched well, change the roughnessess at cross-sections further upstream to match the more upstream observed water surface values.
    - Don't change the roughness values every cross-section, nearby cross-sections likely have similar channel roughness values. One to three unique values for a reach this size is reasonable.
    - Remember, you are matching the water surface elevation, not the top of the ice surface.
    - Expected ice roughness values for this site are between 0.040 and 0.050. This is on the high side for intact ice, but the observed data indicates significant slush ice (Figure 1), which may contribute to energy loss in the reach, and therefore higher apparent roughness values.

An example of results from a calibrated model are shown below:

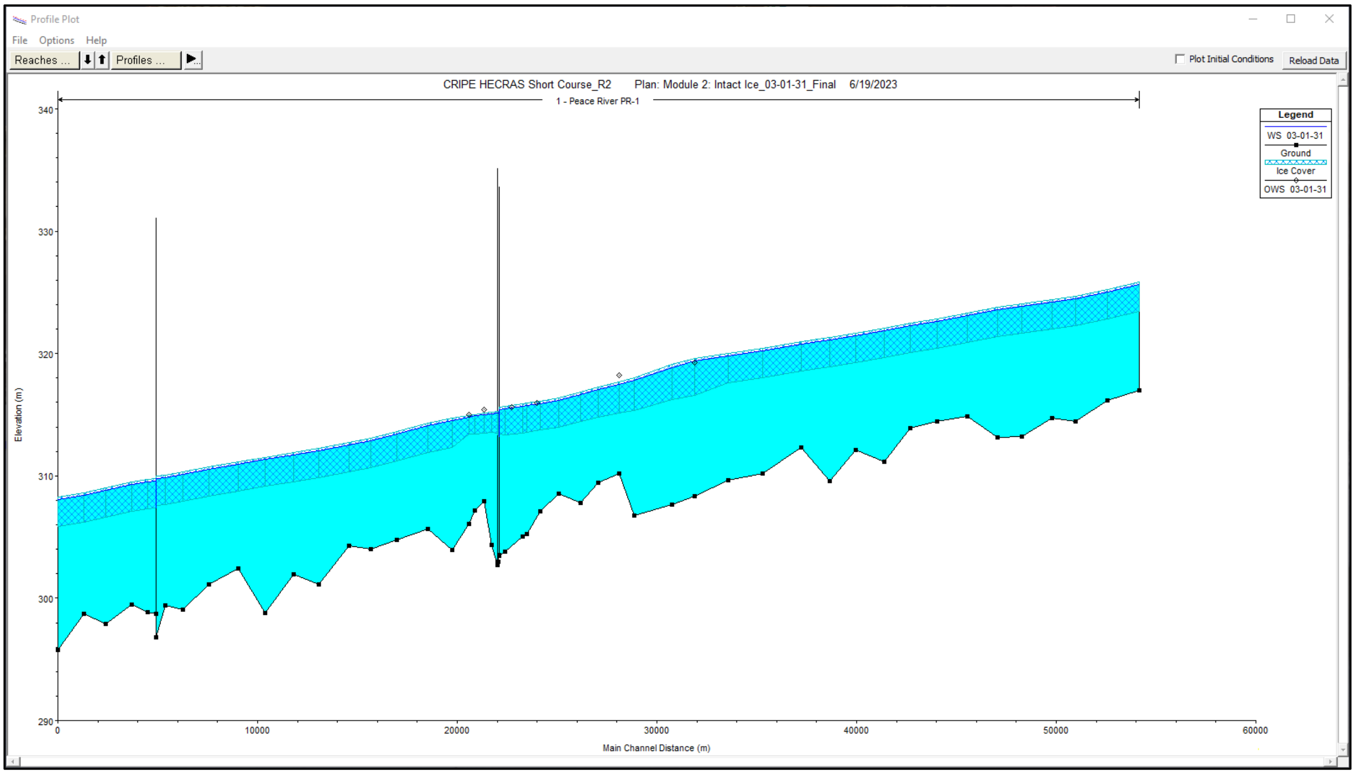
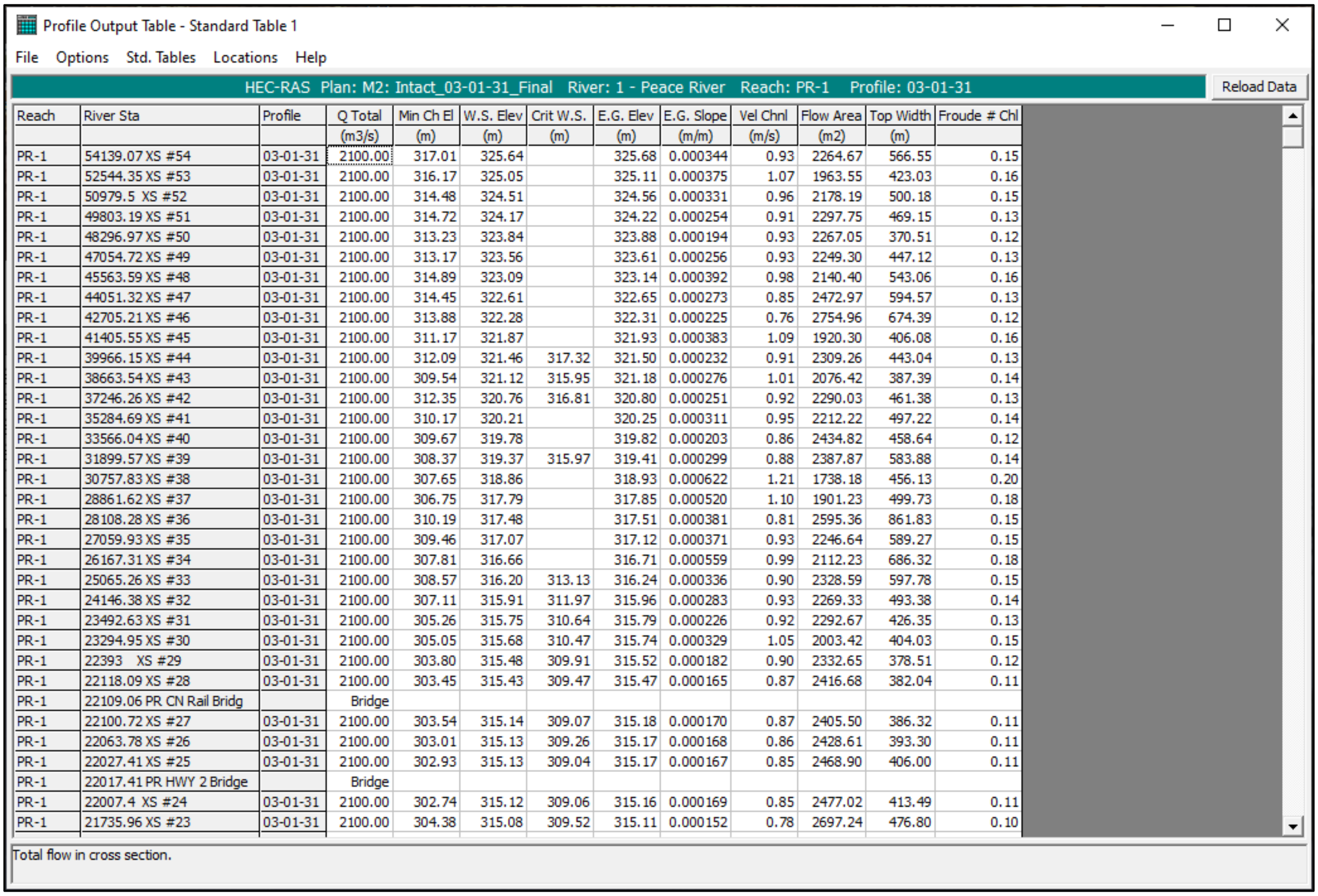


Figure 2: Model results for the January 31, 2003 intact ice cover on the Peace River, showing good calibration results

17. Once you are happy with your calibration, we will review the composite roughness that HEC-RAS is using in the ice jam stability equation. You can do this in the summary output tables. Click on the ▦ in the main interface.

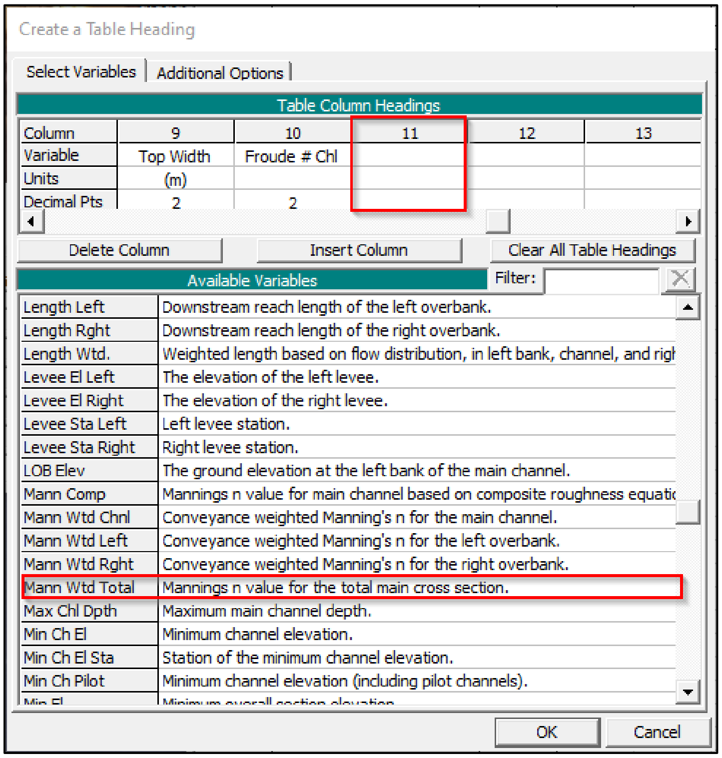


HEC-RAS Plan: M2: Intact_03-01-31_Final River: 1 - Peace River Reach: PR-1 Profile: 03-01-31

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
PR-1	54139.07 XS #54	03-01-31	2100.00	317.01	325.64		325.68	0.000344	0.93	2264.67	566.55	0.15
PR-1	52544.35 XS #53	03-01-31	2100.00	316.17	325.05		325.11	0.000375	1.07	1963.55	423.03	0.16
PR-1	50979.5 XS #52	03-01-31	2100.00	314.48	324.51		324.56	0.000331	0.96	2178.19	500.18	0.15
PR-1	49803.19 XS #51	03-01-31	2100.00	314.72	324.17		324.22	0.000254	0.91	2297.75	469.15	0.13
PR-1	48296.97 XS #50	03-01-31	2100.00	313.23	323.84		323.88	0.000194	0.93	2267.05	370.51	0.12
PR-1	47054.72 XS #49	03-01-31	2100.00	313.17	323.56		323.61	0.000256	0.93	2249.30	447.12	0.13
PR-1	45563.59 XS #48	03-01-31	2100.00	314.89	323.09		323.14	0.000392	0.98	2140.40	543.06	0.16
PR-1	44051.32 XS #47	03-01-31	2100.00	314.45	322.61		322.65	0.000273	0.85	2472.97	594.57	0.13
PR-1	42705.21 XS #46	03-01-31	2100.00	313.88	322.28		322.31	0.000225	0.76	2754.96	674.39	0.12
PR-1	41405.55 XS #45	03-01-31	2100.00	311.17	321.87		321.93	0.000383	1.09	1920.30	406.08	0.16
PR-1	39966.15 XS #44	03-01-31	2100.00	312.09	321.46	317.32	321.50	0.000232	0.91	2309.26	443.04	0.13
PR-1	38663.54 XS #43	03-01-31	2100.00	309.54	321.12	315.95	321.18	0.000276	1.01	2076.42	387.39	0.14
PR-1	37246.26 XS #42	03-01-31	2100.00	312.35	320.76	316.81	320.80	0.000251	0.92	2290.03	461.38	0.13
PR-1	35284.69 XS #41	03-01-31	2100.00	310.17	320.21		320.25	0.000311	0.95	2212.22	497.22	0.14
PR-1	33566.04 XS #40	03-01-31	2100.00	309.67	319.78		319.82	0.000203	0.86	2434.82	458.64	0.12
PR-1	31899.57 XS #39	03-01-31	2100.00	308.37	319.37	315.97	319.41	0.000299	0.88	2387.87	583.88	0.14
PR-1	30757.83 XS #38	03-01-31	2100.00	307.65	318.86		318.93	0.000622	1.21	1738.18	456.13	0.20
PR-1	28861.62 XS #37	03-01-31	2100.00	306.75	317.79		317.85	0.000520	1.10	1901.23	499.73	0.18
PR-1	28108.28 XS #36	03-01-31	2100.00	310.19	317.48		317.51	0.000381	0.81	2595.36	861.83	0.15
PR-1	27059.93 XS #35	03-01-31	2100.00	309.46	317.07		317.12	0.000371	0.93	2246.64	589.27	0.15
PR-1	26167.31 XS #34	03-01-31	2100.00	307.81	316.66		316.71	0.000559	0.99	2112.23	686.32	0.18
PR-1	25065.26 XS #33	03-01-31	2100.00	308.57	316.20	313.13	316.24	0.000336	0.90	2328.59	597.78	0.15
PR-1	24146.38 XS #32	03-01-31	2100.00	307.11	315.91	311.97	315.96	0.000283	0.93	2269.33	493.38	0.14
PR-1	23492.63 XS #31	03-01-31	2100.00	305.26	315.75	310.64	315.79	0.000226	0.92	2292.67	426.35	0.13
PR-1	23294.95 XS #30	03-01-31	2100.00	305.05	315.68	310.47	315.74	0.000329	1.05	2003.42	404.03	0.15
PR-1	22393 XS #29	03-01-31	2100.00	303.80	315.48	309.91	315.52	0.000182	0.90	2332.65	378.51	0.12
PR-1	22118.09 XS #28	03-01-31	2100.00	303.45	315.43	309.47	315.47	0.000165	0.87	2416.68	382.04	0.11
PR-1	22109.06 PR CN Rail Bridg		Bridge									
PR-1	22100.72 XS #27	03-01-31	2100.00	303.54	315.14	309.07	315.18	0.000170	0.87	2405.50	386.32	0.11
PR-1	22063.78 XS #26	03-01-31	2100.00	303.01	315.13	309.26	315.17	0.000168	0.86	2428.61	393.30	0.11
PR-1	22027.41 XS #25	03-01-31	2100.00	302.93	315.13	309.04	315.17	0.000167	0.85	2468.90	406.00	0.11
PR-1	22017.41 PR HWY 2 Bridge		Bridge									
PR-1	22007.4 XS #24	03-01-31	2100.00	302.74	315.12	309.06	315.16	0.000169	0.85	2477.02	413.49	0.11
PR-1	21735.96 XS #23	03-01-31	2100.00	304.38	315.08	309.52	315.11	0.000152	0.78	2697.24	476.80	0.10

Total flow in cross section.

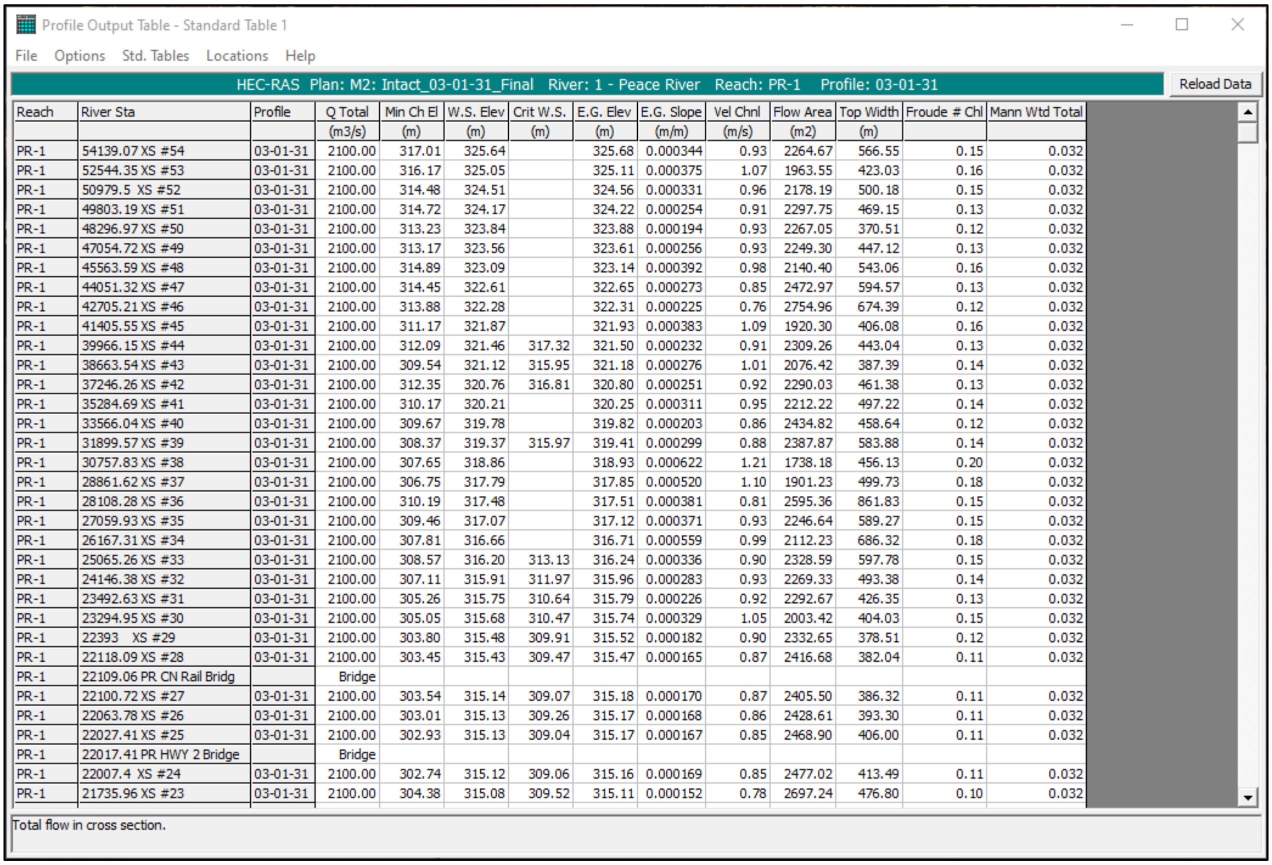
18. Add the variable '*Mann Wtd Total – Mannings n value for the total main cross section*' to the table to view the composite roughness used by HEC-RAS. Choose Options and select '*Define Table …*'. Choose an empty column in the '*Table Column Headings Box*' and double click on Mann Wtd Total and click OK.



Column	9	10	11	12	13
Variable	Top Width	Froude # Chl			
Units	(m)				
Decimal Pts	2	2			

Length Left	Downstream reach length of the left overbank.
Length Rght	Downstream reach length of the right overbank.
Length Wtd.	Weighted length based on flow distribution, in left bank, channel, and rigl
Levee El Left	The elevation of the left levee.
Levee El Right	The elevation of the right levee.
Levee Sta Left	Left levee station.
Levee Sta Right	Right levee station.
LOB Elev	The ground elevation at the left bank of the main channel.
Mann Comp	Mannings n value for main channel based on composite roughness equati
Mann Wtd Chnl	Conveyance weighted Manning's n for the main channel.
Mann Wtd Left	Conveyance weighted Manning's n for the left overbank.
Mann Wtd Rght	Conveyance weighted Manning's n for the right overbank.
Mann Wtd Total	Mannings n value for the total main cross section.
Max Chl Dpth	Maximum main channel depth.
Min Ch El	Minimum channel elevation.
Min Ch El Sta	Station of the minimum channel elevation.
Min Ch Pilot	Minimum channel elevation (including pilot channels).

The table will now look like this:

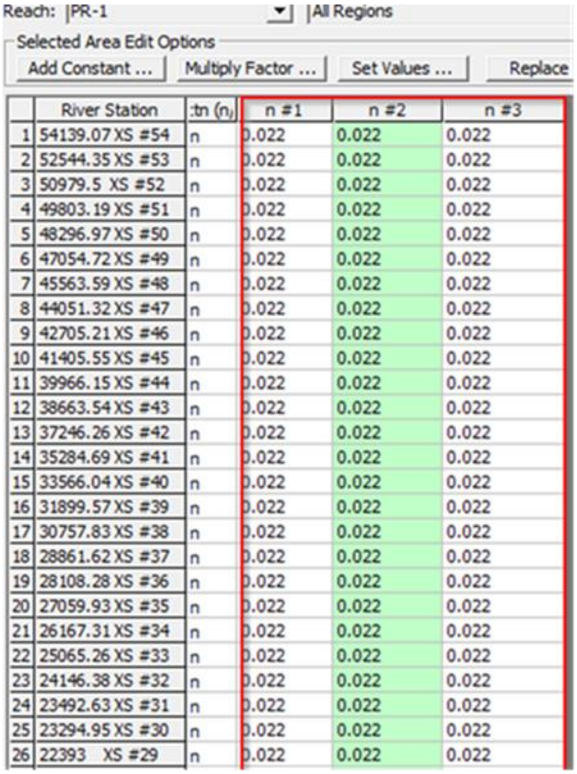


HEC-RAS Plan: M2: Intact_03-01-31_Final River: 1 - Peace River Reach: PR-1 Profile: 03-01-31

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Mann Wtd Total
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)		
PR-1	54139.07 XS #54	03-01-31	2100.00	317.01	325.64		325.68	0.000344	0.93	2264.67	566.55	0.15	0.032
PR-1	52544.35 XS #53	03-01-31	2100.00	316.17	325.05		325.11	0.000375	1.07	1963.55	423.03	0.16	0.032
PR-1	50979.5 XS #52	03-01-31	2100.00	314.48	324.51		324.56	0.000331	0.96	2178.19	500.18	0.15	0.032
PR-1	49803.19 XS #51	03-01-31	2100.00	314.72	324.17		324.22	0.000254	0.91	2297.75	469.15	0.13	0.032
PR-1	48296.97 XS #50	03-01-31	2100.00	313.23	323.84		323.88	0.000194	0.93	2267.05	370.51	0.12	0.032
PR-1	47054.72 XS #49	03-01-31	2100.00	313.17	323.56		323.61	0.000256	0.93	2249.30	447.12	0.13	0.032
PR-1	45563.59 XS #48	03-01-31	2100.00	314.89	323.09		323.14	0.000392	0.98	2140.40	543.06	0.16	0.032
PR-1	44051.32 XS #47	03-01-31	2100.00	314.45	322.61		322.65	0.000273	0.85	2472.97	594.57	0.13	0.032
PR-1	42705.21 XS #46	03-01-31	2100.00	313.88	322.28		322.31	0.000225	0.76	2754.96	674.39	0.12	0.032
PR-1	41405.55 XS #45	03-01-31	2100.00	311.17	321.87		321.93	0.000383	1.09	1920.30	406.08	0.16	0.032
PR-1	39966.15 XS #44	03-01-31	2100.00	312.09	321.46	317.32	321.50	0.000232	0.91	2309.26	443.04	0.13	0.032
PR-1	38663.54 XS #43	03-01-31	2100.00	309.54	321.12	315.95	321.18	0.000276	1.01	2076.42	387.39	0.14	0.032
PR-1	37246.26 XS #42	03-01-31	2100.00	312.35	320.76	316.81	320.80	0.000251	0.92	2290.03	461.38	0.13	0.032
PR-1	35284.69 XS #41	03-01-31	2100.00	310.17	320.21		320.25	0.000311	0.95	2212.22	497.22	0.14	0.032
PR-1	33566.04 XS #40	03-01-31	2100.00	309.67	319.78		319.82	0.000203	0.86	2434.82	458.64	0.12	0.032
PR-1	31899.57 XS #39	03-01-31	2100.00	308.37	319.37	315.97	319.41	0.000299	0.88	2387.87	583.88	0.14	0.032
PR-1	30757.83 XS #38	03-01-31	2100.00	307.65	318.86		318.93	0.000622	1.21	1738.18	456.13	0.20	0.032
PR-1	28861.62 XS #37	03-01-31	2100.00	306.75	317.79		317.85	0.000520	1.10	1901.23	499.73	0.18	0.032
PR-1	28108.28 XS #36	03-01-31	2100.00	310.19	317.48		317.51	0.000381	0.81	2595.36	861.83	0.15	0.032
PR-1	27059.93 XS #35	03-01-31	2100.00	309.46	317.07		317.12	0.000371	0.93	2246.64	589.27	0.15	0.032
PR-1	26167.31 XS #34	03-01-31	2100.00	307.81	316.66		316.71	0.000559	0.99	2112.23	686.32	0.18	0.032
PR-1	25065.26 XS #33	03-01-31	2100.00	308.57	316.20	313.13	316.24	0.000336	0.90	2328.59	597.78	0.15	0.032
PR-1	24146.38 XS #32	03-01-31	2100.00	307.11	315.91	311.97	315.96	0.000283	0.93	2269.33	493.38	0.14	0.032
PR-1	23492.63 XS #31	03-01-31	2100.00	305.26	315.75	310.64	315.79	0.000226	0.92	2292.67	426.35	0.13	0.032
PR-1	23294.95 XS #30	03-01-31	2100.00	305.05	315.68	310.47	315.74	0.000329	1.05	2003.42	404.03	0.15	0.032
PR-1	22393 XS #29	03-01-31	2100.00	303.80	315.48	309.91	315.52	0.000182	0.90	2332.65	378.51	0.12	0.032
PR-1	22118.09 XS #28	03-01-31	2100.00	303.45	315.43	309.47	315.47	0.000165	0.87	2416.68	382.04	0.11	0.032
PR-1	22109.06 PR CN Rail Bridg		Bridge										
PR-1	22100.72 XS #27	03-01-31	2100.00	303.54	315.14	309.07	315.18	0.000170	0.87	2405.50	386.32	0.11	0.032
PR-1	22063.78 XS #26	03-01-31	2100.00	303.01	315.13	309.26	315.17	0.000168	0.86	2428.61	393.30	0.11	0.032
PR-1	22027.41 XS #25	03-01-31	2100.00	302.93	315.13	309.04	315.17	0.000167	0.85	2468.90	406.00	0.11	0.032
PR-1	22017.41 PR HWY 2 Bridge		Bridge										
PR-1	22007.4 XS #24	03-01-31	2100.00	302.74	315.12	309.06	315.16	0.000169	0.85	2477.02	413.49	0.11	0.032
PR-1	21735.96 XS #23	03-01-31	2100.00	304.38	315.08	309.52	315.11	0.000152	0.78	2697.24	476.80	0.10	0.032

Total flow in cross section.

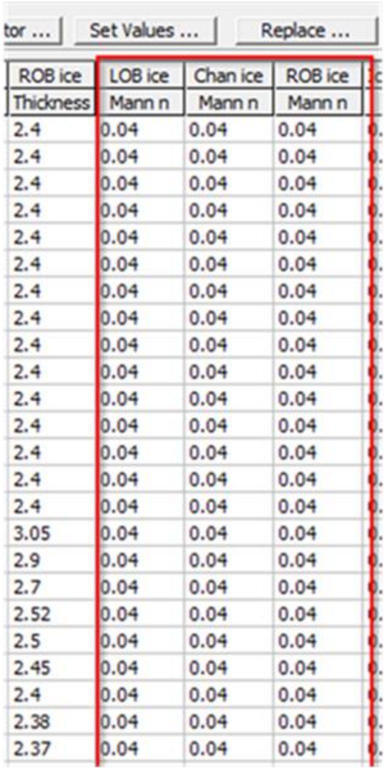
19. Compare the 'Mann Wtd Total' to the ice roughness values you entered in the geometry file in this Task. Keep the 'Profile Output table' open, and open the 'Geometric Data' window by clicking the ⩘ in the main interface. Choose Tables and select '*Ice Cover …*' Or choose Tables and select '*Manning's n or k values (Horizontally varied) …*'



	River Station	:tn (n/	n #1	n #2	n #3
1	54139.07 XS #54	n	0.022	0.022	0.022
2	52544.35 XS #53	n	0.022	0.022	0.022
3	50979.5 XS #52	n	0.022	0.022	0.022
4	49803.19 XS #51	n	0.022	0.022	0.022
5	48296.97 XS #50	n	0.022	0.022	0.022
6	47054.72 XS #49	n	0.022	0.022	0.022
7	45563.59 XS #48	n	0.022	0.022	0.022
8	44051.32 XS #47	n	0.022	0.022	0.022
9	42705.21 XS #46	n	0.022	0.022	0.022
10	41405.55 XS #45	n	0.022	0.022	0.022
11	39966.15 XS #44	n	0.022	0.022	0.022
12	38663.54 XS #43	n	0.022	0.022	0.022
13	37246.26 XS #42	n	0.022	0.022	0.022
14	35284.69 XS #41	n	0.022	0.022	0.022
15	33566.04 XS #40	n	0.022	0.022	0.022
16	31899.57 XS #39	n	0.022	0.022	0.022
17	30757.83 XS #38	n	0.022	0.022	0.022
18	28861.62 XS #37	n	0.022	0.022	0.022
19	28108.28 XS #36	n	0.022	0.022	0.022
20	27059.93 XS #35	n	0.022	0.022	0.022
21	26167.31 XS #34	n	0.022	0.022	0.022
22	25065.26 XS #33	n	0.022	0.022	0.022
23	24146.38 XS #32	n	0.022	0.022	0.022
24	23492.63 XS #31	n	0.022	0.022	0.022
25	23294.95 XS #30	n	0.022	0.022	0.022
26	22393 XS #29	n	0.022	0.022	0.022

Bed Roughness

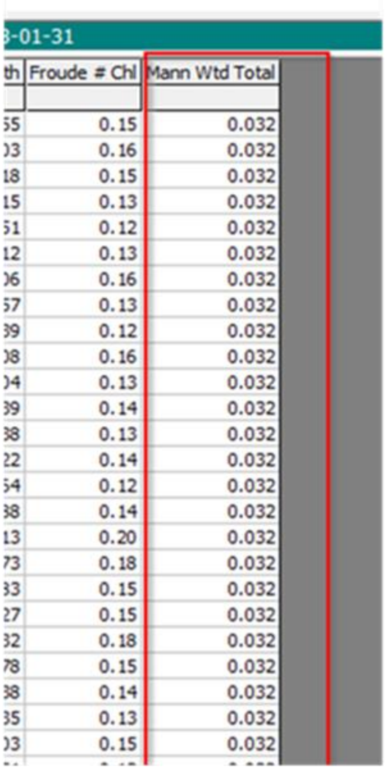
(Geometry Data Table: "Manning's n or k values")



ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ic
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
3.05	0.04	0.04	0.04	0.
2.9	0.04	0.04	0.04	0.
2.7	0.04	0.04	0.04	0.
2.52	0.04	0.04	0.04	0.
2.5	0.04	0.04	0.04	0.
2.45	0.04	0.04	0.04	0.
2.4	0.04	0.04	0.04	0.
2.38	0.04	0.04	0.04	0.
2.37	0.04	0.04	0.04	0.

Ice Cover Roughness

(Geometry Data Table: "Ice Cover")



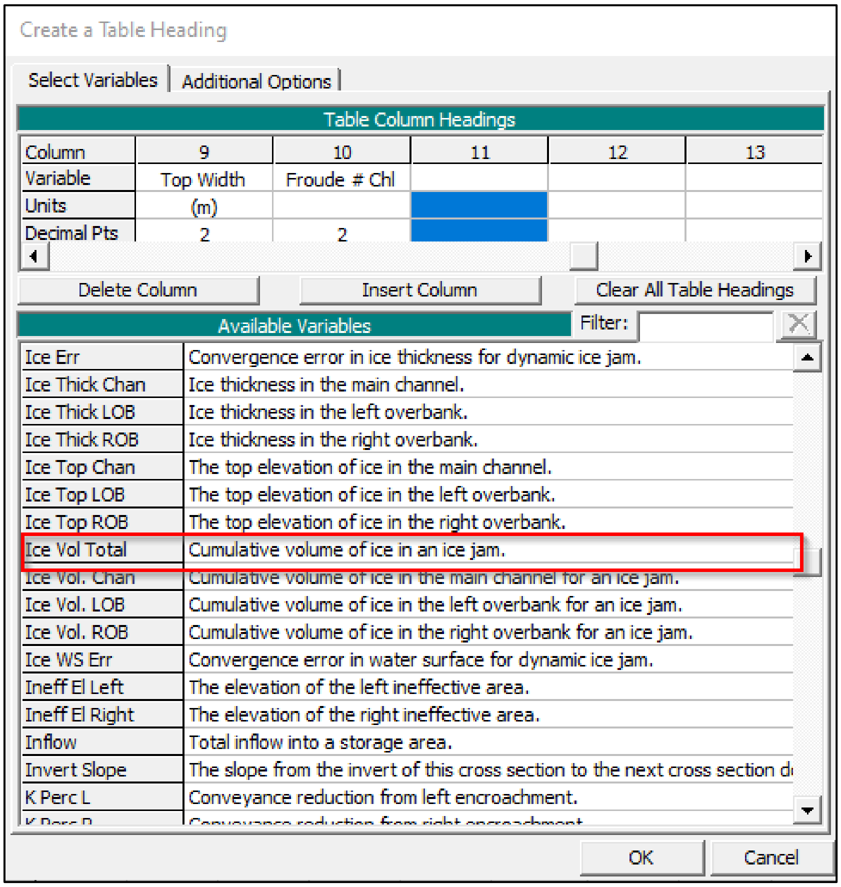
th	Froude # Chl	Mann Wtd Total
55	0.15	0.032
3	0.16	0.032
18	0.15	0.032
15	0.13	0.032
51	0.12	0.032
12	0.13	0.032
6	0.16	0.032
57	0.13	0.032
39	0.12	0.032
8	0.16	0.032
4	0.13	0.032
39	0.14	0.032
38	0.13	0.032
22	0.14	0.032
54	0.12	0.032
38	0.14	0.032
13	0.20	0.032
73	0.18	0.032
33	0.15	0.032
27	0.15	0.032
32	0.18	0.032
78	0.15	0.032
38	0.14	0.032
35	0.13	0.032
3	0.15	0.032

Composite Roughness

(Profile Output Table)

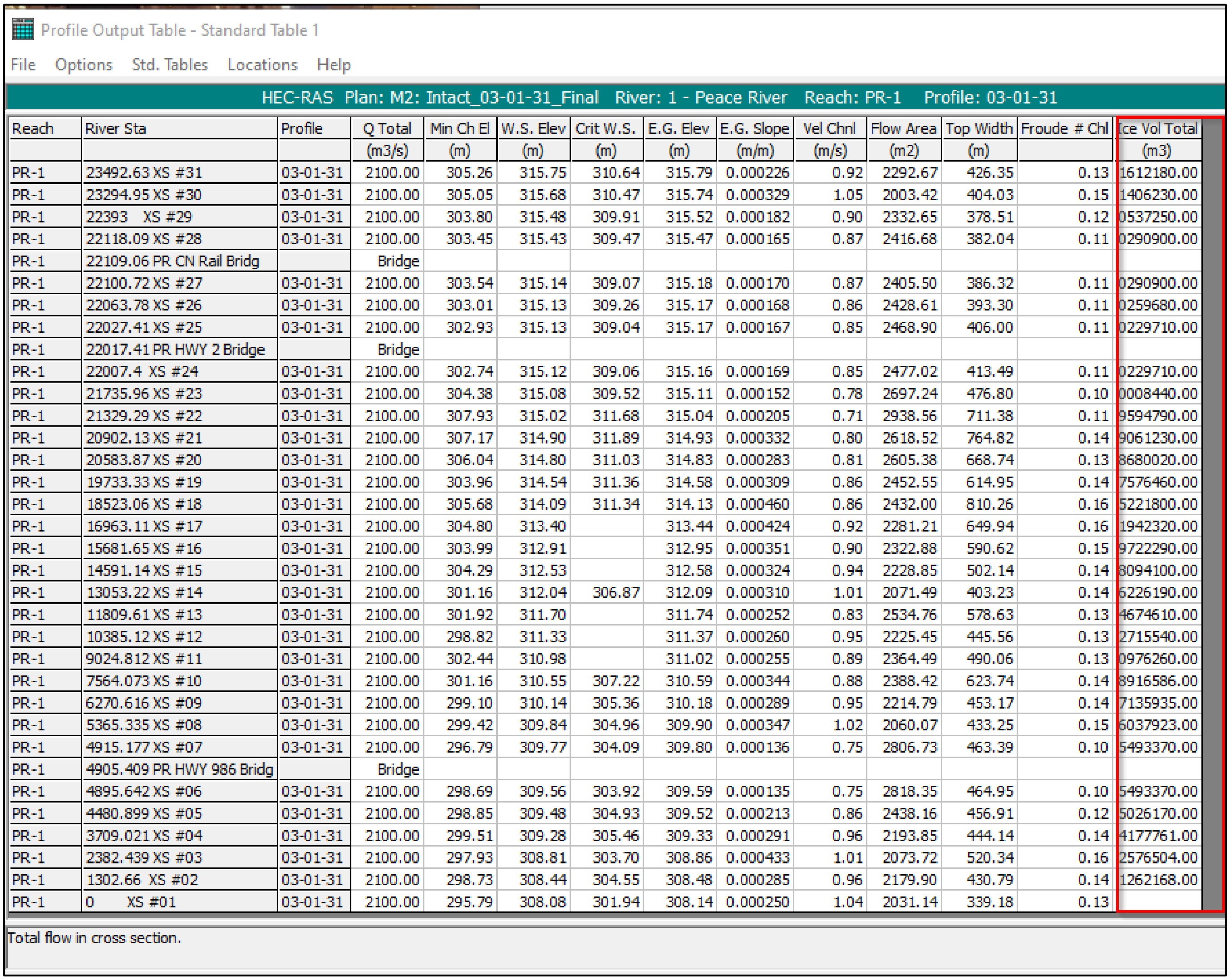
Notice that the composite roughness values are intermediate to the bed and ice roughness values.

20. You can also view the volume of ice in the model domain. Choose the 'Profile Output Table' ▦ from the main interface. Choose Options and select '*Define Table …*' Add a new variable after the last column by double clicking on '*Ice Vol Total: Cumulative volume of ice in an ice jam*'. Click OK.



Column	9	10	11	12	13
Variable	Top Width	Froude # Chl			
Units	(m)				
Decimal Pts	2	2			

Ice Err	Convergence error in ice thickness for dynamic ice jam.
Ice Thick Chan	Ice thickness in the main channel.
Ice Thick LOB	Ice thickness in the left overbank.
Ice Thick ROB	Ice thickness in the right overbank.
Ice Top Chan	The top elevation of ice in the main channel.
Ice Top LOB	The top elevation of ice in the left overbank.
Ice Top ROB	The top elevation of ice in the right overbank.
Ice Vol Total	Cumulative volume of ice in an ice jam.
Ice Vol. Chan	Cumulative volume of ice in the main channel for an ice jam.
Ice Vol. LOB	Cumulative volume of ice in the left overbank for an ice jam.
Ice Vol. ROB	Cumulative volume of ice in the right overbank for an ice jam.
Ice WS Err	Convergence error in water surface for dynamic ice jam.
Ineff El Left	The elevation of the left ineffective area.
Ineff El Right	The elevation of the right ineffective area.
Inflow	Total inflow into a storage area.
Invert Slope	The slope from the invert of this cross section to the next cross section d
K Perc L	Conveyance reduction from left encroachment.
K Perc R	Conveyance reduction from right encroachment.



HEC-RAS Plan: M2: Intact_03-01-31_Final River: 1 - Peace River Reach: PR-1 Profile: 03-01-31

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Ice Vol Total
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)		(m3)
PR-1	23492.63 XS #31	03-01-31	2100.00	305.26	315.75	310.64	315.79	0.000226	0.92	2292.67	426.35	0.13	1612180.00
PR-1	23294.95 XS #30	03-01-31	2100.00	305.05	315.68	310.47	315.74	0.000329	1.05	2003.42	404.03	0.15	1406230.00
PR-1	22393 XS #29	03-01-31	2100.00	303.80	315.48	309.91	315.52	0.000182	0.90	2332.65	378.51	0.12	0537250.00
PR-1	22118.09 XS #28	03-01-31	2100.00	303.45	315.43	309.47	315.47	0.000165	0.87	2416.68	382.04	0.11	0290900.00
PR-1	22109.06 PR CN Rail Bridg		Bridge										
PR-1	22100.72 XS #27	03-01-31	2100.00	303.54	315.14	309.07	315.18	0.000170	0.87	2405.50	386.32	0.11	0290900.00
PR-1	22063.78 XS #26	03-01-31	2100.00	303.01	315.13	309.26	315.17	0.000168	0.86	2428.61	393.30	0.11	0259680.00
PR-1	22027.41 XS #25	03-01-31	2100.00	302.93	315.13	309.04	315.17	0.000167	0.85	2468.90	406.00	0.11	0229710.00
PR-1	22017.41 PR HWY 2 Bridge		Bridge										
PR-1	22007.4 XS #24	03-01-31	2100.00	302.74	315.12	309.06	315.16	0.000169	0.85	2477.02	413.49	0.11	0229710.00
PR-1	21735.96 XS #23	03-01-31	2100.00	304.38	315.08	309.52	315.11	0.000152	0.78	2697.24	476.80	0.10	0008440.00
PR-1	21329.29 XS #22	03-01-31	2100.00	307.93	315.02	311.68	315.04	0.000205	0.71	2938.56	711.38	0.11	9594790.00
PR-1	20902.13 XS #21	03-01-31	2100.00	307.17	314.90	311.89	314.93	0.000332	0.80	2618.52	764.82	0.14	9061230.00
PR-1	20583.87 XS #20	03-01-31	2100.00	306.04	314.80	311.03	314.83	0.000283	0.81	2605.38	668.74	0.13	8680020.00
PR-1	19733.33 XS #19	03-01-31	2100.00	303.96	314.54	311.36	314.58	0.000309	0.86	2452.55	614.95	0.14	7576460.00
PR-1	18523.06 XS #18	03-01-31	2100.00	305.68	314.09	311.34	314.13	0.000460	0.86	2432.00	810.26	0.16	5221800.00
PR-1	16963.11 XS #17	03-01-31	2100.00	304.80	313.40		313.44	0.000424	0.92	2281.21	649.94	0.16	1942320.00
PR-1	15681.65 XS #16	03-01-31	2100.00	303.99	312.91		312.95	0.000351	0.90	2322.88	590.62	0.15	9722290.00
PR-1	14591.14 XS #15	03-01-31	2100.00	304.29	312.53		312.58	0.000324	0.94	2228.85	502.14	0.14	8094100.00
PR-1	13053.22 XS #14	03-01-31	2100.00	301.16	312.04	306.87	312.09	0.000310	1.01	2071.49	403.23	0.14	6226190.00
PR-1	11809.61 XS #13	03-01-31	2100.00	301.92	311.70		311.74	0.000252	0.83	2534.76	578.63	0.13	4674610.00
PR-1	10385.12 XS #12	03-01-31	2100.00	298.82	311.33		311.37	0.000260	0.95	2225.45	445.56	0.13	2715540.00
PR-1	9024.812 XS #11	03-01-31	2100.00	302.44	310.98		311.02	0.000255	0.89	2364.49	490.06	0.13	0976260.00
PR-1	7564.073 XS #10	03-01-31	2100.00	301.16	310.55	307.22	310.59	0.000344	0.88	2388.42	623.74	0.14	8916586.00
PR-1	6270.616 XS #09	03-01-31	2100.00	299.10	310.14	305.36	310.18	0.000289	0.95	2214.79	453.17	0.14	7135935.00
PR-1	5365.335 XS #08	03-01-31	2100.00	299.42	309.84	304.96	309.90	0.000347	1.02	2060.07	433.25	0.15	6037923.00
PR-1	4915.177 XS #07	03-01-31	2100.00	296.79	309.77	304.09	309.80	0.000136	0.75	2806.73	463.39	0.10	5493370.00
PR-1	4905.409 PR HWY 986 Bridg		Bridge										
PR-1	4895.642 XS #06	03-01-31	2100.00	298.69	309.56	303.92	309.59	0.000135	0.75	2818.35	464.95	0.10	5493370.00
PR-1	4480.899 XS #05	03-01-31	2100.00	298.85	309.48	304.93	309.52	0.000213	0.86	2438.16	456.91	0.12	5026170.00
PR-1	3709.021 XS #04	03-01-31	2100.00	299.51	309.28	305.46	309.33	0.000291	0.96	2193.85	444.14	0.14	4177761.00
PR-1	2382.439 XS #03	03-01-31	2100.00	297.93	308.81	303.70	308.86	0.000433	1.01	2073.72	520.34	0.16	2576504.00
PR-1	1302.66 XS #02	03-01-31	2100.00	298.73	308.44	304.55	308.48	0.000285	0.96	2179.90	430.79	0.14	1262168.00
PR-1	0 XS #01	03-01-31	2100.00	295.79	308.08	301.94	308.14	0.000250	1.04	2031.14	339.18	0.13	

Total flow in cross section.

This is the volume of ice (or ice jam) in the model. It provides the ice volume (in m^3) in the reach downstream of each cross-section. This value is the volume of the ice cover, in order to obtain the volume of solid ice contained in an ice jam, the total volume must be multiplied by the solid fraction of the jam (1 - jam porosity). HEC-RAS will calculate the ice volume but it will not limit jam size based on volume.

21. Close all the open windows except the main interface.

Task 2C Instructions: OPTIONAL – Review A Complete Intact Ice Calibration from Another Date

1. If you are done, review another ice thickness and roughness calibration that has been completed for another date: January 20, 2004. Click to open the 'Steady Flow Analysis' window.
2. Choose File and select '*Open plan…*'. Choose "**Module 2: Intact Ice_04_01_20_Final**" and click OK.
3. Verify that the correct **Geometry** and **Steady Flow** files are chosen:

Table 6: Model Files Used for HEC-RAS Module 2 - Task 2C

File Type	Filename
Plan	"Module 2: Intact Ice_04_01_20_Final"
Geometry	"Module 2: Intact Ice_04_01_20_Final"
Steady Flow	"Module 2: Intact Ice_04_01_20_Final"

4. Run the model by clicking Compute and then Close.
5. Review the output profiles and geometry tables.

QUESTION: In what way is this ice cover different than the one in Task 2A?

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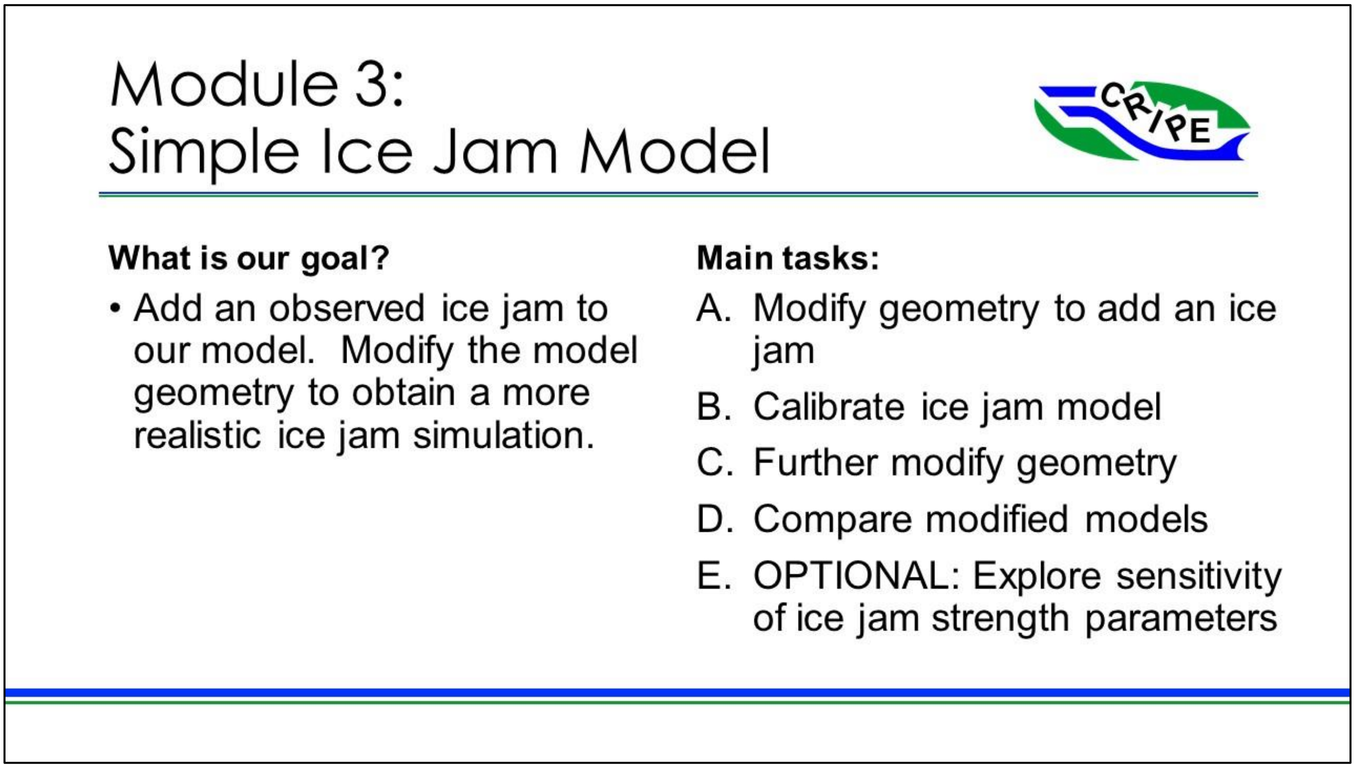
Module 3: Simple Ice Jam Model



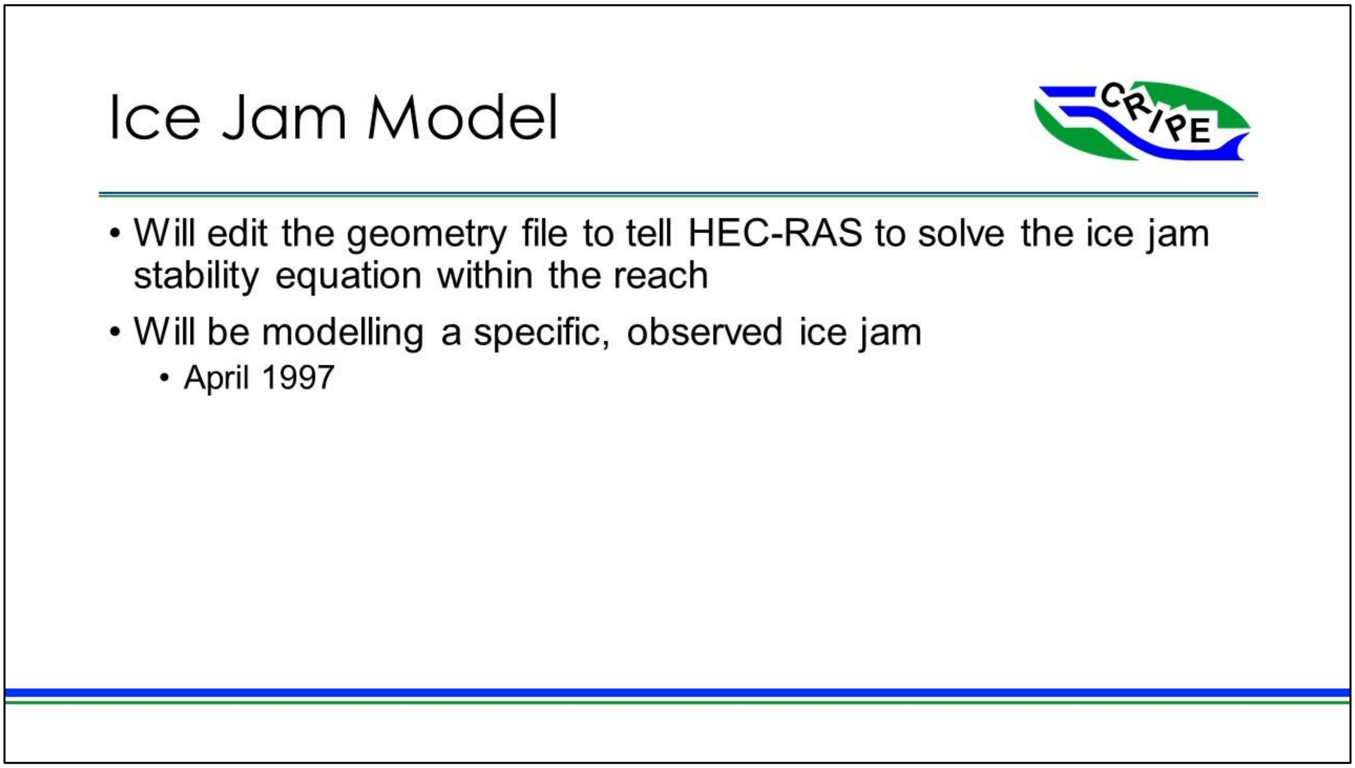
Module 3:
Simple Ice Jam Model

What is our goal?

- Add an observed ice jam to our model. Modify the model geometry to obtain a more realistic ice jam simulation.

Main tasks:

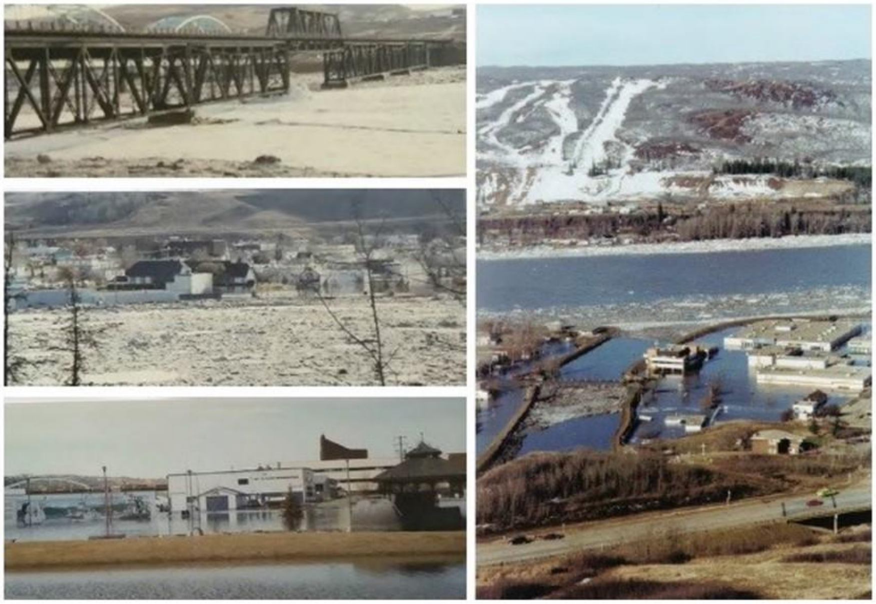
A. Modify geometry to add an ice jam
B. Calibrate ice jam model
C. Further modify geometry
D. Compare modified models
E. OPTIONAL: Explore sensitivity of ice jam strength parameters



Ice Jam Model

- Will edit the geometry file to tell HEC-RAS to solve the ice jam stability equation within the reach
- Will be modelling a specific, observed ice jam
    - April 1997

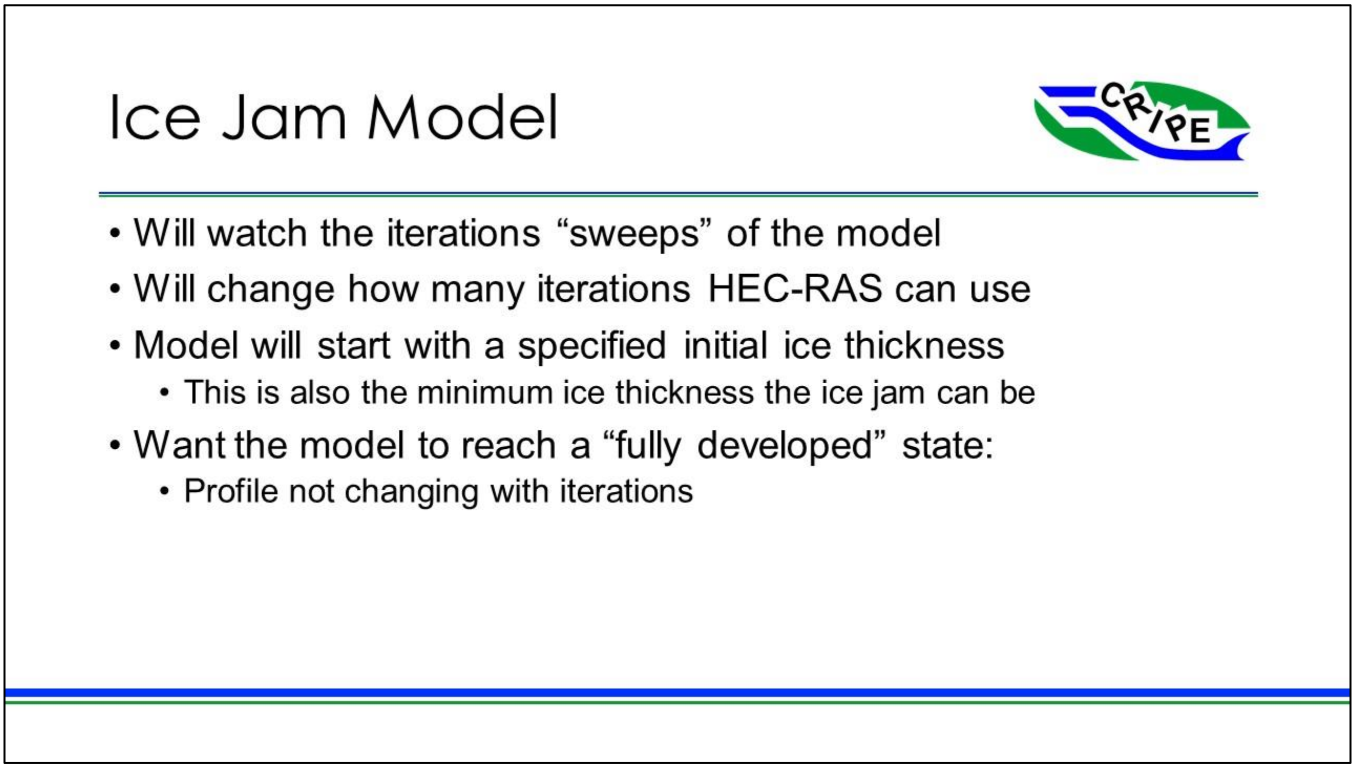
1997 Ice Jam



Peace River Hazard Study, NHC (2021)

1997 Ice Jam

- 4,000 residents were evacuated from the Town of Peace River
- 45 businesses flooded in downtown
- Damages over $20 million ($35 million in 2023)



Ice Jam Model

- Will watch the iterations "sweeps" of the model
- Will change how many iterations HEC-RAS can use
- Model will start with a specified initial ice thickness
  - This is also the minimum ice thickness the ice jam can be
- Want the model to reach a "fully developed" state:
  - Profile not changing with iterations

Task 3A Instructions: Modify the Geometry File to Include a Simple Ice Jam and Run the Simulation

1. Click to open the 'Steady Flow Analysis' window.
2. Go to File and select '*Open plan…*' Choose "**Module 3: Simple Ice Jam_Student**" and click OK.
3. Verify that the correct <u>Geometry</u> and <u>Steady Flow</u> files are chosen:

Table 7: Model Files Used for HEC-RAS Module 3 - Task 3A

File Type	Filename
Plan	"Module 3: Simple Ice Jam_Student"
Geometry	"Module 3: Simple Ice Jam_Student"
Steady Flow	"Module 3: Simple Ice Jam"

These files currently contain the following information:

<u>Geometry File:</u>

- The intact ice cover with the ice thickness observed on January 20, 2004 (from optional Task 2C). The ice roughnesses were calibrated to the water surface elevations observed on January 20,

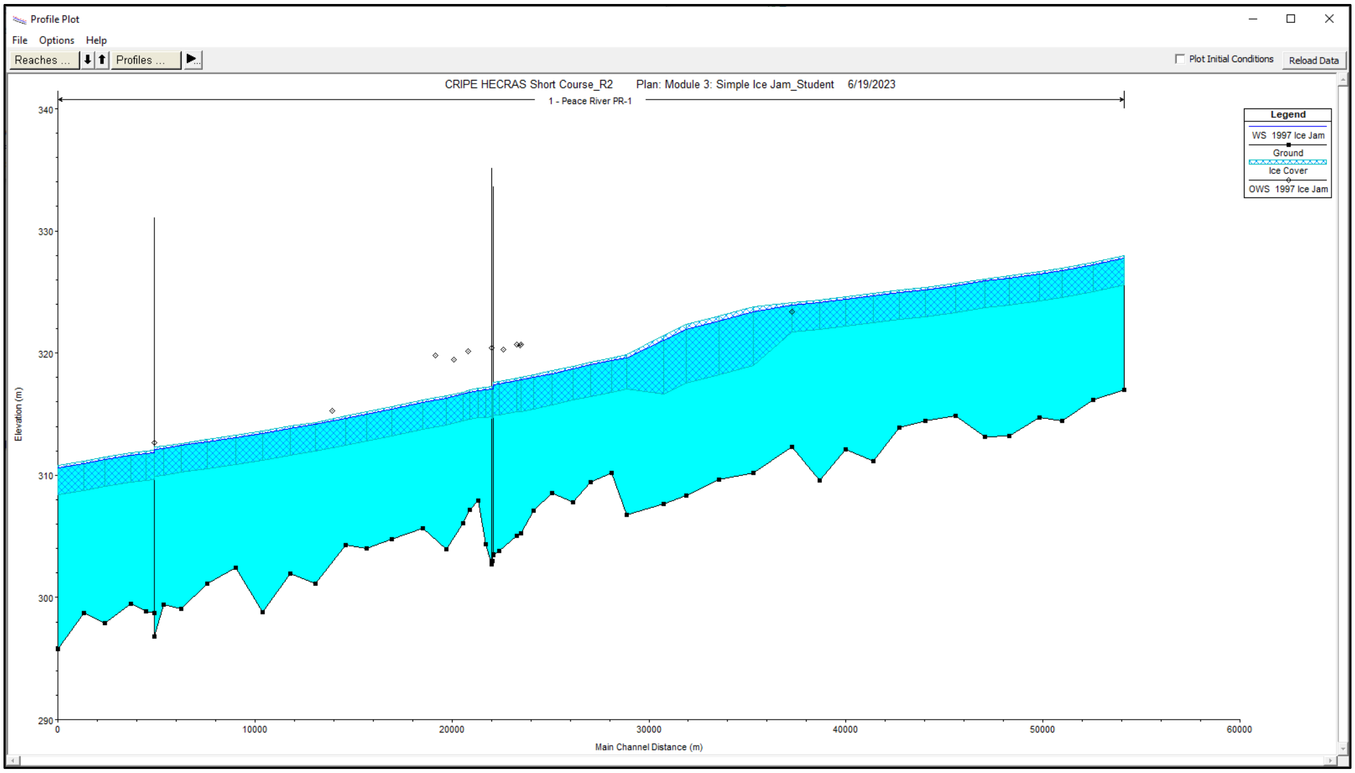
2004. The bed roughness are the bed roughnesses calibrated from the 1990 open water event (the same as used in all previous tasks).

<u>Steady Flow File:</u>

- The flow in the Peace River is the estimated peak flow that occurred during the 1997 breakup ice jam event (3,600 m^3/s).
- The observed water surface evaluations taken from high water marks observed after the 1997 breakup ice jam event.

4. Run the model by clicking [Compute] and then [Close].

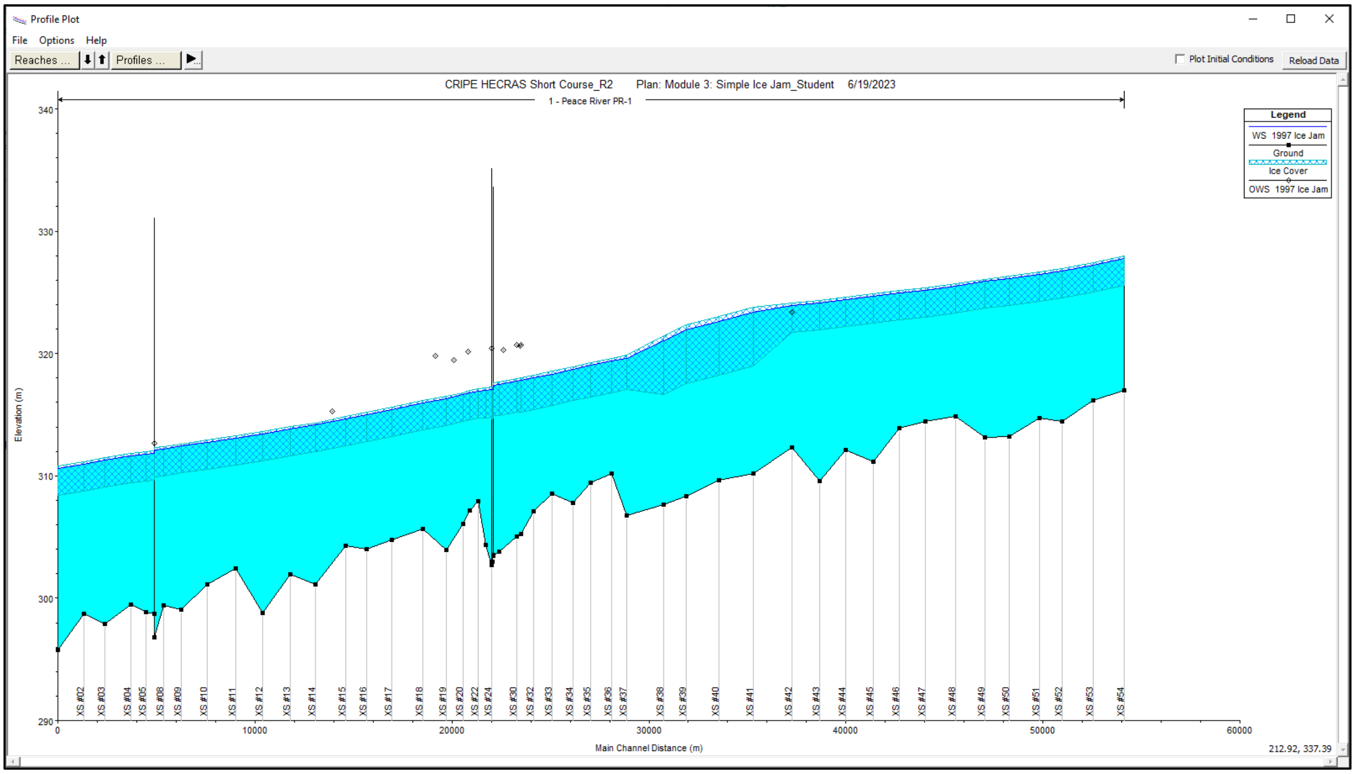
5. View a 'Profile Plot' of the results by clicking 📈 in the main interface.



Notice that the computed water surface elevation is well below the observed water surface points.

QUESTION: Why is the computed water surface elevation below the observed water surface points? (HINT: think about where the roughness and flow values have come from).

6. Turn on the cross-section landmarks in the profile plot by choosing Options. From the drop down menu, select '*Landmarks*', and then '*Node Name*'. Now the location of the cross-sections are visible in the profile view.



Notice that the computed water surface matches the two most downstream observed water surface elevations better than the ones further upstream.

QUESTION: Based on the observed water surface elevations, approximately where in the study reach was the toe of the ice jam located in 1997?

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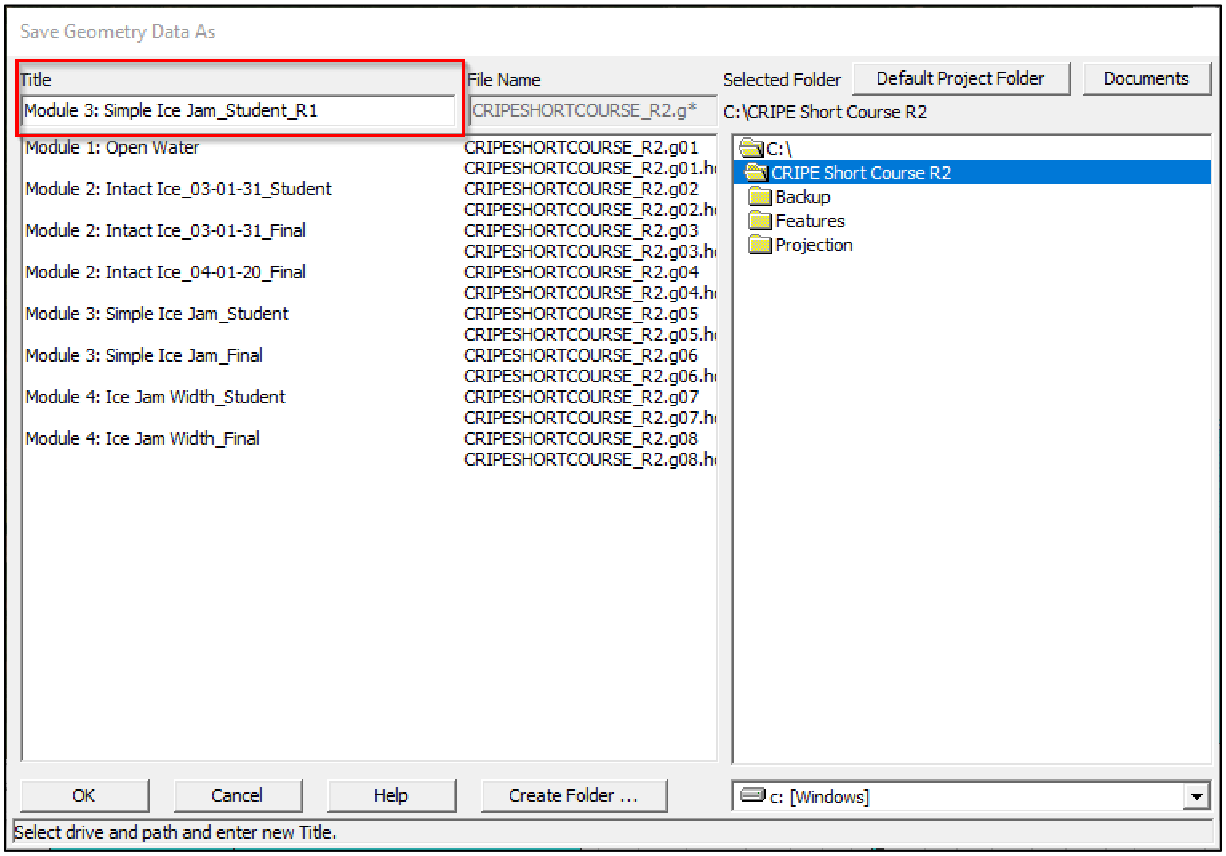
For this exercise, we will assume the ice jam toe was located at XS #16, which agrees with field observations from when the ice jam occurred. The River Station (RS) value for **XS #16 is 15,681.65 m** (this value will come in handy in this task).

7. We will save a new version of the geometry file, so that we can edit the geometry and compare results. Open the 'Geometric Data' window by clicking the in the main interface. Go to File and select '*Save Geometry File As …*'. Change the 'Title' of the file to "**Module 3: Simple Ice Jam_Student_R1**". Click OK.



Save Geometry Data As

Title: Module 3: Simple Ice Jam_Student_R1

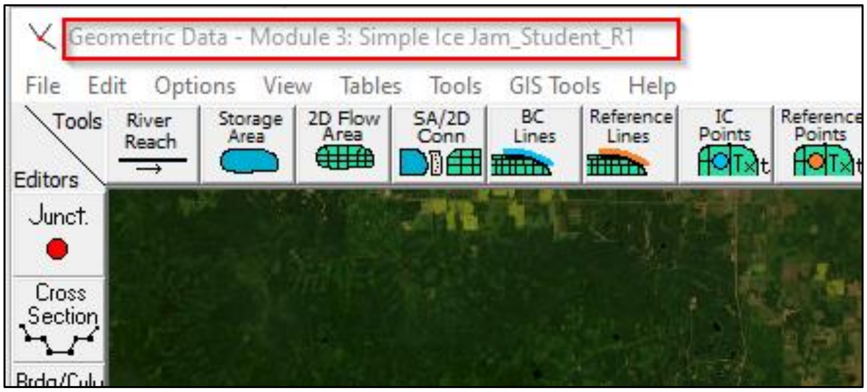
File Name: CRIPESHORTCOURSE_R2.g*

Selected Folder: C:\CRIPE Short Course R2

Title	File Name
Module 1: Open Water	CRIPESHORTCOURSE_R2.g01
	CRIPESHORTCOURSE_R2.g01.h
Module 2: Intact Ice_03-01-31_Student	CRIPESHORTCOURSE_R2.g02
	CRIPESHORTCOURSE_R2.g02.h
Module 2: Intact Ice_03-01-31_Final	CRIPESHORTCOURSE_R2.g03
	CRIPESHORTCOURSE_R2.g03.h
Module 2: Intact Ice_04-01-20_Final	CRIPESHORTCOURSE_R2.g04
	CRIPESHORTCOURSE_R2.g04.h
Module 3: Simple Ice Jam_Student	CRIPESHORTCOURSE_R2.g05
	CRIPESHORTCOURSE_R2.g05.h
Module 3: Simple Ice Jam_Final	CRIPESHORTCOURSE_R2.g06
	CRIPESHORTCOURSE_R2.g06.h
Module 4: Ice Jam Width_Student	CRIPESHORTCOURSE_R2.g07
	CRIPESHORTCOURSE_R2.g07.h
Module 4: Ice Jam Width_Final	CRIPESHORTCOURSE_R2.g08
	CRIPESHORTCOURSE_R2.g08.h

Select drive and path and enter new Title.

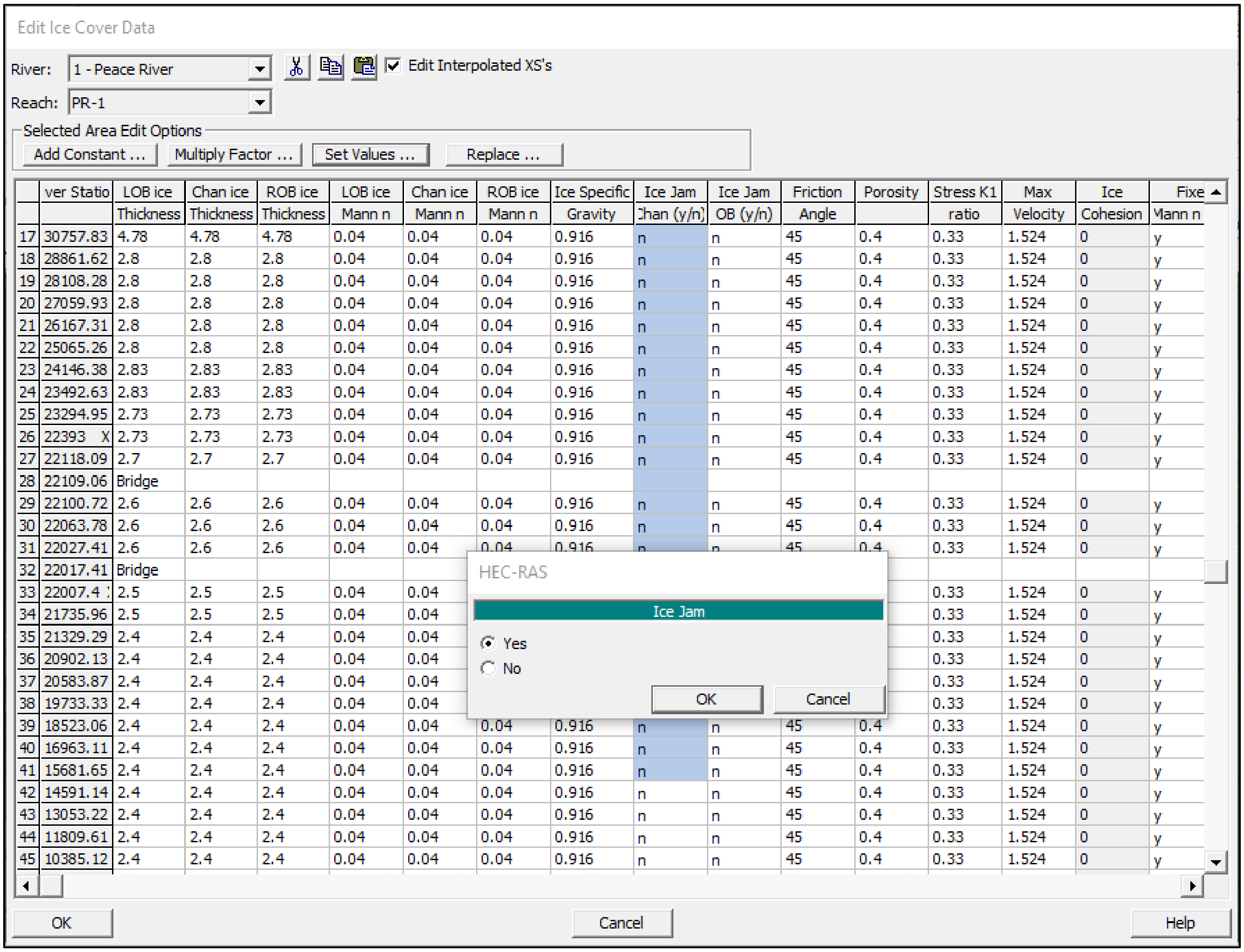
Notice that the file name that appears in the ‘Geometric Data’ window has changed to the new filename:



Geometric Data - Module 3: Simple Ice Jam_Student_R1

8. We will now change the intact ice cover to an ice jam. In the ‘Geometric Data’ window choose Tables and select ‘*Ice Cover …*’ to open the ‘Edit Ice Cover Data’ window.

9. Select the ‘*Ice Jam Chan (y/n)*’ from *XS #53 (second most upstream section)* up to and including *XS #16 (the toe of the ice jam)*. Then select Set Values ... . Set the value as ‘*Yes*’.



Edit Ice Cover Data

River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

	ver Statio	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam han (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity	Ice Cohesion	Fixe Mann n
17	30757.83	4.78	4.78	4.78	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
18	28861.62	2.8	2.8	2.8	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
19	28108.28	2.8	2.8	2.8	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
20	27059.93	2.8	2.8	2.8	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
21	26167.31	2.8	2.8	2.8	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
22	25065.26	2.8	2.8	2.8	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
23	24146.38	2.83	2.83	2.83	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
24	23492.63	2.83	2.83	2.83	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
25	23294.95	2.73	2.73	2.73	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
26	22393 X	2.73	2.73	2.73	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
27	22118.09	2.7	2.7	2.7	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
28	22109.06	Bridge														
29	22100.72	2.6	2.6	2.6	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
30	22063.78	2.6	2.6	2.6	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
31	22027.41	2.6	2.6	2.6	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
32	22017.41	Bridge														
33	22007.4	2.5	2.5	2.5	0.04	0.04							0.33	1.524	0	y
34	21735.96	2.5	2.5	2.5	0.04	0.04							0.33	1.524	0	y
35	21329.29	2.4	2.4	2.4	0.04	0.04							0.33	1.524	0	y
36	20902.13	2.4	2.4	2.4	0.04	0.04							0.33	1.524	0	y
37	20583.87	2.4	2.4	2.4	0.04	0.04							0.33	1.524	0	y
38	19733.33	2.4	2.4	2.4	0.04	0.04							0.33	1.524	0	y
39	18523.06	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
40	16963.11	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
41	15681.65	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
42	14591.14	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
43	13053.22	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
44	11809.61	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
45	10385.12	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y

HEC-RAS

Ice Jam

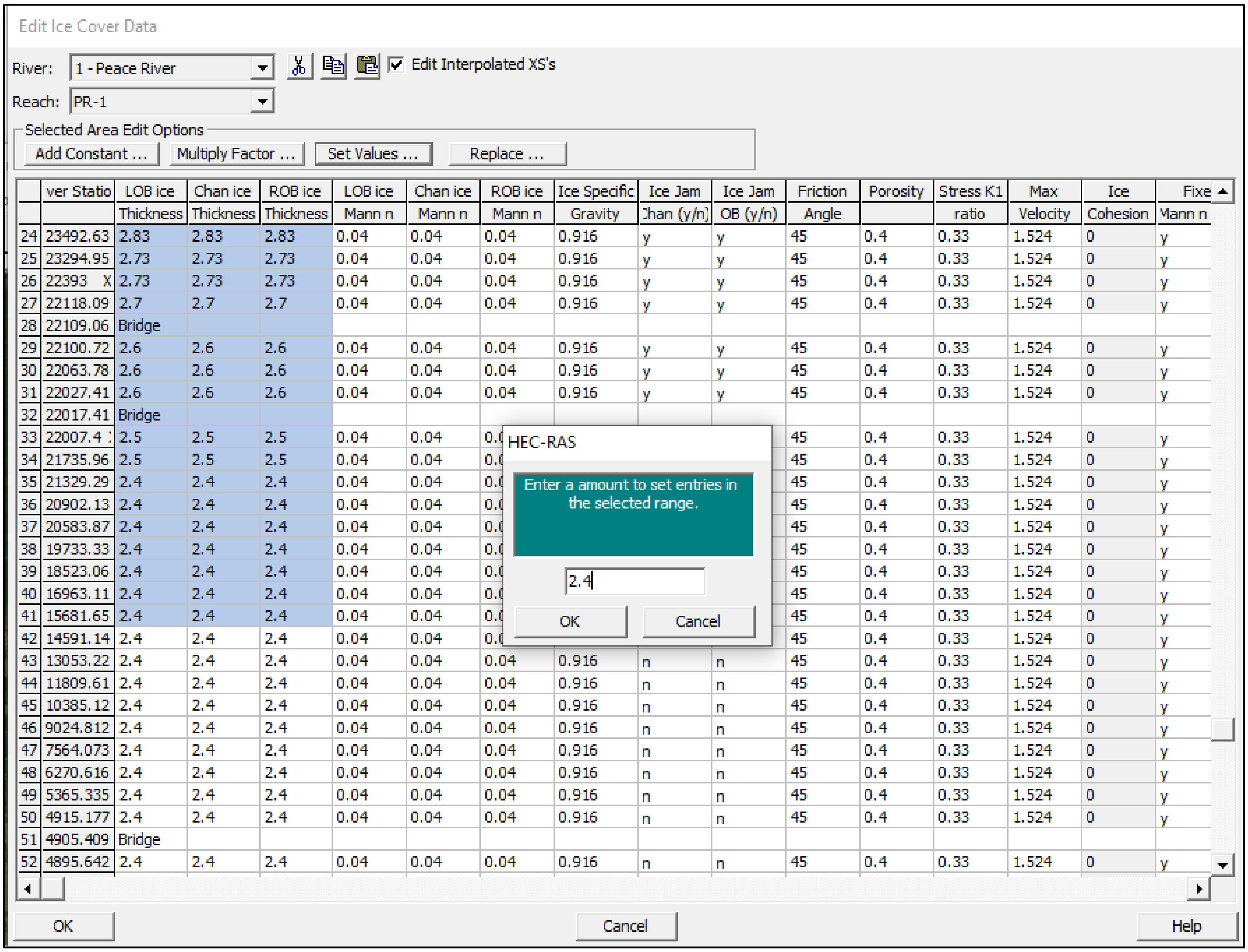
● Yes
○ No

Note that the most upstream and most downstream cross-sections in a HEC-RAS model cannot have ice jam (y/n) set to 'yes'.

10. Repeat the previous step for the '*Ice Jam OB (y/n)*' to also simulate an ice jam in the overbank area.

By adding an ice jam to both the channel and the overbank, the top width of the wetted area will be used as the width of the ice jam in the ice jam stability equation. The importance of the ice jam width will be explored further in Module 4.

11. Set the ice jam thickness to *2.4 m* for all ice jam sections (in the channel and the overbanks) from *XS #53* to *XS#16* Select the '*LOB ice thickness*', *'Chan ice Thickness'*, and *'ROB ice Thickness*' columns for all rows with a 'y' in the 'Ice Jam Chan (y/n)' column. Click Set Values ... and input the thickness. Click OK. Click OK to exit the 'Edit Ice Cover' window.



River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

Enter a amount to set entries in the selected range.

2.4

	ver Statio	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam han (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity	Ice Cohesion	Fixe Mann n
24	23492.63	2.83	2.83	2.83	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
25	23294.95	2.73	2.73	2.73	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
26	22393 X	2.73	2.73	2.73	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
27	22118.09	2.7	2.7	2.7	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
28	22109.06	Bridge														
29	22100.72	2.6	2.6	2.6	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
30	22063.78	2.6	2.6	2.6	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
31	22027.41	2.6	2.6	2.6	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
32	22017.41	Bridge														
33	22007.4	2.5	2.5	2.5	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
34	21735.96	2.5	2.5	2.5	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
35	21329.29	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
36	20902.13	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
37	20583.87	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
38	19733.33	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
39	18523.06	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
40	16963.11	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
41	15681.65	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
42	14591.14	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
43	13053.22	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
44	11809.61	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
45	10385.12	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
46	9024.812	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
47	7564.073	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
48	6270.616	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
49	5365.335	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
50	4915.177	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
51	4905.409	Bridge														
52	4895.642	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y

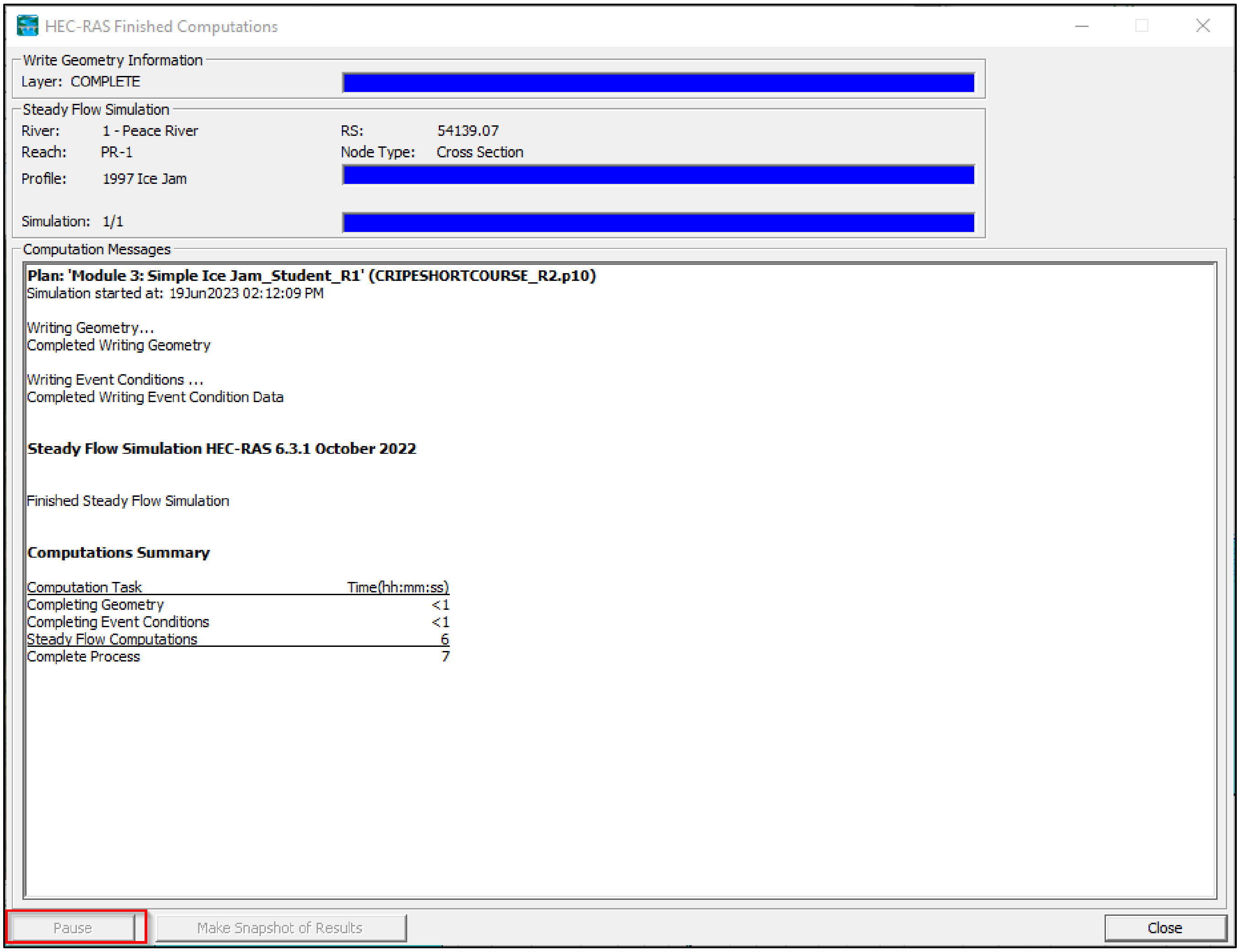
This input ice thickness is the initial ice thickness used when solving the ice jam stability equation, as well as the *minimum* ice thickness that the final solution will have at each cross-section. For this reason, if you start with an ice jam ice thickness that is too high at this step, it will affect the final results. Note that here we have started with a thickness close to the intact ice thickness.

12. Save your changes to the **Geometry** file. Choose File and click '*Save Geometry Data*'.
13. Click to open the 'Steady Flow Analysis' window.
14. Save a new plan by going to File and selecting '*Save Plan As…*'. Then, type "**Module 3: Simple Ice Jam_Student_R1**" in the 'Title' box and click OK.
15. In the next window, give the plan a short ID of: "**M3: Simple Jam_Student_R1**"
16. Verify that the correct **Geometry** and **Steady Flow** files are chosen:

Table 8: Model Files Used for HEC-RAS Module 3 - Task 3A, Geometry Revision 1

File Type	Filename
Plan	“Module 3: Simple Ice Jam_Student_R1”
Geometry	“Module 3: Simple Ice Jam_Student_R1”
Steady Flow	“Module 3: Simple Ice Jam”

17. Click Compute. Wait for the simulation to complete. Notice that it takes longer for an ice jam to compute than an open water or intact ice model.



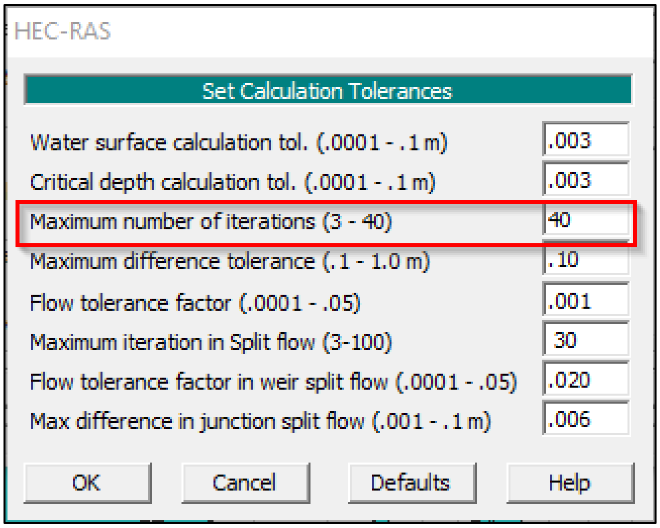
Layer: COMPLETE

River: 1 - Peace River
Reach: PR-1
Profile: 1997 Ice Jam
RS: 54139.07
Node Type: Cross Section
Simulation: 1/1

```
Plan: 'Module 3: Simple Ice Jam_Student_R1' (CRIPESHORTCOURSE_R2.p10)
Simulation started at: 19Jun2023 02:12:09 PM

Writing Geometry...
Completed Writing Geometry

Writing Event Conditions ...
Completed Writing Event Condition Data


Steady Flow Simulation HEC-RAS 6.3.1 October 2022


Finished Steady Flow Simulation


Computations Summary

Computation Task                       Time(hh:mm:ss)
Completing Geometry                                <1
Completing Event Conditions                        <1
Steady Flow Computations                            6
Complete Process                                    7
```

51 iterations were performed to compute the ice jam. Depending on the modelled conditions, this may not be enough iterations for the ice jam thickness to reach its “fully developed” state. We will change the maximum number of iterations in the coming steps.

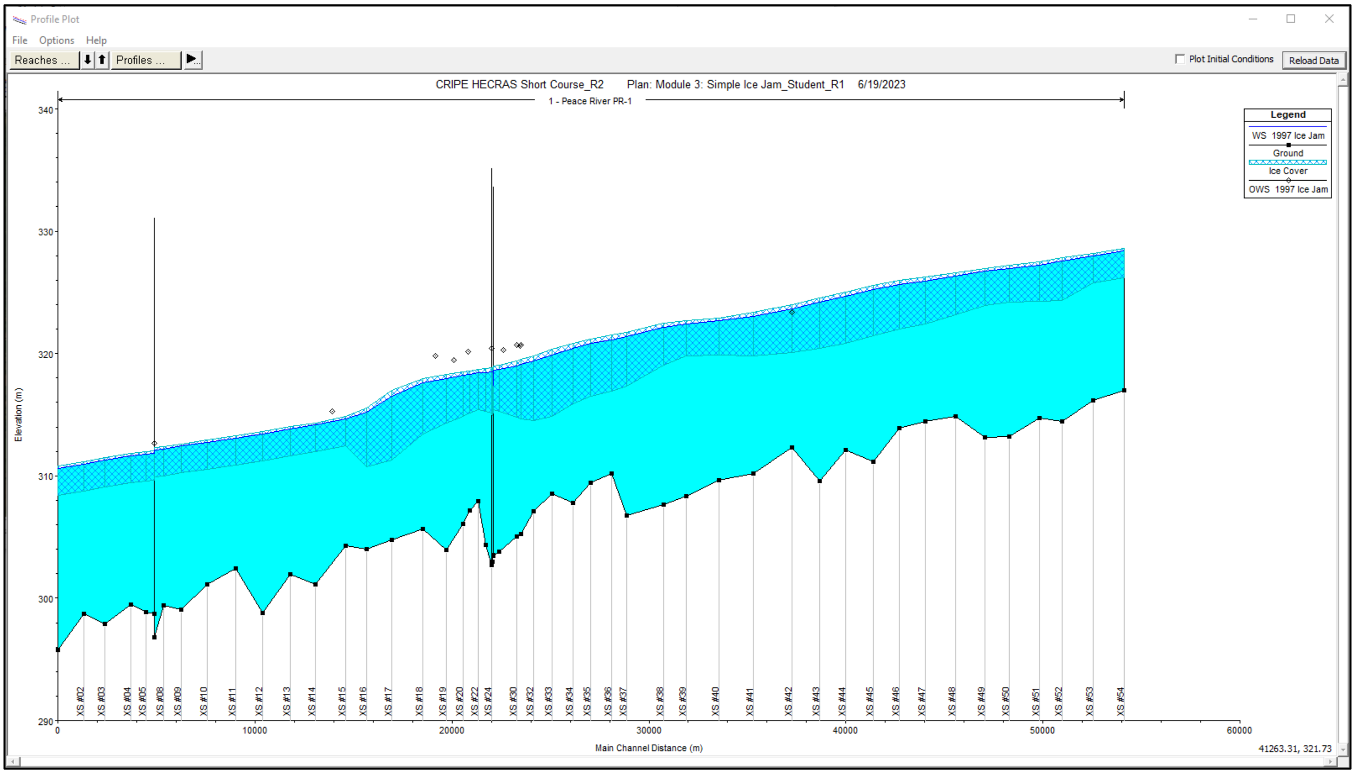
18. Choose Close in the HEC-RAS Finished Computations window.
19. Edit the maximum number of iterations in the ‘Steady Flow Analysis’ window. Go to Options and select ‘*Set Calculation Tolerances …*’. Change this value to *40* (which is the maximum number of iterations).



Water surface calculation tol. (.0001 - .1 m)	.003
Critical depth calculation tol. (.0001 - .1 m)	.003
Maximum number of iterations (3 - 40)	40
Maximum difference tolerance (.1 - 1.0 m)	.10
Flow tolerance factor (.0001 - .05)	.001
Maximum iteration in Split flow (3-100)	30
Flow tolerance factor in weir split flow (.0001 - .05)	.020
Max difference in junction split flow (.001 - .1 m)	.006

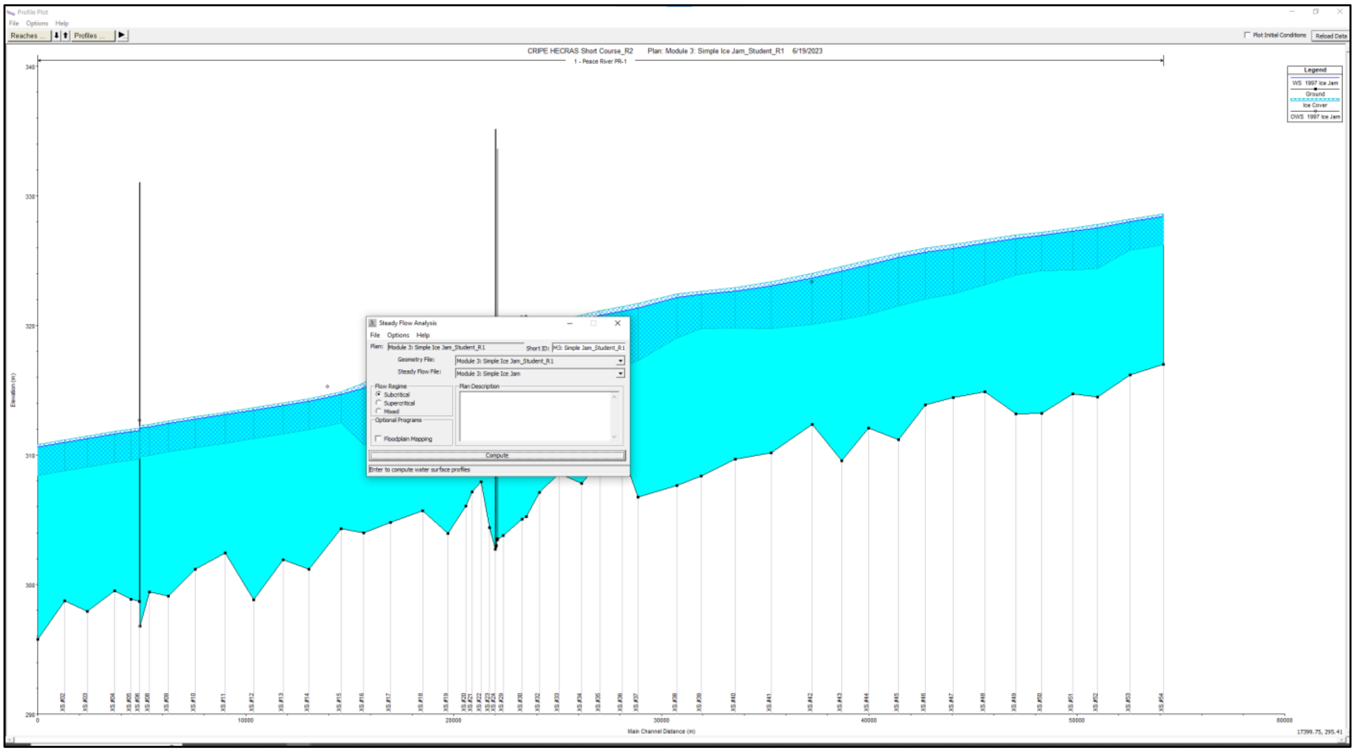
The number of iterations HEC-RAS will perform for an ice jam analysis is 2.5 times the value in this table plus 1. Therefore, the maximum number of iterations HEC-RAS will perform in an ice jam model is 101.

20. Click OK to exit.
21. Re-compute the ice jam profile but this time, get ready to pause the simulation at some point. Click Compute in the ‘Steady Flow Analysis’ window and then click Pause in the computation window during the simulation.
22. With the simulation paused, view the ‘Profile Plot’ window and then click Reload Data. The profile will now look different. An ice jam has been computed in the study reach, which looks like a thickened area of the ice, and a toe region.



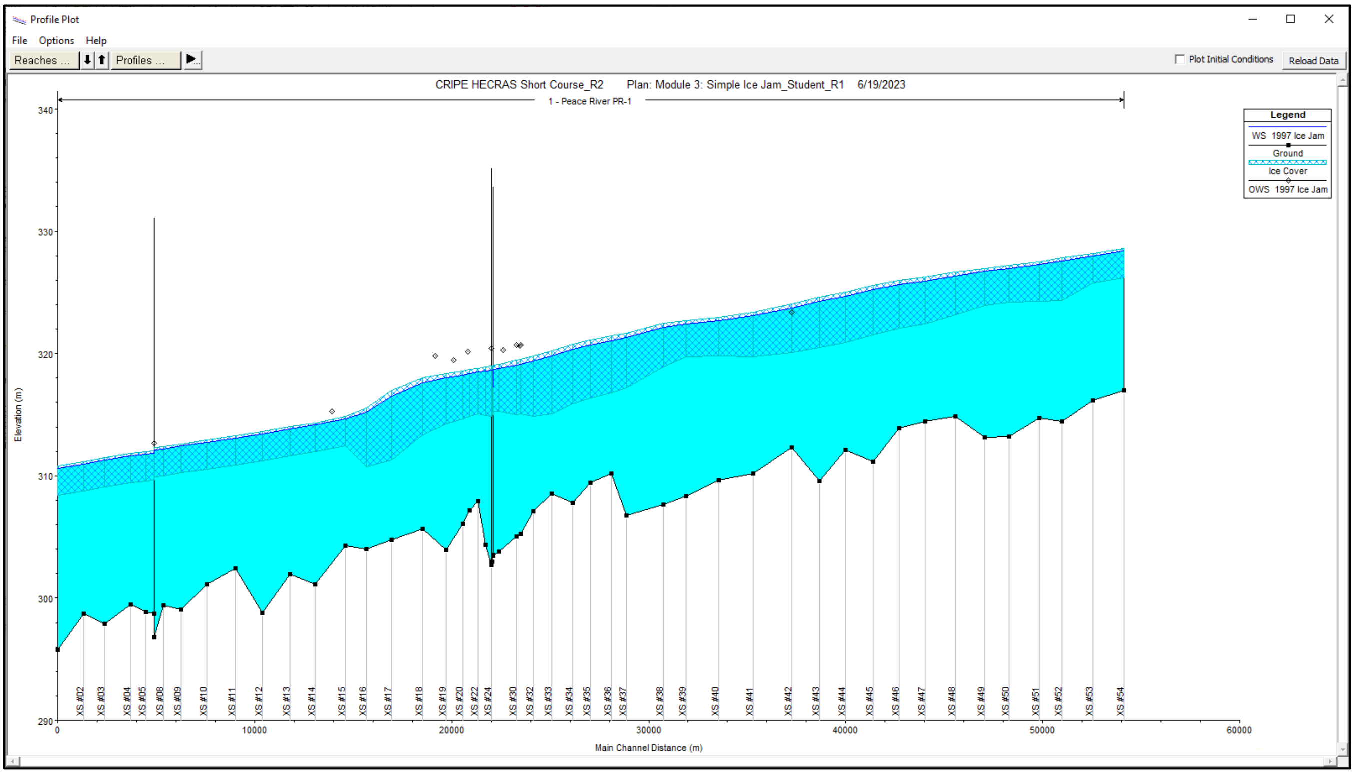
23. Go back to the computation window and click Resume to finish the computation. Then click Close to exit the computation window.

24. To understand how the computed solution changes during iterations, we will repeatedly update the profile as the model runs. Get your windows set up so this is easier to achieve. Maximize the ‘Profile Plot’ window, and have the ‘Steady Flow Analysis’ window in front of it:



Plan: Module 3: Simple Ice Jam_Student_R1
Short ID: M3: Simple Jam_Student_R1
Geometry File: Module 3: Simple Ice Jam_Student_R1
Steady Flow File: Module 3: Simple Ice Jam
Flow Regime: ● Subcritical ○ Supercritical ○ Mixed
Optional Programs: ☐ Floodplain Mapping
Plan Description:
Enter to compute water surface profiles

25. Click Compute on the 'Steady Flow Analysis' window, and then directly click on the 'Profile Plot' in behind, to bring it to the front. Click on the Reload Data button in the upper right of the 'Profile Plot' window repeatedly to see the results of the iterations as they occur.
26. Repeat the previous two steps a few times to see how the computed ice jam is changing as the model runs.
27. Once you have watched the model run a few times, inspect the model results in the 'Profile Plot'.



Notice that the computed water surface elevation does not go through the observed water surface data points. What still needs to be changed so that the points match?

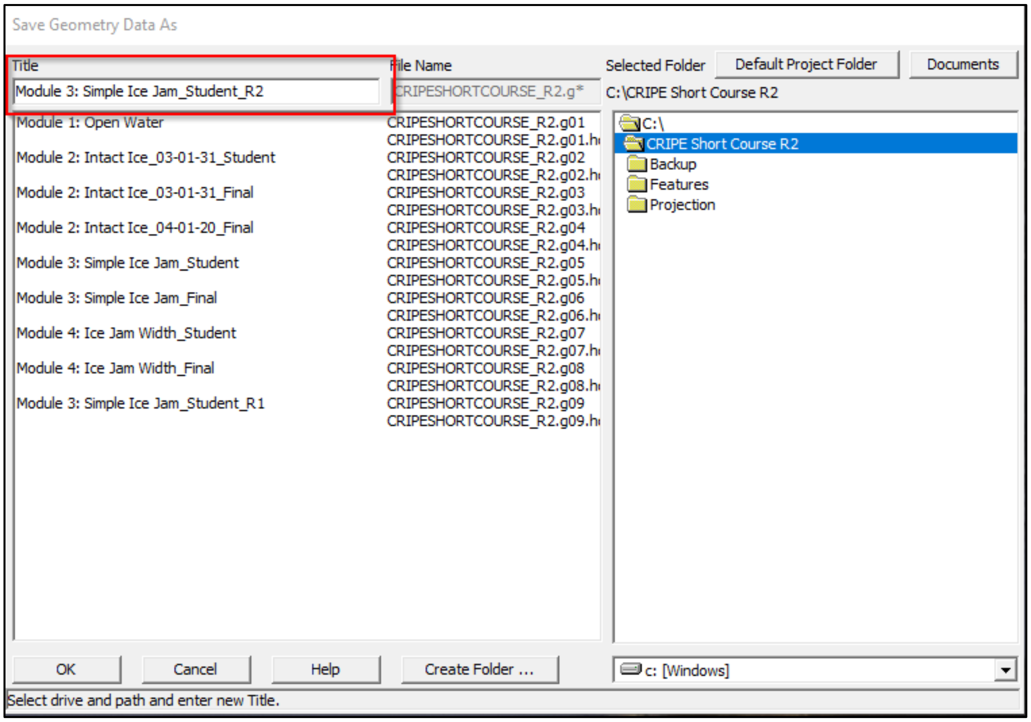
QUESTION: What still needs to be changed so that the points match? In what way (increase/decrease) do we need to make that change?

28. Close all tabs and windows except the main interface.

Task 3B Instructions: Calibrate the Simplified Ice Jam Model

In Task 3A we changed the geometry file of the intact ice cover to include an ice jam. However, that geometry file still contained the ice roughnesses that were calibrated to the intact ice observations. In this task, we need to calibrate the roughness of the ice cover to match the observed water surface points.

1. We will save a new version of the geometry file, so that we can edit the geometry and compare results. Open the 'Geometric Data' window by clicking the in the main interface. Choose File and select '*Save Geometry File As …*'. Change the 'Title' of the file to "**Module 3: Simple Ice Jam_Student_R2**", click OK .



Title: Module 3: Simple Ice Jam_Student_R2

File Name: CRIPESHORTCOURSE_R2.g*

Selected Folder: C:\CRIPE Short Course R2

Module 1: Open Water
Module 2: Intact Ice_03-01-31_Student
Module 2: Intact Ice_03-01-31_Final
Module 2: Intact Ice_04-01-20_Final
Module 3: Simple Ice Jam_Student
Module 3: Simple Ice Jam_Final
Module 4: Ice Jam Width_Student
Module 4: Ice Jam Width_Final
Module 3: Simple Ice Jam_Student_R1

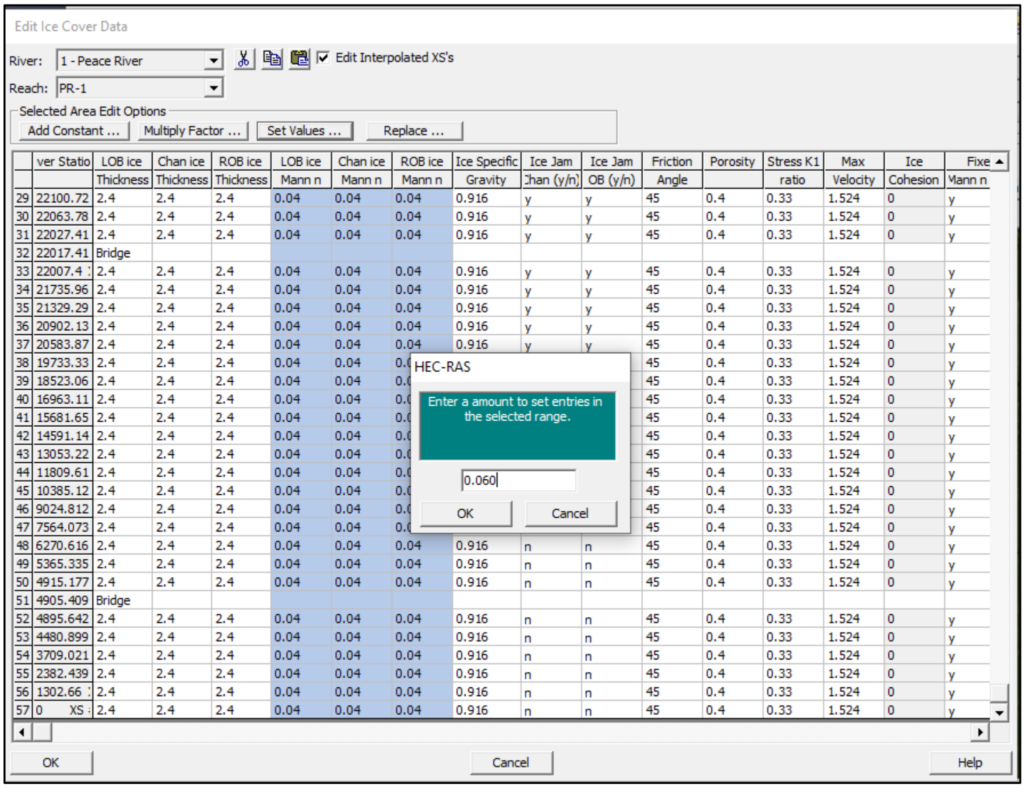
CRIPESHORTCOURSE_R2.g01
CRIPESHORTCOURSE_R2.g01.h
CRIPESHORTCOURSE_R2.g02
CRIPESHORTCOURSE_R2.g02.h
CRIPESHORTCOURSE_R2.g03
CRIPESHORTCOURSE_R2.g03.h
CRIPESHORTCOURSE_R2.g04
CRIPESHORTCOURSE_R2.g04.h
CRIPESHORTCOURSE_R2.g05
CRIPESHORTCOURSE_R2.g05.h
CRIPESHORTCOURSE_R2.g06
CRIPESHORTCOURSE_R2.g06.h
CRIPESHORTCOURSE_R2.g07
CRIPESHORTCOURSE_R2.g07.h
CRIPESHORTCOURSE_R2.g08
CRIPESHORTCOURSE_R2.g08.h
CRIPESHORTCOURSE_R2.g09
CRIPESHORTCOURSE_R2.g09.h

C:\
CRIPE Short Course R2
Backup
Features
Projection

c: [Windows]

Select drive and path and enter new Title.

2. Change the roughness of the ice cover. Go to Tables and select '*Ice Cover …*' to open the 'Edit Ice Cover Data' window. Set the ice cover roughness to *0.060*.



Enter a amount to set entries in the selected range.

0.060

	ver Statio	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam Chan (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity	Ice Cohesion	Fixe Mann n
29	22100.72	2.4	2.4	2.4	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
30	22063.78	2.4	2.4	2.4	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
31	22027.41	2.4	2.4	2.4	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
32	22017.41	Bridge														
33	22007.4 :	2.4	2.4	2.4	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
34	21735.96	2.4	2.4	2.4	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
35	21329.29	2.4	2.4	2.4	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
36	20902.13	2.4	2.4	2.4	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
37	20583.87	2.4	2.4	2.4	0.04	0.04	0.04	0.916	y	y	45	0.4	0.33	1.524	0	y
38	19733.33	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
39	18523.06	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
40	16963.11	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
41	15681.65	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
42	14591.14	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
43	13053.22	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
44	11809.61	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
45	10385.12	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
46	9024.812	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
47	7564.073	2.4	2.4	2.4	0.04	0.04	0.0				45	0.4	0.33	1.524	0	y
48	6270.616	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
49	5365.335	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
50	4915.177	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
51	4905.409	Bridge														
52	4895.642	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
53	4480.899	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
54	3709.021	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
55	2382.439	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
56	1302.66 :	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y
57	0 XS :	2.4	2.4	2.4	0.04	0.04	0.04	0.916	n	n	45	0.4	0.33	1.524	0	y

Recall that in the previous run of our model, the computed water surface elevation was below the observed water surface elevations. This was true for the ice jam area and for the intact ice section downstream of the ice jam toe.

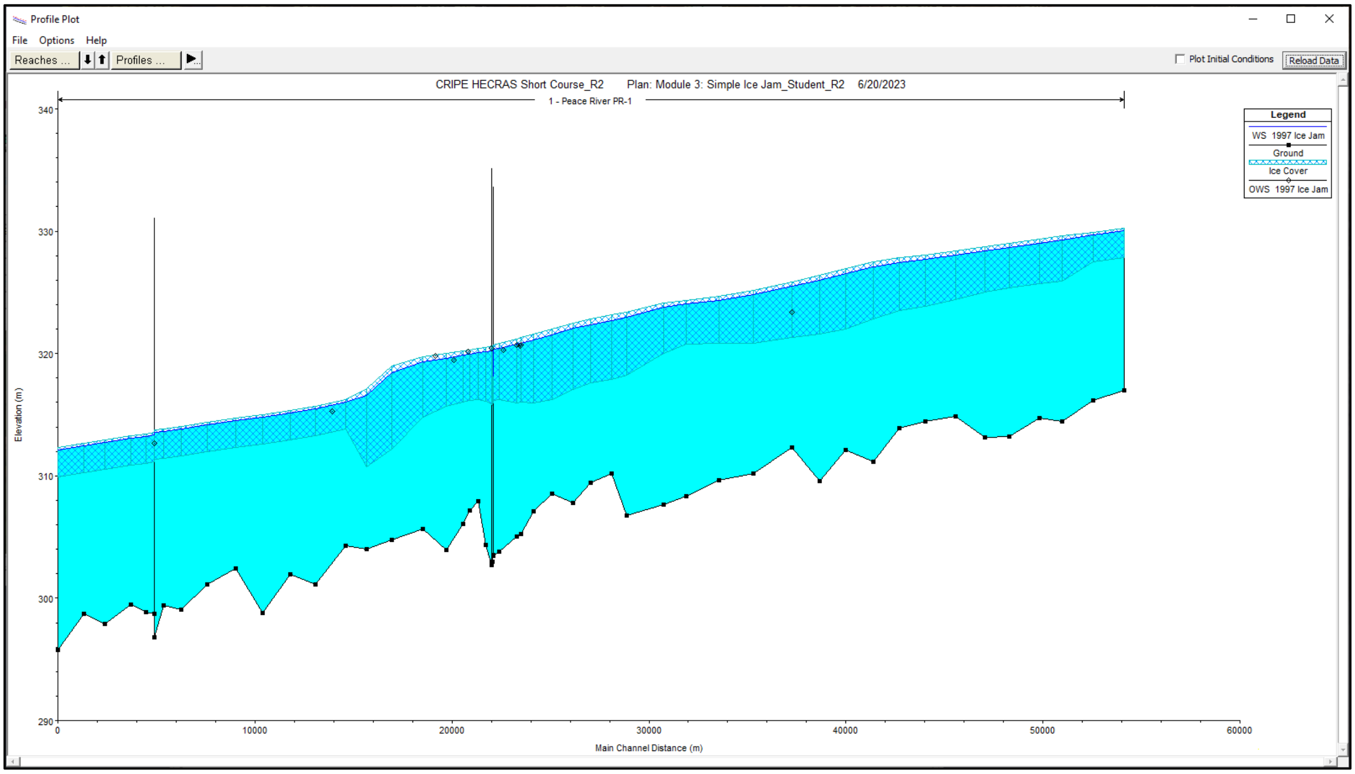
We want the computed water surface to go through the observed data points downstream of the ice jam toe so that we have the correct water level for the toe of the ice jam. This can be achieved by modifying the ice roughness or ice thickness in the intact ice section (or a combination of both).

3. Open the 'Profile Plot' from the main interface. Get your windows ready so that you can monitor the progress of the model run using the Reload Data button.
4. Click to open the 'Steady Flow Analysis' window.
5. Save a new plan by choosing File and select '*Save Plan As…'* and type "**Module 3: Simple Ice Jam_Student_R2**" in the 'Title' box and click OK.
6. In the next window, give the plan a short ID of: "**M3: Simple Jam_Student_R2**"
7. Verify that the correct **Geometry** and **Steady Flow** files are chosen:

Table 9: Model Files Used for HEC-RAS Module 3 - Task 3B, Geometry Revision 2

File Type	Filename
Plan	“Module 3: Simple Ice Jam_Student_R2”
Geometry	“Module 3: Simple Ice Jam_Student_R2”
Steady Flow	“Module 3: Simple Ice Jam”

8. Click Compute. Monitor the progression of the model by clicking the Reload Data button repeatedly.

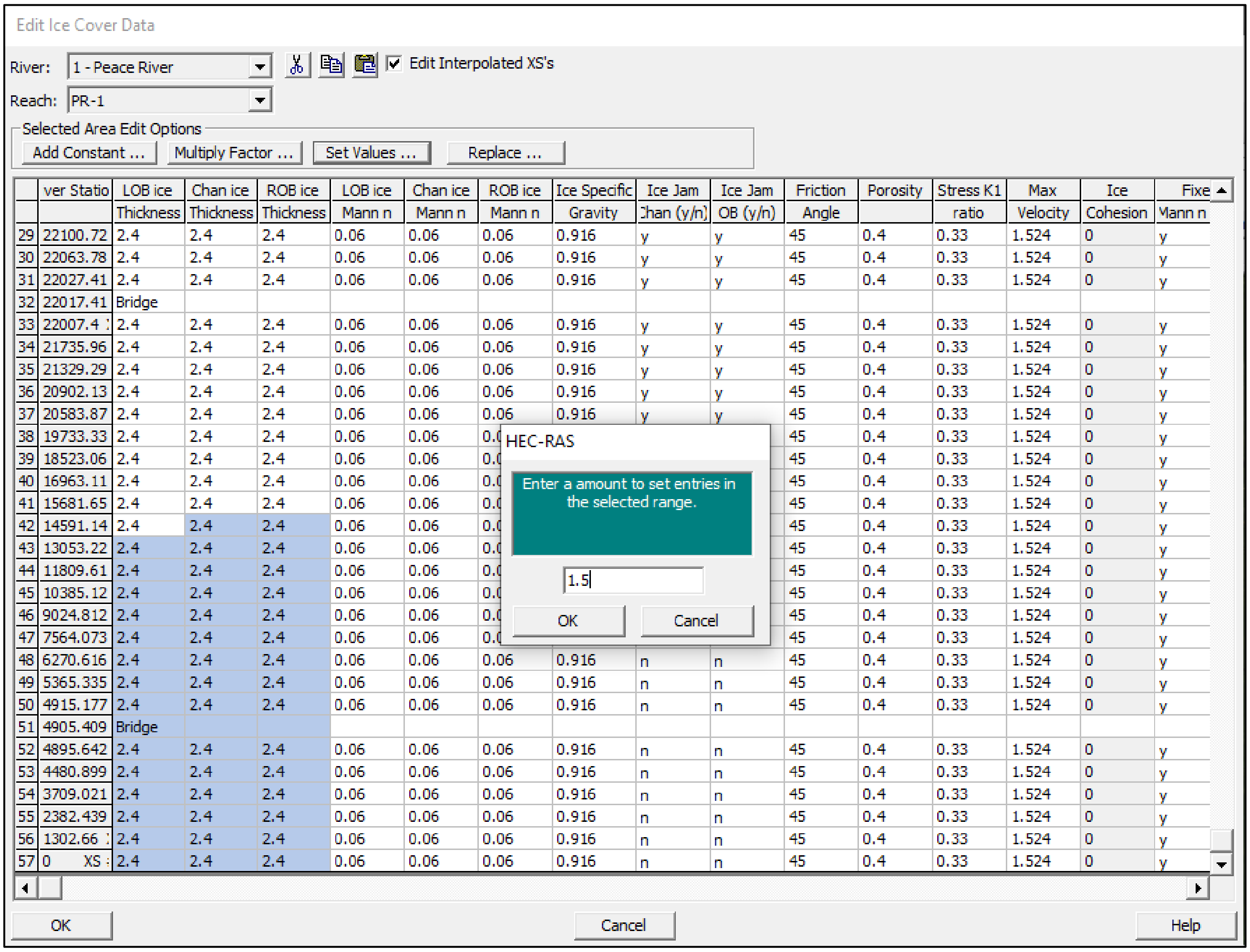


Notice that water level in the intact ice section is now higher than the observed water surface elevation. We now will modify the ice thickness in that section.

Note that the most upstream Observed Water Surface elevation is not being matched by the model. This could be a survey error, or perhaps the ice jam head didn’t reach as far upstream as we have assumed. We have tried to match historical accounts, but the head location was not well described in historical records. For this exercise we will assume it is a survey error.

QUESTION: What direction (thicker/thinner) do we need to change the ice thickness? Why might this reasonable?

9. Open the 'Geometric Data' window by clicking the in the main interface, or switching to that window if it is still open.
10. Change the thickness of the *intact* ice cover. Go to Tables and click '*Ice Cover …*' to open the 'Edit Ice Cover Data' window. Set the ice thickness to *1.5* m in only those cross-sections where there is an "n" in the '*Ice Jam Chan (y/n)*' column. Click OK .



	ver Statio	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam Chan (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity	Ice Cohesion	Fixe Mann n
29	22100.72	2.4	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	1.524	0	y
30	22063.78	2.4	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	1.524	0	y
31	22027.41	2.4	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	1.524	0	y
32	22017.41	Bridge														
33	22007.4	2.4	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	1.524	0	y
34	21735.96	2.4	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	1.524	0	y
35	21329.29	2.4	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	1.524	0	y
36	20902.13	2.4	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	1.524	0	y
37	20583.87	2.4	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	1.524	0	y
38	19733.33	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
39	18523.06	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
40	16963.11	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
41	15681.65	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
42	14591.14	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
43	13053.22	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
44	11809.61	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
45	10385.12	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
46	9024.812	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
47	7564.073	2.4	2.4	2.4	0.06	0.06	0.0				45	0.4	0.33	1.524	0	y
48	6270.616	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y
49	5365.335	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y
50	4915.177	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y
51	4905.409	Bridge														
52	4895.642	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y
53	4480.899	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y
54	3709.021	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y
55	2382.439	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y
56	1302.66	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y
57	0 XS	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	1.524	0	y

HEC-RAS

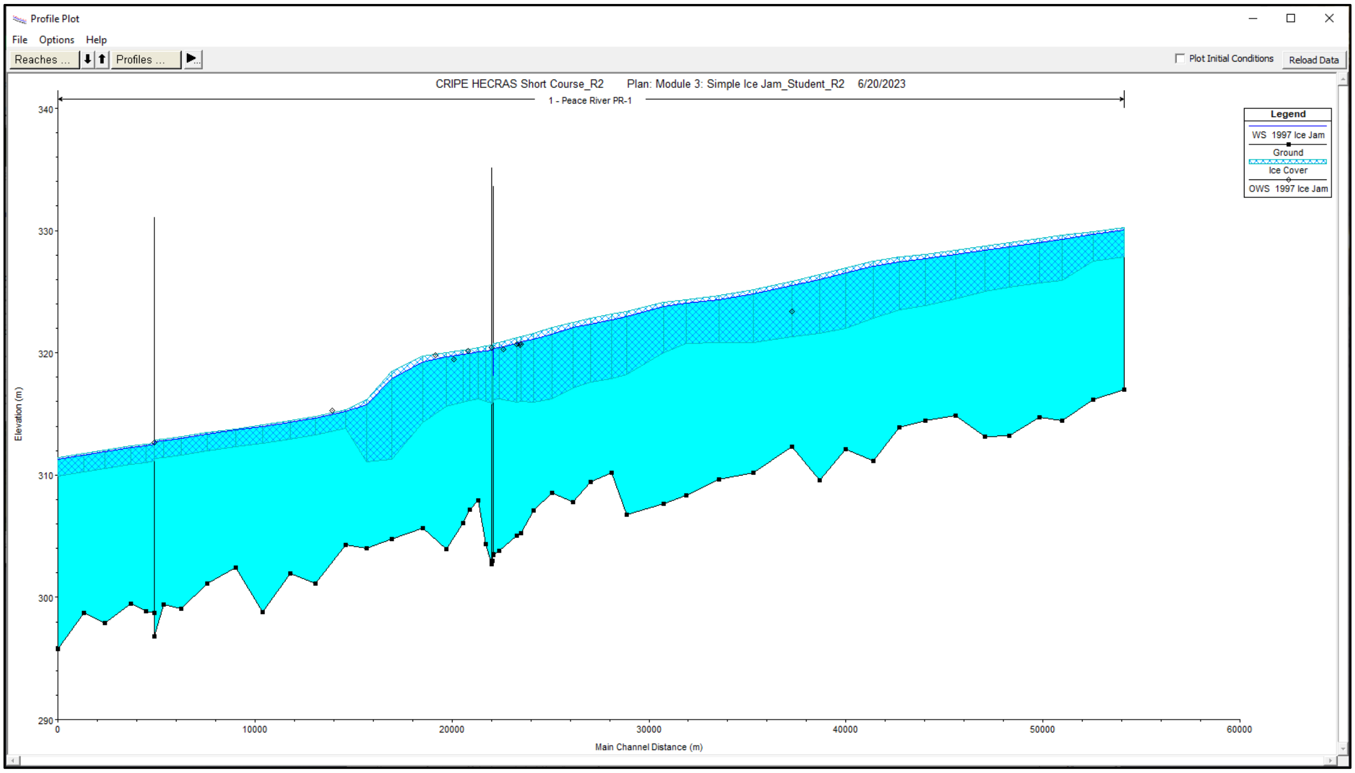
Enter a amount to set entries in the selected range.

1.5

11. Save your changes to the **Geometry** file. Choose File and click *'Save Geometry Data'*.

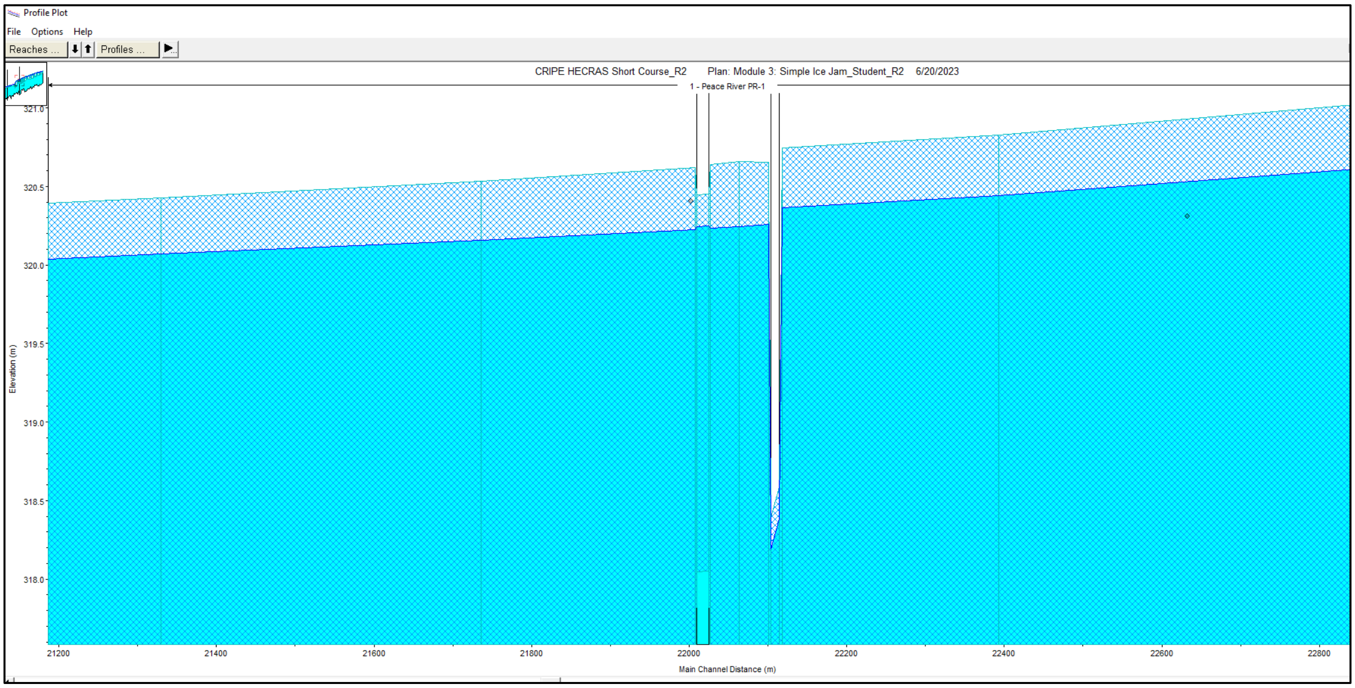
12. Run the model again, with the same files as last time. Click to open the 'Steady Flow Analysis' window. Click Compute.

13. View the results in the 'Profile Plot'.



Notice that the computed water surface matches the observed water surface elevations downstream of the ice jam better now.

14. Zoom in on the water surface profile where it goes through the bridges in the centre of the model domain. Go to Options and select *'Zoom in'* and draw your zoom area on the bridges.



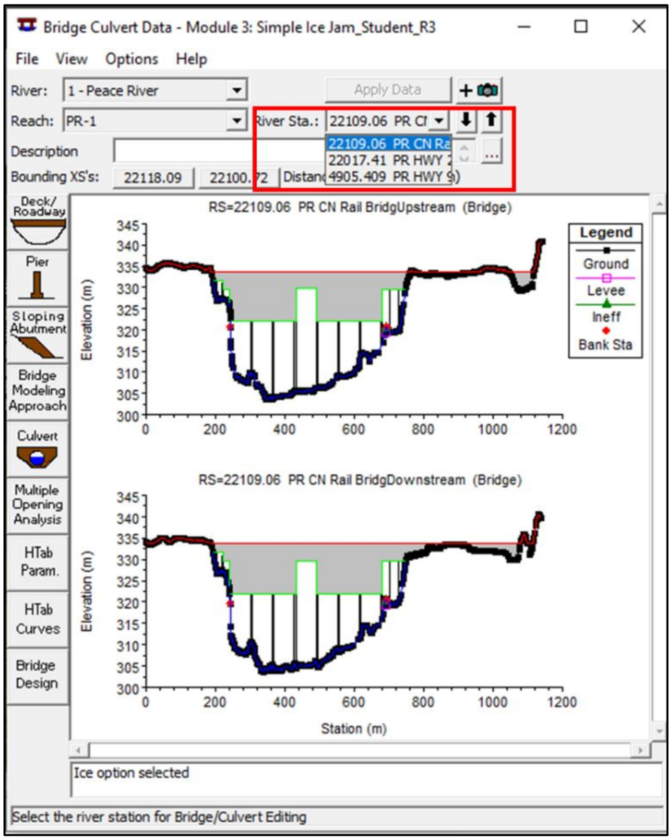
HEC-RAS often does not compute a realistic ice jam profile through bridge openings. Therefore, bridges are often removed from the model geometry when modelling ice jams.

QUESTION: In what way does the ice jam profile computed through the bridge openings look unrealistic?

15. Close all tabs and windows except the main interface.

Task 3C Instructions: Further Modify the Geometry

1. We will save a new version of the geometry file, so that we can edit the geometry and compare results. Open the 'Geometric Data' window by clicking the in the main interface. Go to File and select '*Save Geometry File As …*'. Change the 'Title' of the file to "**Module 3: Simple Ice Jam_Student_R3**", click OK.
2. In the 'Geometric Data' window, select the 'Bridge Culvert Data' editor Brdg/Culv.
3. Look thorough the 3 bridges in the model domain by choosing the different bridges from the dropdown menu.


Bridge Culvert Data - Module 3: Simple Ice Jam_Student_R3

River: 1 - Peace River

Reach: PR-1

River Sta.: 22109.06 PR CI

22109.06 PR CN Ra
22017.41 PR HWY 2
4905.409 PR HWY 9)

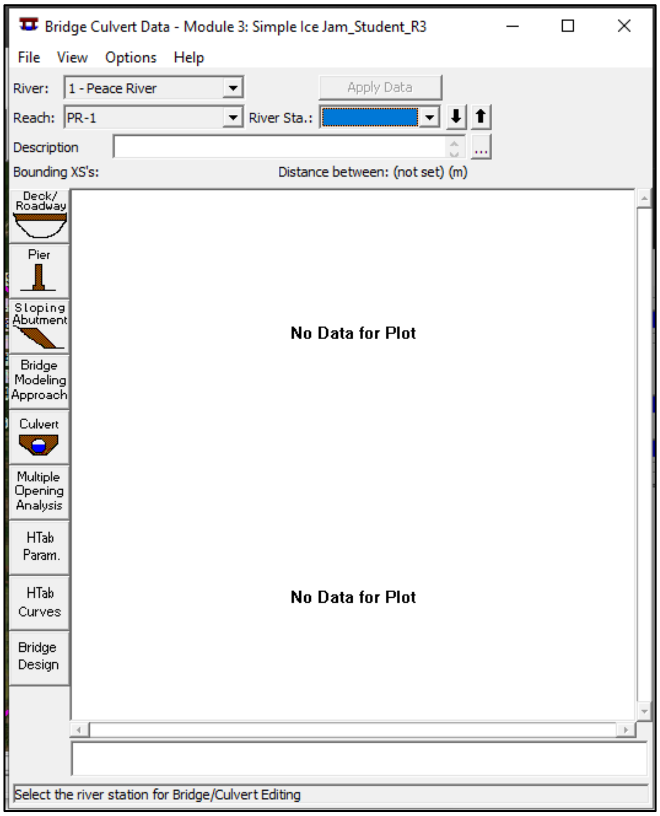
Bounding XS's: 22118.09 22100.72

Ice option selected

Select the river station for Bridge/Culvert Editing

Bridges are normally simulated in a HEC-RAS model with bridge sections as well as closely-spaced cross-sections upstream and downstream of the bridges. This facilitates the different manner in which HEC-RAS computes the water surface through bridges. However, convergence of the ice jam stability equation is improved if these closely-spaced cross-sections are also removed. We will remove the bridges and the extra cross-sections.

4. Delete the current bridge in the geometry by choosing Options and select '*Delete Bridge/Culvert*'. Then click Yes. Do this for each of the three bridges:



Bridge Culvert Data - Module 3: Simple Ice Jam_Student_R3

River: 1 - Peace River

Reach: PR-1

River Sta.:

Description

Bounding XS's:

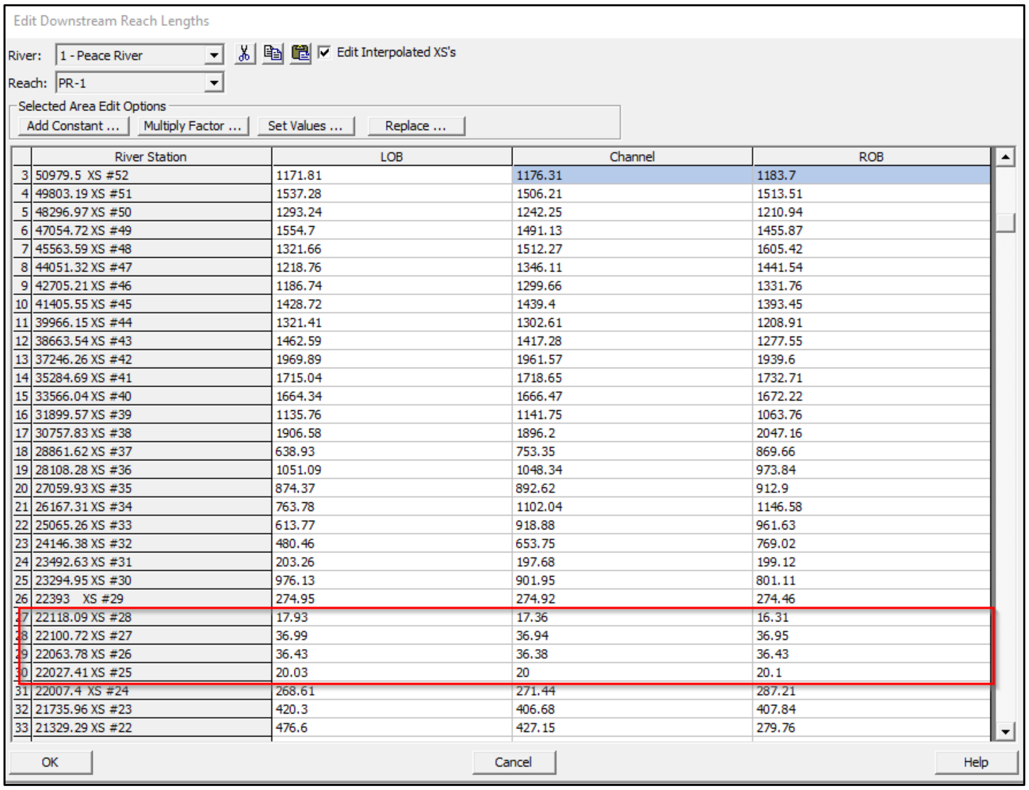
Distance between: (not set) (m)

No Data for Plot

No Data for Plot

Select the river station for Bridge/Culvert Editing

5. Exit the ‘Bridge Culvert Data’ window by clicking on the ✕.
6. Save your changes to the **Geometry** file. Choose File and select ‘*Save Geometry Data*’.
7. Find the closely-spaced cross-sections at the bridges and at the Heart River confluence. In the ‘Geometric Data window’, choose Tables and select ‘*Reach Lengths …*’. Find the cross-sections that are 10s of meters apart instead of 100s of meters.



River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

	River Station	LOB	Channel	ROB
3	50979.5 XS #52	1171.81	1176.31	1183.7
4	49803.19 XS #51	1537.28	1506.21	1513.51
5	48296.97 XS #50	1293.24	1242.25	1210.94
6	47054.72 XS #49	1554.7	1491.13	1455.87
7	45563.59 XS #48	1321.66	1512.27	1605.42
8	44051.32 XS #47	1218.76	1346.11	1441.54
9	42705.21 XS #46	1186.74	1299.66	1331.76
10	41405.55 XS #45	1428.72	1439.4	1393.45
11	39966.15 XS #44	1321.41	1302.61	1208.91
12	38663.54 XS #43	1462.59	1417.28	1277.55
13	37246.26 XS #42	1969.89	1961.57	1939.6
14	35284.69 XS #41	1715.04	1718.65	1732.71
15	33566.04 XS #40	1664.34	1666.47	1672.22
16	31899.57 XS #39	1135.76	1141.75	1063.76
17	30757.83 XS #38	1906.58	1896.2	2047.16
18	28861.62 XS #37	638.93	753.35	869.66
19	28108.28 XS #36	1051.09	1048.34	973.84
20	27059.93 XS #35	874.37	892.62	912.9
21	26167.31 XS #34	763.78	1102.04	1146.58
22	25065.26 XS #33	613.77	918.88	961.63
23	24146.38 XS #32	480.46	653.75	769.02
24	23492.63 XS #31	203.26	197.68	199.12
25	23294.95 XS #30	976.13	901.95	801.11
26	22393 XS #29	274.95	274.92	274.46
27	22118.09 XS #28	17.93	17.36	16.31
28	22100.72 XS #27	36.99	36.94	36.95
29	22063.78 XS #26	36.43	36.38	36.43
30	22027.41 XS #25	20.03	20	20.1
31	22007.4 XS #24	268.61	271.44	287.21
32	21735.96 XS #23	420.3	406.68	407.84
33	21329.29 XS #22	476.6	427.15	279.76

8. Plan to delete the following cross-sections (check them off here when deleted in the next steps).

   ☐ XS #6 from the Hwy 986 Bridge

   ☐ XS #24 from the Hwy 2 Bridge

   ☐ XS #25 from the Hwy 2 Bridge

   ☐ XS #27 from the CN Rail Bridge

   ☐ XS #28 from the CN Rail Bridge

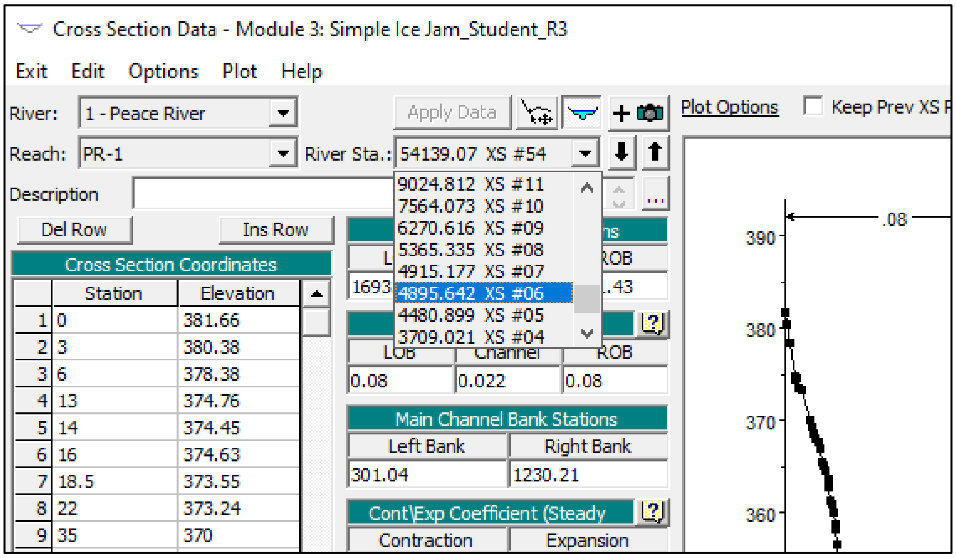
   ☐ XS #31 from the Hear River confluence

We will keep XS #26 from between the Hwy 2 and CN Rail Bridges.

9. Close the 'Edit Downstream Reach Lengths' window by clicking OK.

10. Open the 'Cross-Section editor' window from the 'Geometric Data' window by clicking Cross Section

11. Navigate to each cross-section to be removed using the dropdown menu:



River: 1 - Peace River
Reach: PR-1
River Sta.: 54139.07 XS #54

9024.812 XS #11
7564.073 XS #10
6270.616 XS #09
5365.335 XS #08
4915.177 XS #07
4895.642 XS #06
4480.899 XS #05
3709.021 XS #04

Cross Section Coordinates

	Station	Elevation
1	0	381.66
2	3	380.38
3	6	378.38
4	13	374.76
5	14	374.45
6	16	374.63
7	18.5	373.55
8	22	373.24
9	35	370

LOB	Channel	ROB
0.08	0.022	0.08

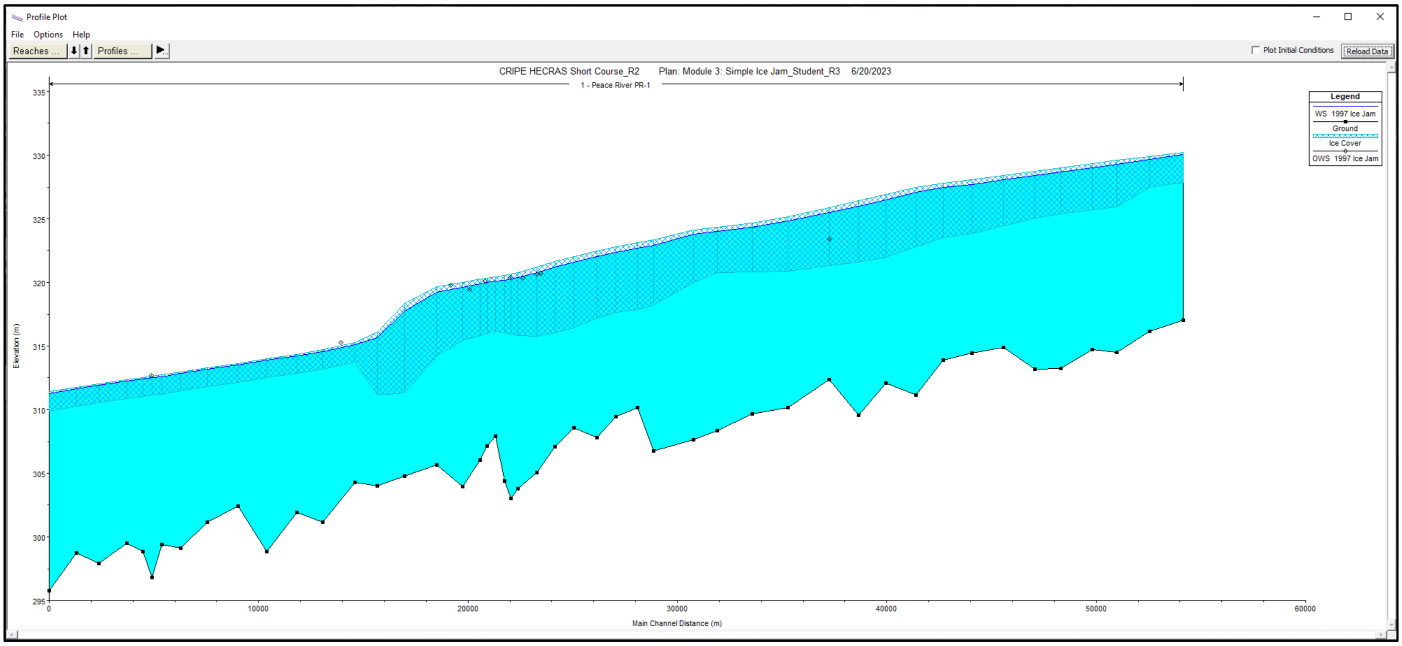
Left Bank	Right Bank
301.04	1230.21

12. For each cross-section, choose Options and select '*Delete Cross Section …*'. Be sure to click Yes and Yes in the dialog boxes that follow. The second dialog box ensures that the distances between existing cross-sections are re-calculated.
13. Save your changes to the **Geometry** file. Choose File and select '*Save Geometry Data*'.
14. Open the 'Profile Plot' from the main interface. Get your windows ready so that you can monitor the progress of the model run using the Reload Data button.
15. Click to open the 'Steady Flow Analysis' window.
16. Save a new plan by choosing File and select the 'Save Plan As…' option. Type "**Module 3: Simple Ice Jam_Student_R3**" in the 'Title' box and click OK.
17. In the next window, give the plan a short ID of: "**M3: Simple Jam_Student_R3**"
18. Verify that the correct **Geometry** and **Steady Flow** files are chosen:

Table 10: Model Files Used for HEC-RAS Module 3 - Task 3B, Geometry Revision 3

File Type	Filename
Plan	"Module 3: Simple Ice Jam_Student_R3"
Geometry	"Module 3: Simple Ice Jam_Student_R3"
Steady Flow	"Module 3: Simple Ice Jam"

19. Click Compute. Monitor the progression of the model by clicking the Reload Data button repeatedly. The model should complete in fewer iterations than it did previously.



20. The shape of the ice jam toe is being affected by the parameter that limits the flow velocity under the toe of the jam. The default value of the parameter is 1.54 m/s. We will increase this value to a large value (*10 m/s*), effectively removing the limitation (see also Beltaos and Tang, 2013). Click on the in the main interface to open the 'Geometric Data window'. Save a new version of the **Geometry File**. Choose File and select '*Save Geometry File As …*'. Change the 'Title' of the file to "**Module 3: Simple Ice Jam_Student_R4**", click OK.

21. In the 'Geometric Data' window, choose Tables and select '*Ice Cover …*'. Select all rows in the '*Max Velocity*' column and choose Set Values ... . Enter *10* into the box and click OK.

22. Close the 'Edit Ice Cover Data' window by clicking OK.

23. Save your changes to the **Geometry** file. Go to File and select '*Save Geometry Data*'.

24. Open the 'Profile Plot' from the main interface. Get your windows ready so that you can monitor the progress of the model run using the Reload Data button.

25. Click to open the 'Steady Flow Analysis' window.

26. Save a new plan by choosing File and select the '*Save Plan As…*' option. Then, type "**Module 3: Simple Ice Jam_Student_R4**" in the 'Title' box and click OK.

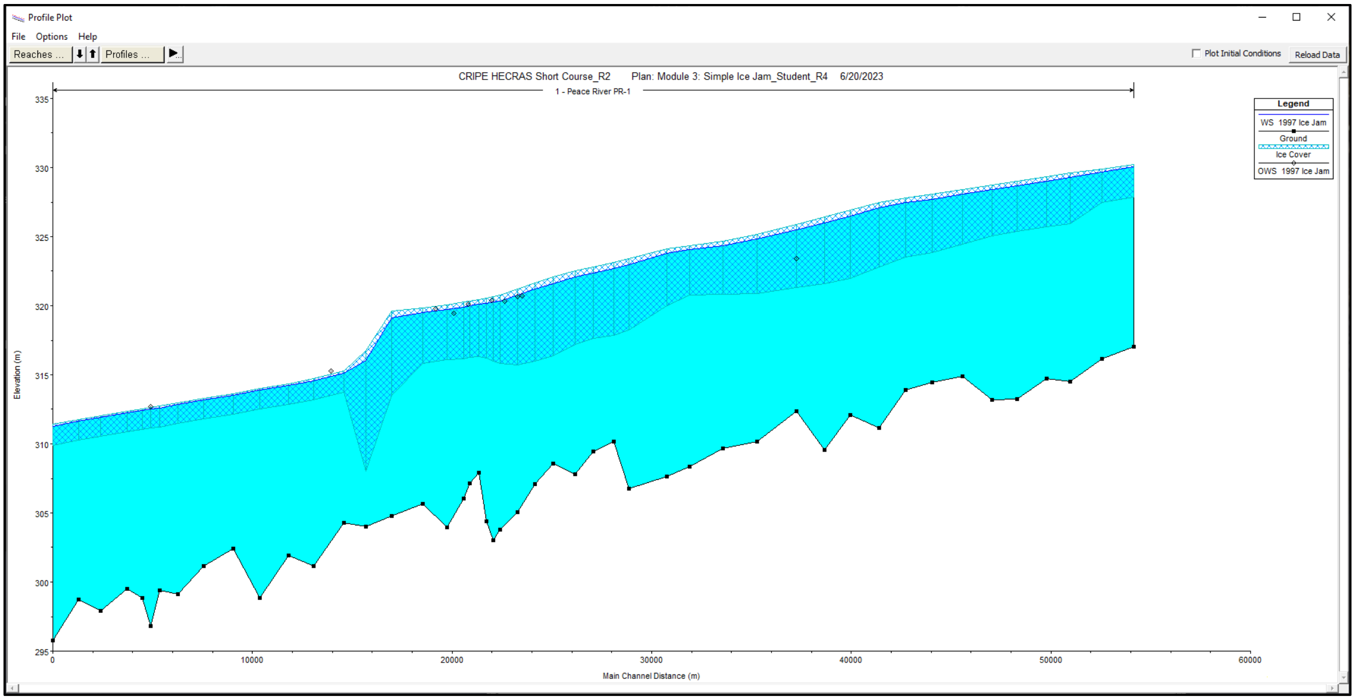
27. In the next window, give the plan a short ID of: "**M3: Simple Jam_Student_R4**"

28. Verify that the correct **Geometry** and **Steady Flow** files are chosen:

Table 11: Model Files Used for HEC-RAS Module 3 - Task 3B, Geometry Revision 4

File Type	Filename
Plan	“Module 3: Simple Ice Jam_Student_R4”
Geometry	“Module 3: Simple Ice Jam_Student_R4”
Steady Flow	“Module 3: Simple Ice Jam”

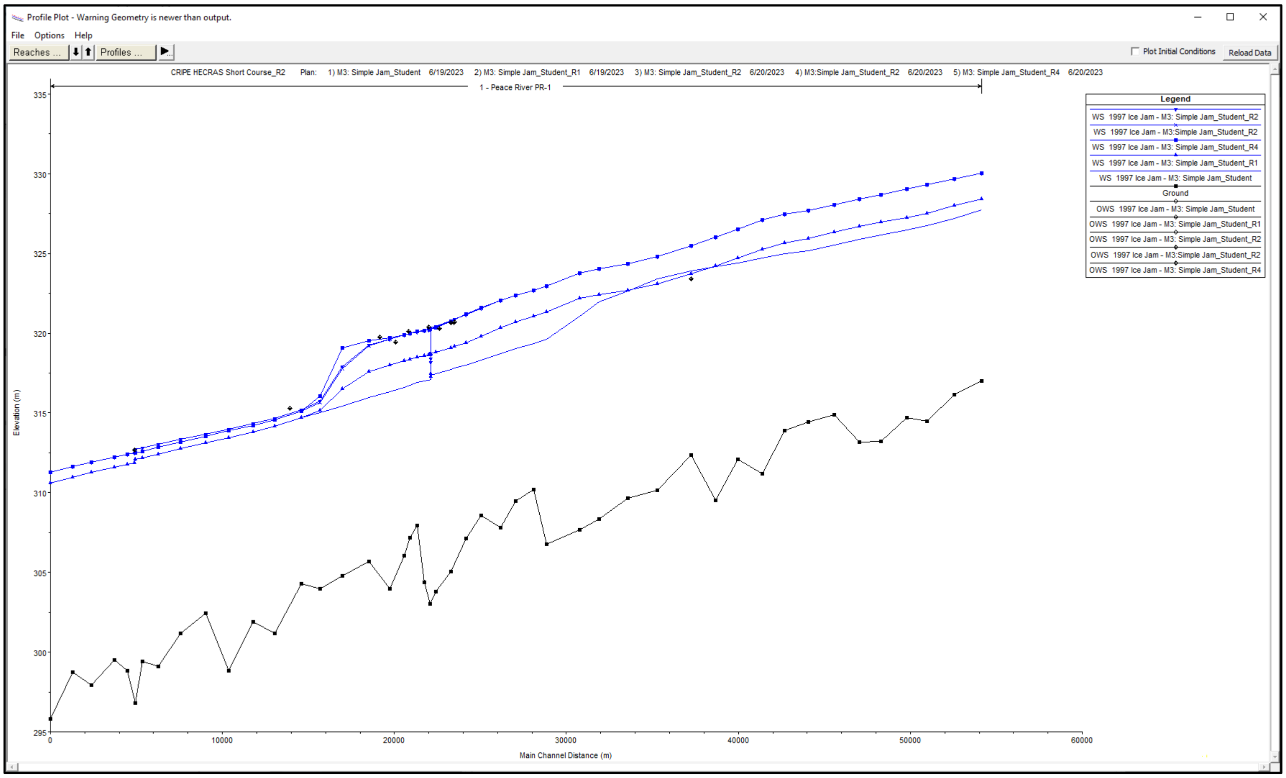
29. Click Compute. Monitor the progression of the model by clicking the Reload Data button repeatedly.



Notice the change in the shape of the ice jam toe region. The toe is much thicker and the water surface slope is much steeper. Remember that the vertical scale is much exaggerated.

Task 3D Instructions: Compare the Results of The Geometric Modifications

30. In the profile view choose Options and select ‘*Plans…*’. Check off the 5 plans we built in Module 3. Click OK. Remove the ice cover from the plots, because it makes it difficult to see the results. Choose Options and then ‘*Variables …*’. Deselect ‘*Ice Cover*’ and ‘*Filled In Water Surface*’ and click OK.



Here is a brief summary of the model plans that we ran. Make some notes on these differences if you wish.

Table 12: Model Files Used for HEC-RAS Module 3

Plan	Description	Student Notes
“Module 3: Simple Ice Jam_Student”	Intact ice measured on January 20, 2004, (no ice jam computations) with peak 1997 breakup flow.	
“Module 3: Simple Ice Jam_Student_R1”	Ice jam computations using intact ice roughness values, with peak 1997 breakup flow.	
“Module 3: Simple Ice Jam_Student_R2”	Ice jam computations, with rougher ice and 1997 peak breakup flow.	
“Module 3: Simple Ice Jam_Student_R3”	Same as above with bridges removed.	
“Module 3: Simple Ice Jam_Student_R4”	Same as above with maximum under-ice velocity increased.	

31. Close all tabs and windows except the main interface.

Task 3E Instructions: OPTIONAL – Explore Sensitivity of Ice Jam Strength Parameters

In this optional task we will explore the effect of changing the parameters that control the strength of the ice jam mass. You will modify the default ice jam strength parameters in the "**Module 3: Simple Ice Jam_Student_R4**" plan to create a weaker and stronger ice jam and compare the difference in the water level profiles. Note there is little guidance in the literature about what K_1 values might be realistic. Choose from the following schemes to compare. Keep track of your plans in the following table.

Table 13: Possible Schemes for Comparing Ice Jam Strength Parameters

Scheme	Porosity	Friction Angle (°)	K_1	μ	Plan Name
Default Parameters	0.4	45	0.33	1.15	Module 3: Simple Ice Jam_Student_R4
Reduce Friction Angle	0.4	40	0.33	0.76	
Increase Friction Angle	0.4	50	0.33	1.78	
Decrease Porosity	0.3	45	0.33	1.35	
Increase Porosity	0.5	45	0.33	0.96	
Decrease lateral stress coefficient	0.4	45	0.25		
Increase lateral stress coefficient	0.4	45	0.825		

Equation for computing μ:

$$\mu = tan(\Phi)tan^2(45 + \frac{\Phi}{2})k_1(1 - P)$$

Where:

μ = coefficient describing the internal strength of an ice jam

Φ = angle of internal friction of ice accumulation

K_1 = lateral stress coefficient

P = ice jam porosity

For your reference, here are some published values of μ (Table 2 of White, 1999):

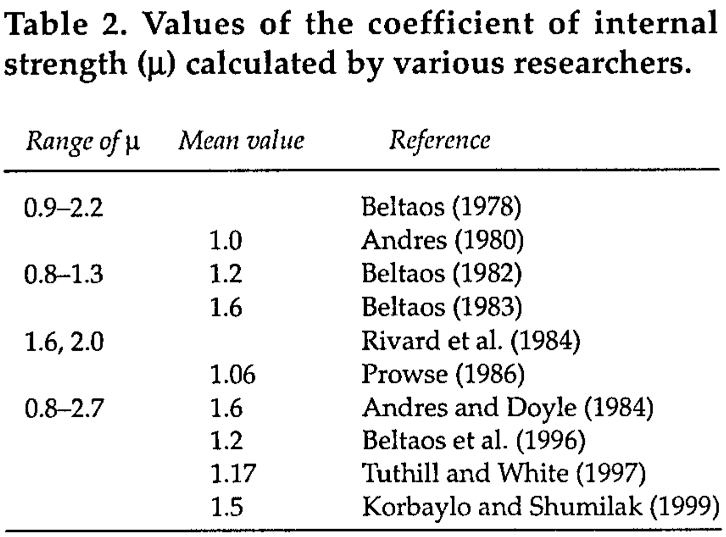
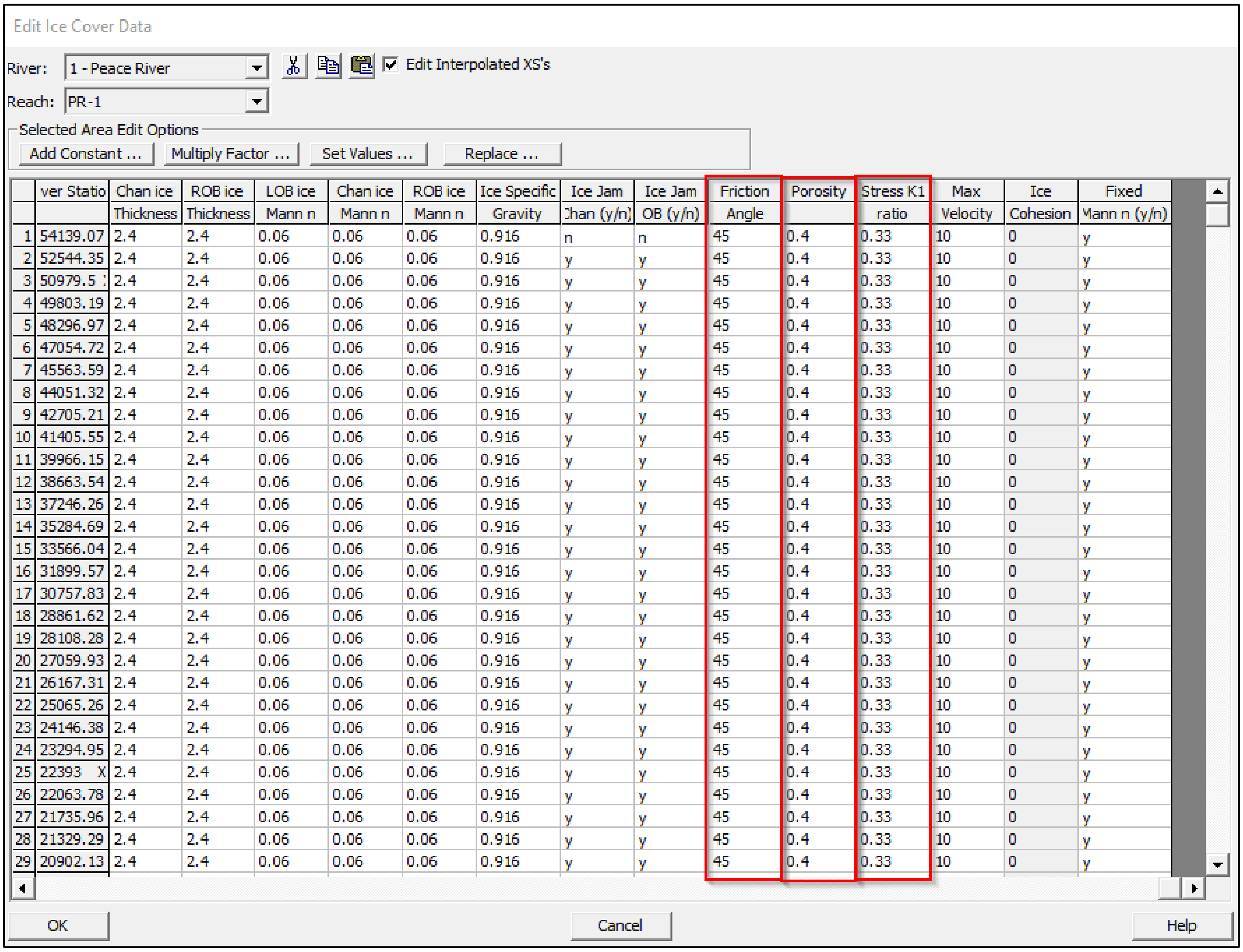


Table 2. Values of the coefficient of internal strength (μ) calculated by various researchers.

Range of μ	*Mean value*	*Reference*
0.9–2.2		Beltaos (1978)
	1.0	Andres (1980)
0.8–1.3	1.2	Beltaos (1982)
	1.6	Beltaos (1983)
1.6, 2.0		Rivard et al. (1984)
	1.06	Prowse (1986)
0.8–2.7	1.6	Andres and Doyle (1984)
	1.2	Beltaos et al. (1996)
	1.17	Tuthill and White (1997)
	1.5	Korbaylo and Shumilak (1999)

1. In the profile plot from the end of Task 3D, go to Options and select '*Plans …*'. Turn off all plans except "**Module 3: Simple Ice Jam_Student_R4**". Click OK.
2. "Save As" the geometry data with a new name representing your scheme, such as "**Module 3: Trial_LessPorosity**"
3. Open the Ice Cover table in the 'Geometric Data' Table. Change the values for all cross-sections of the parameter(s) you are changing.



River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

	ver Statio	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam Chan (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity	Ice Cohesion	Fixed Mann n (y/n)
1	54139.07	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
2	52544.35	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
3	50979.5	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
4	49803.19	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
5	48296.97	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
6	47054.72	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
7	45563.59	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
8	44051.32	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
9	42705.21	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
10	41405.55	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
11	39966.15	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
12	38663.54	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
13	37246.26	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
14	35284.69	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
15	33566.04	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
16	31899.57	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
17	30757.83	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
18	28861.62	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
19	28108.28	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
20	27059.93	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
21	26167.31	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
22	25065.26	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
23	24146.38	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
24	23294.95	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
25	22393 X	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
26	22063.78	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
27	21735.96	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
28	21329.29	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y
29	20902.13	2.4	2.4	0.06	0.06	0.06	0.916	y	y	45	0.4	0.33	10	0	y

4. Open the ‘Steady Flow Analysis’ window and “Save Plan As” a new plan file with an appropriate name and short name. Check your desired **geometry** and **steady flow** files are chosen.
5. Compute the plan.
6. Repeat the above steps for the different schemes you would like to test.
7. Open the Profile Plot window, and choose Options and select ‘*Plans …*’ Choose the plans you would like to display.

QUESTION: What did you notice about the ice jam profile when you varied a strength parameter?

____

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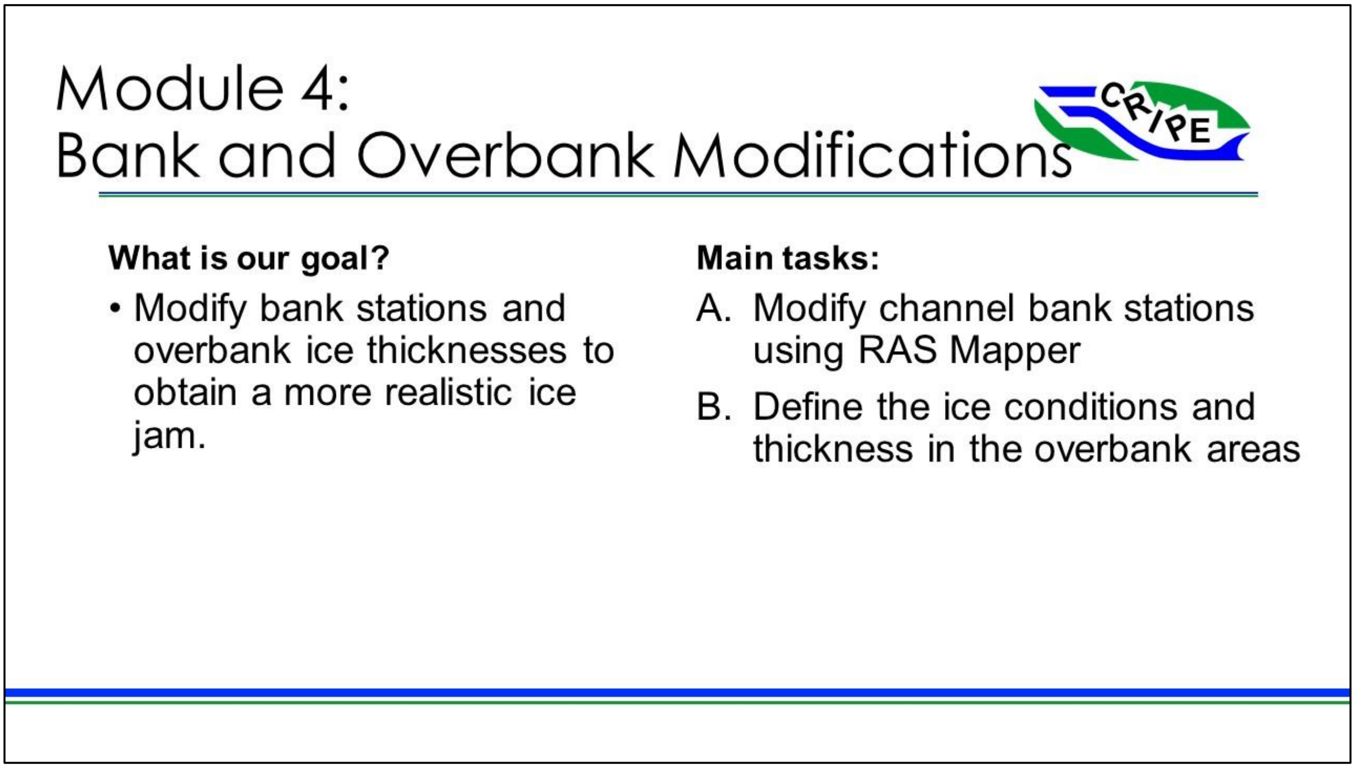
____

____

8. Close all tabs and windows except the main interface.

Module 4: Modify Ice Jam Width and Consider Overbank Areas



Module 4: Bank and Overbank Modifications

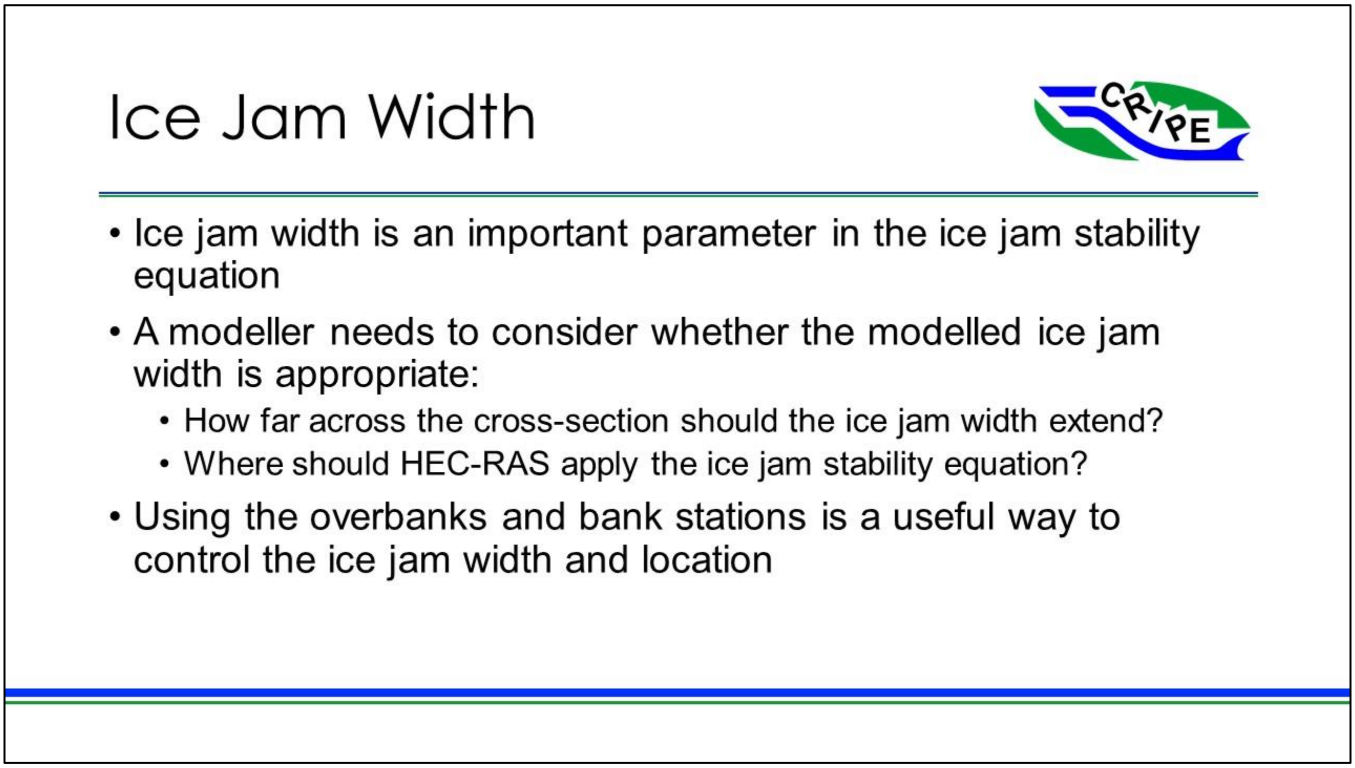
What is our goal?

- Modify bank stations and overbank ice thicknesses to obtain a more realistic ice jam.

Main tasks:

A. Modify channel bank stations using RAS Mapper

B. Define the ice conditions and thickness in the overbank areas

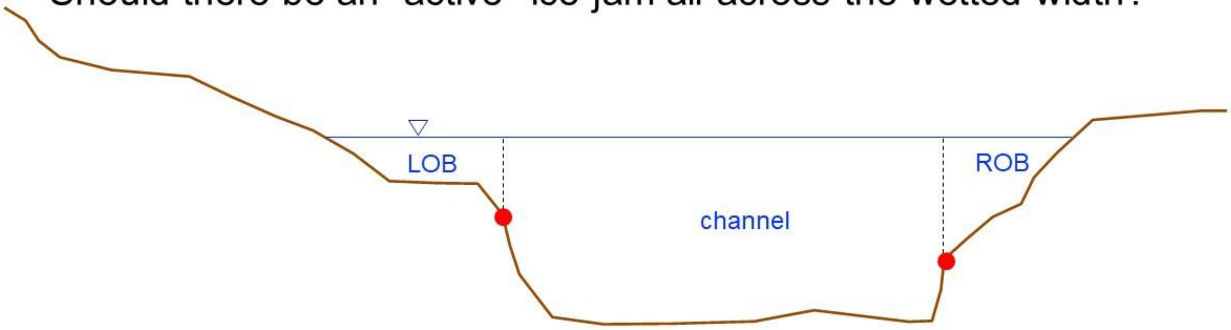


Ice Jam Width

- Ice jam width is an important parameter in the ice jam stability equation
- A modeller needs to consider whether the modelled ice jam width is appropriate:
  - How far across the cross-section should the ice jam width extend?
  - Where should HEC-RAS apply the ice jam stability equation?
- Using the overbanks and bank stations is a useful way to control the ice jam width and location

Ice Jam Width

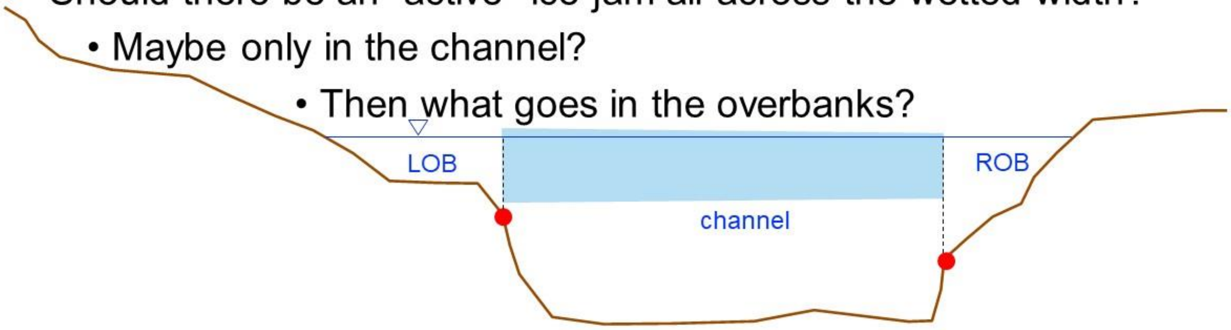
- Should there be an “active” ice jam all across the wetted width?



* “Active” means included in the ice jam stability equation

Ice Jam Width

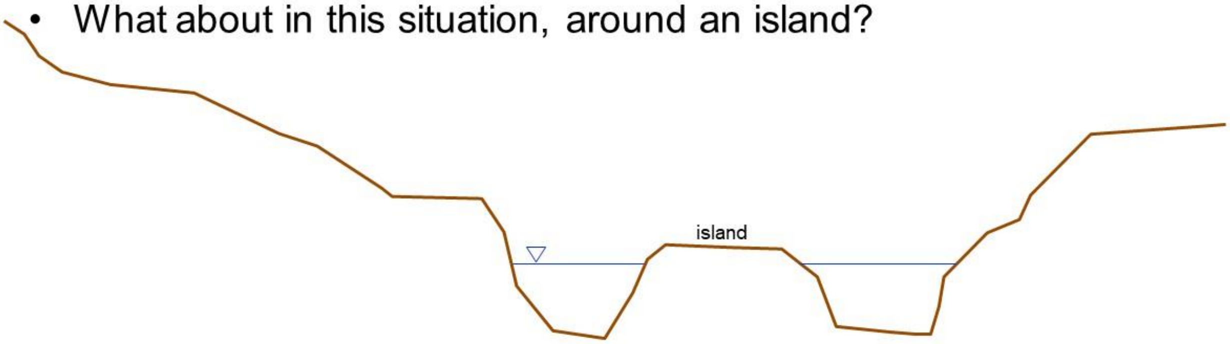
- Should there be an “active” ice jam all across the wetted width?
  - Maybe only in the channel?
    - Then what goes in the overbanks?



* “Active” means included in the ice jam stability equation

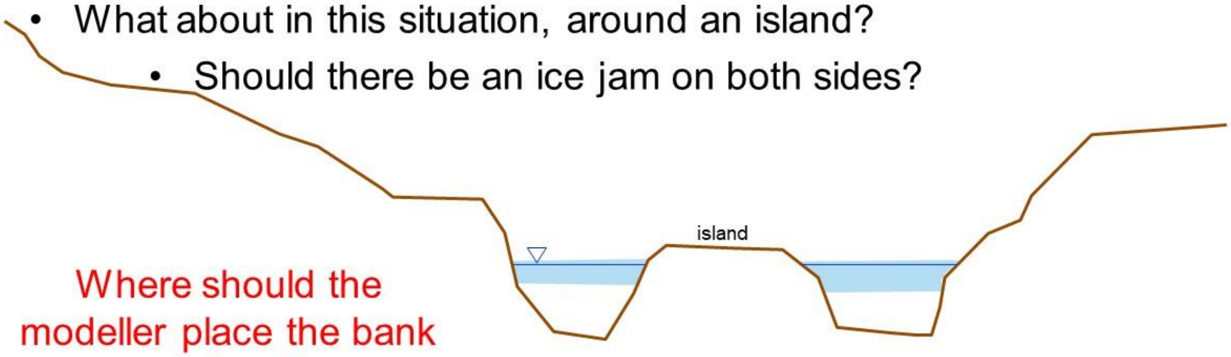
Ice Jam Width

- What about in this situation, around an island?



Ice Jam Width

- What about in this situation, around an island?
    - Should there be an ice jam on both sides?



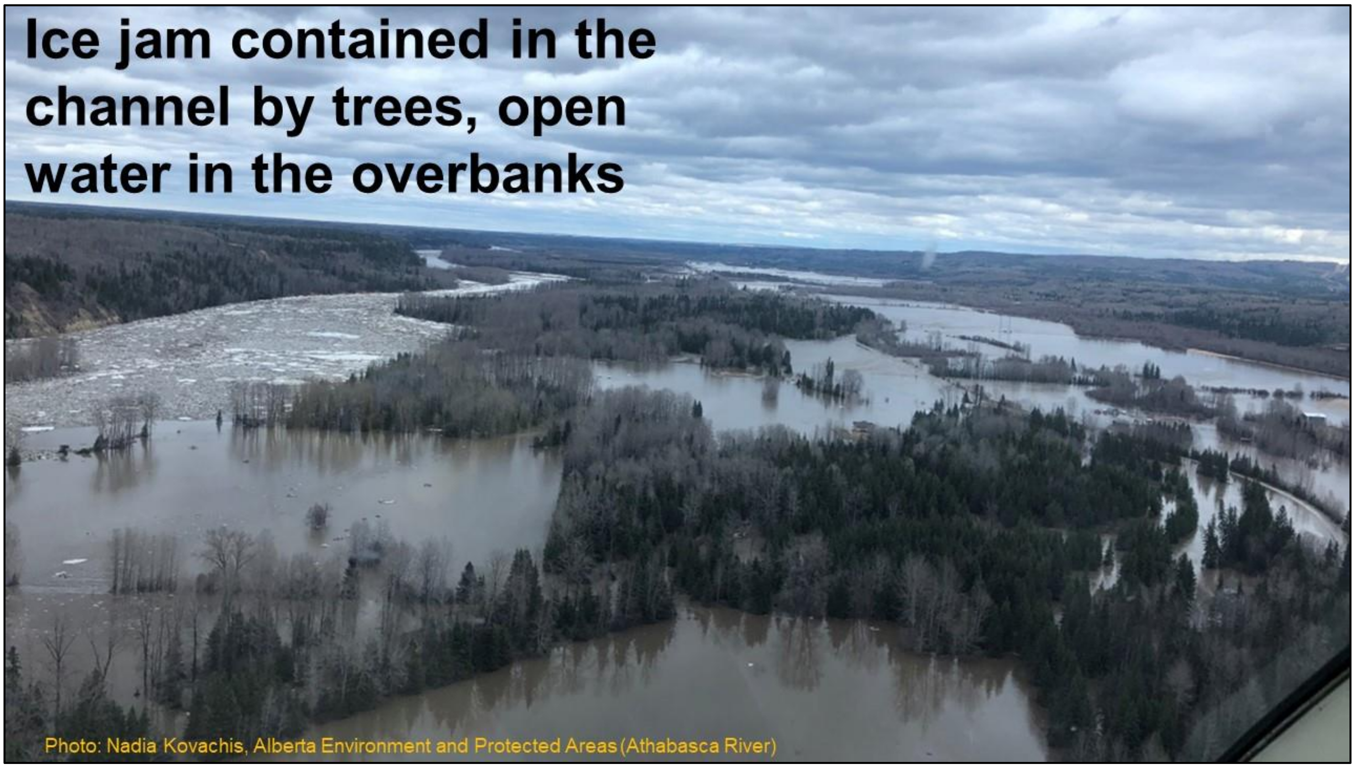
Where should the modeller place the bank stations?

Ice Jam Width and Placement

- Depends on the situation you are modelling
- Choice depends on observations and/or expected ice jam behavior:
  - What is the active width?
  - Where is the active ice jam located?
  - What are the ice conditions in the overbank areas?
- There are several possibilities
  - Examples on next slides

Ice jam and water contained in the channel

Photo: Nadia Kovachis, Alberta Environment and Protected Areas (Athabasca River)



Ice jam contained in the channel by trees, open water in the overbanks

Photo: Nadia Kovachis, Alberta Environment and Protected Areas (Athabasca River)

Ice jam on both sides of an island

Photo: Jennifer Nafziger, University of Alberta (Hay River)

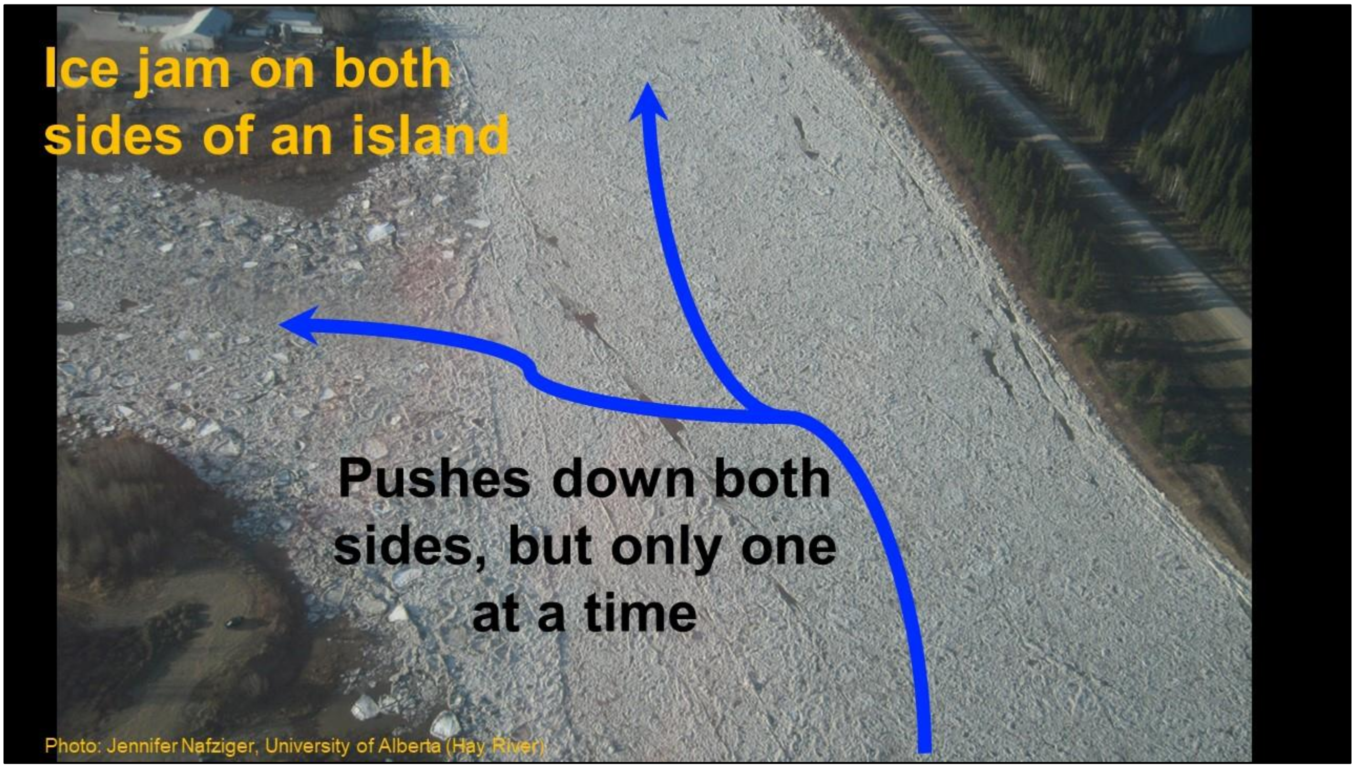
Ice jam on both sides of an island

Photo: Jennifer Nafziger, University of Alberta (Hay River)

Ice jam on both sides of an island

What is the active width?

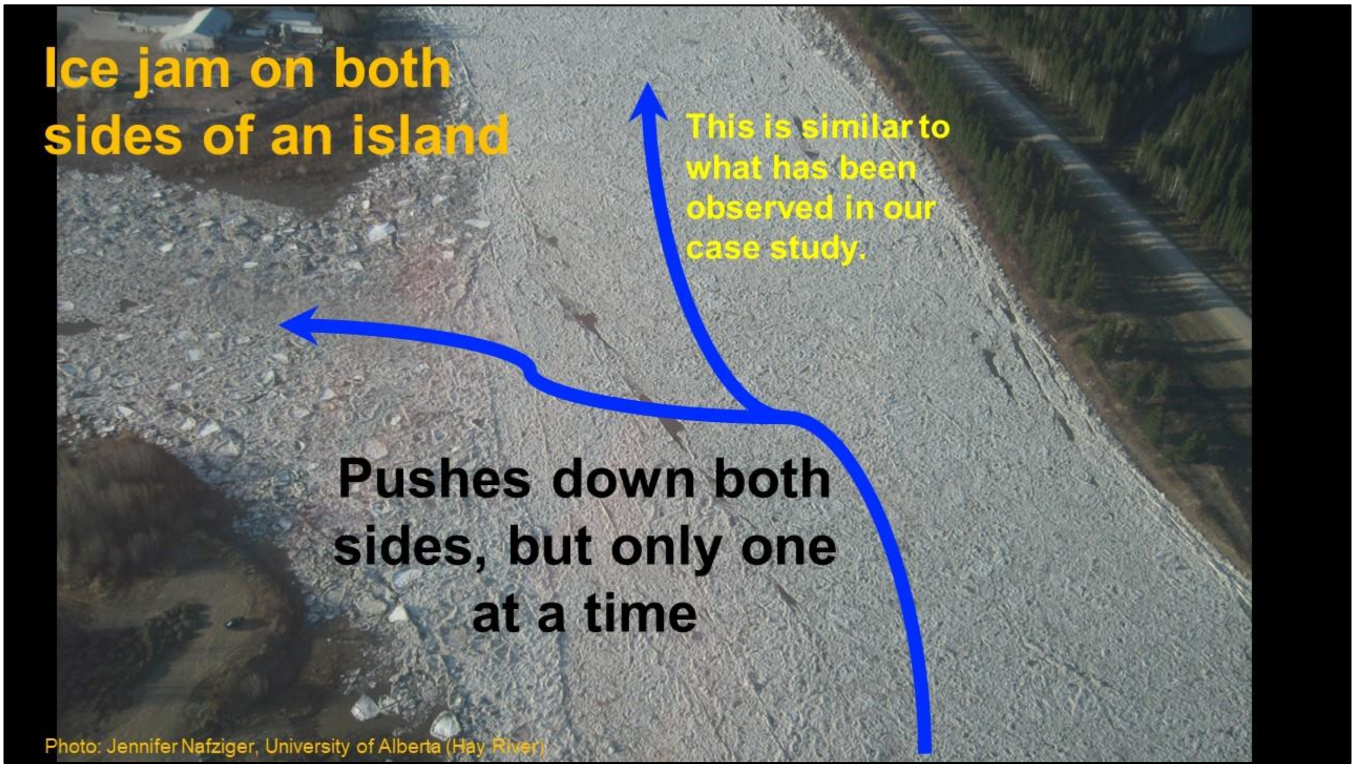
Photo: Jennifer Nafziger, University of Alberta (Hay River)



Ice jam on both sides of an island

Pushes down both sides, but only one at a time

Photo: Jennifer Nafziger, University of Alberta (Hay River)



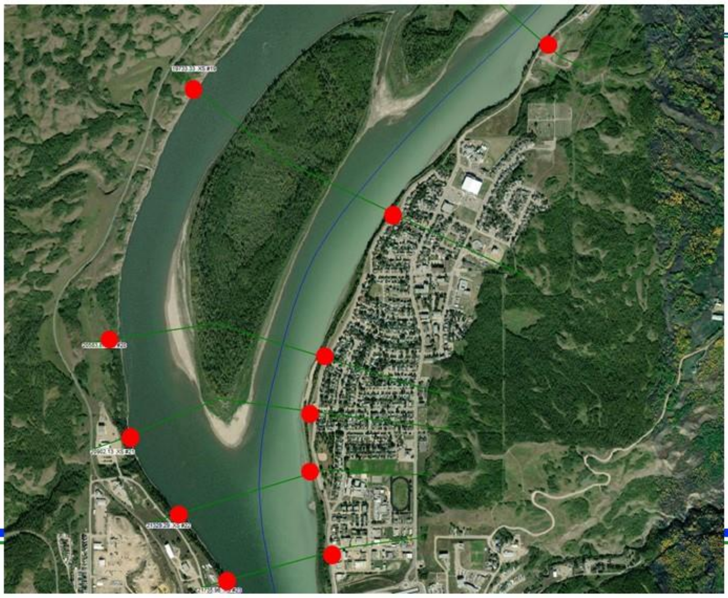
Ice jam on both sides of an island

This is similar to what has been observed in our case study.

Pushes down both sides, but only one at a time

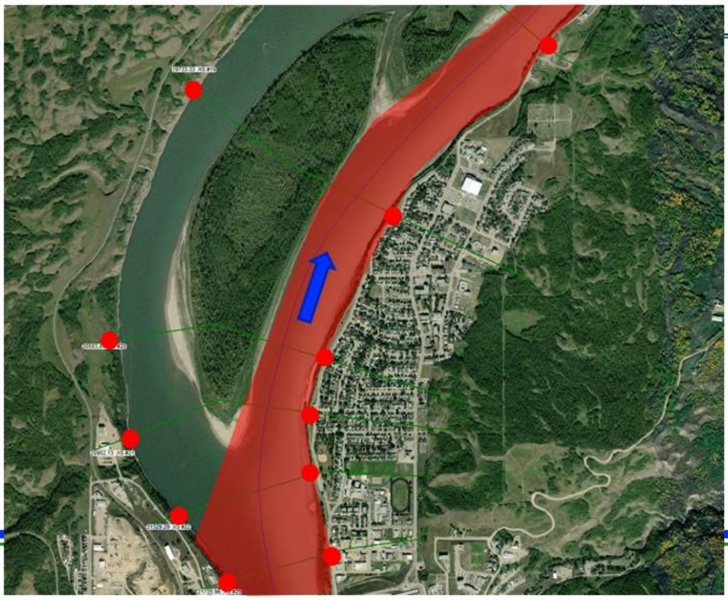
Photo: Jennifer Nafziger, University of Alberta (Hay River)

Beweley Island Bank Stations



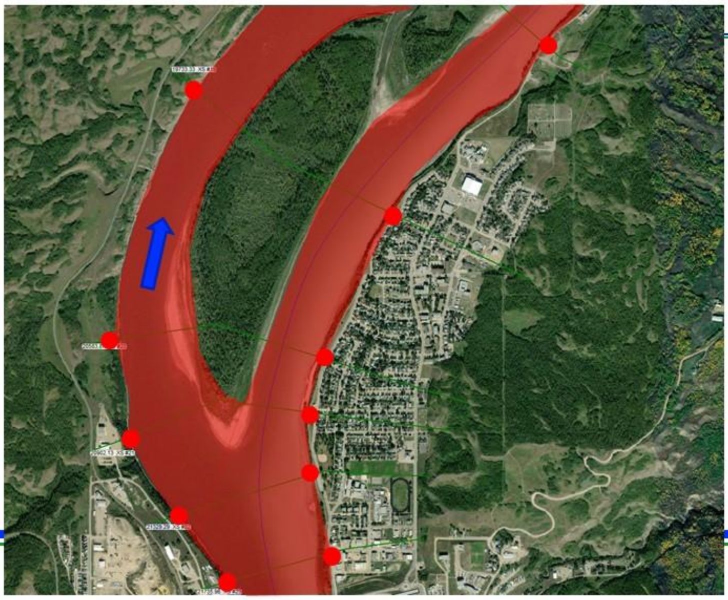
In the open water model the bank stations were on the outside of the entire river, so that the island was included in the channel.

Beweley Island Bank Stations



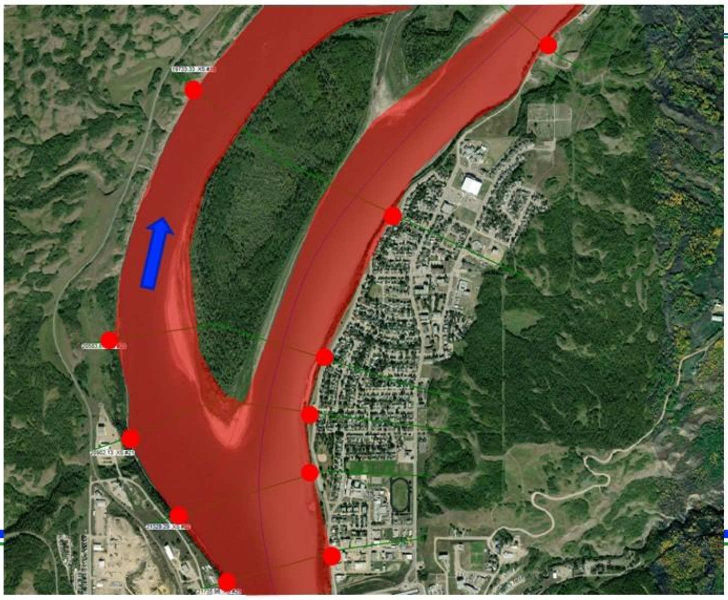
Observations indicate that in our case study ice jams are active down only one side of the island at a time.

Beweley Island Bank Stations



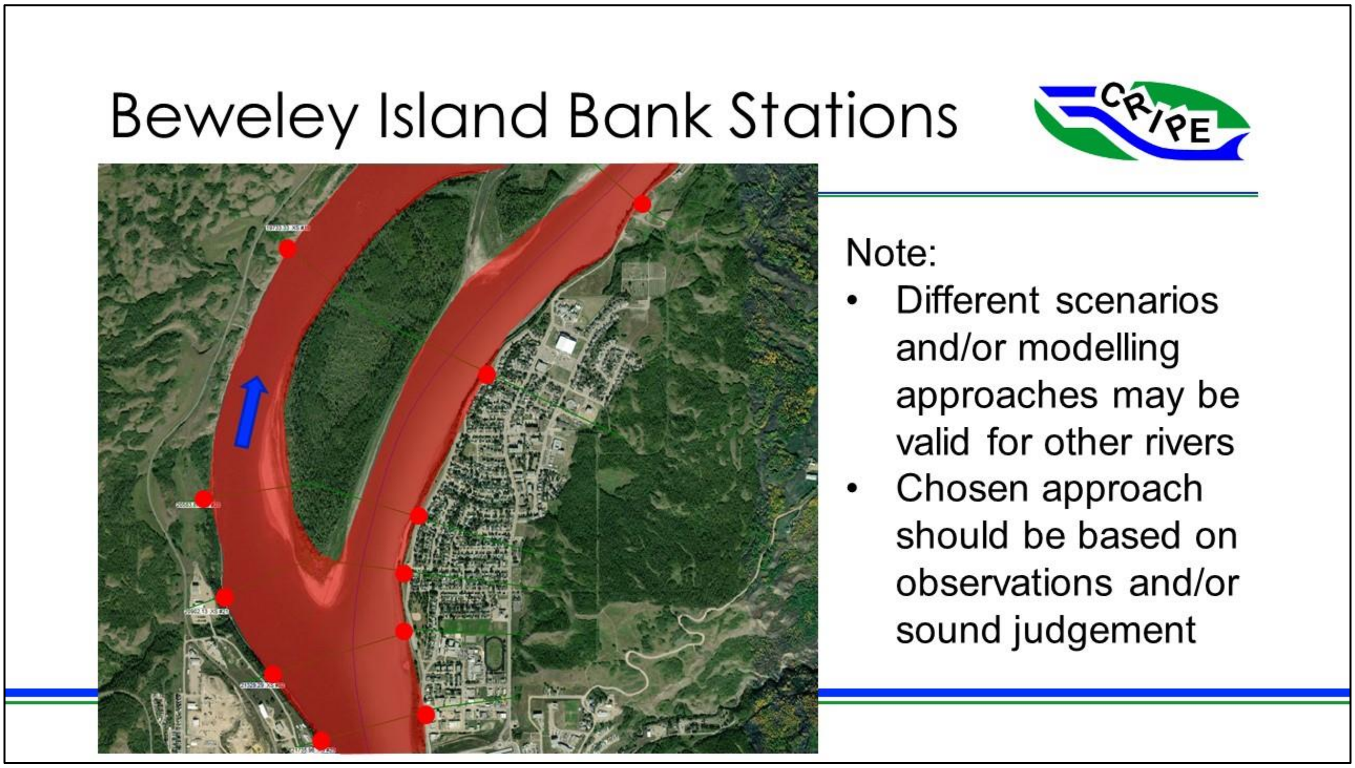
But both sides eventually fill with ice.

Beweley Island Bank Stations



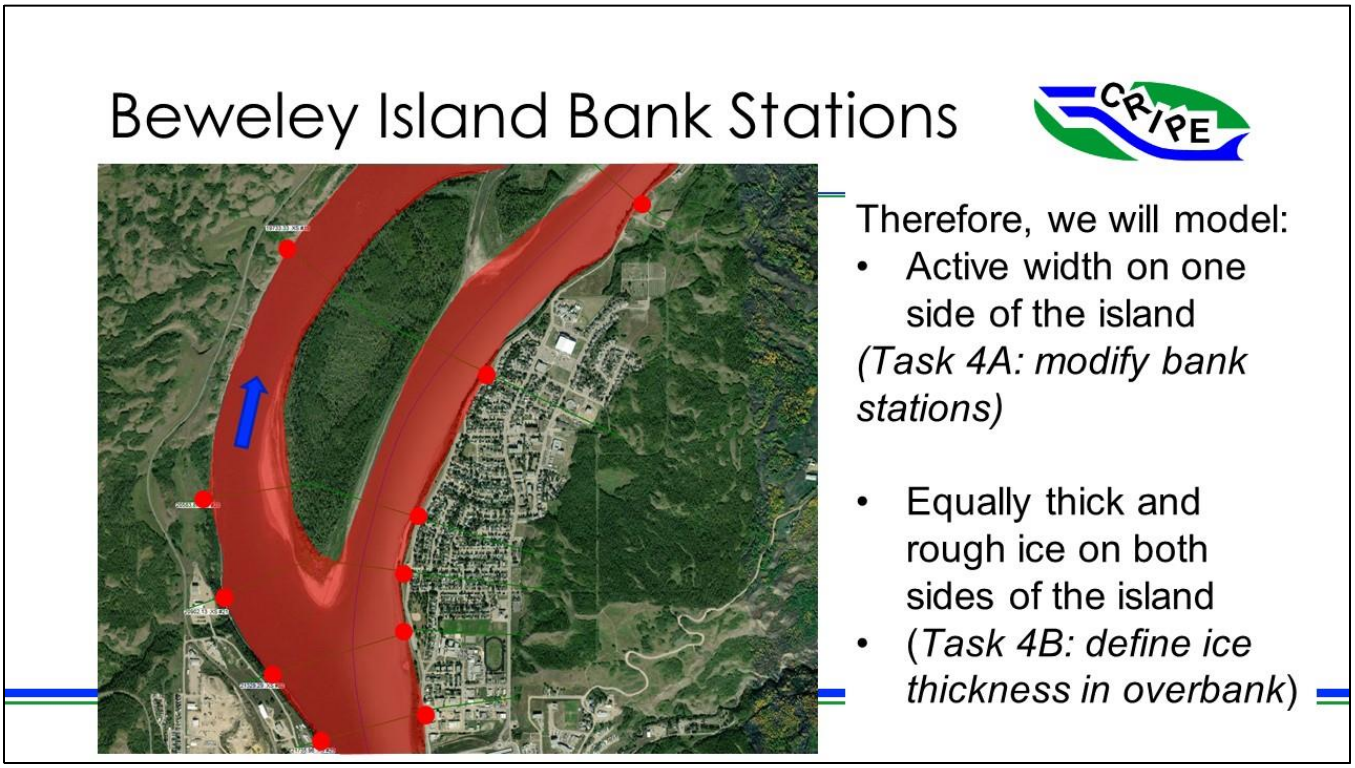
Therefore, we will model:

- Active width on one side of the island
- Equally thick and rough ice on both sides of the island



Beweley Island Bank Stations

Note:
- Different scenarios and/or modelling approaches may be valid for other rivers
- Chosen approach should be based on observations and/or sound judgement



Beweley Island Bank Stations

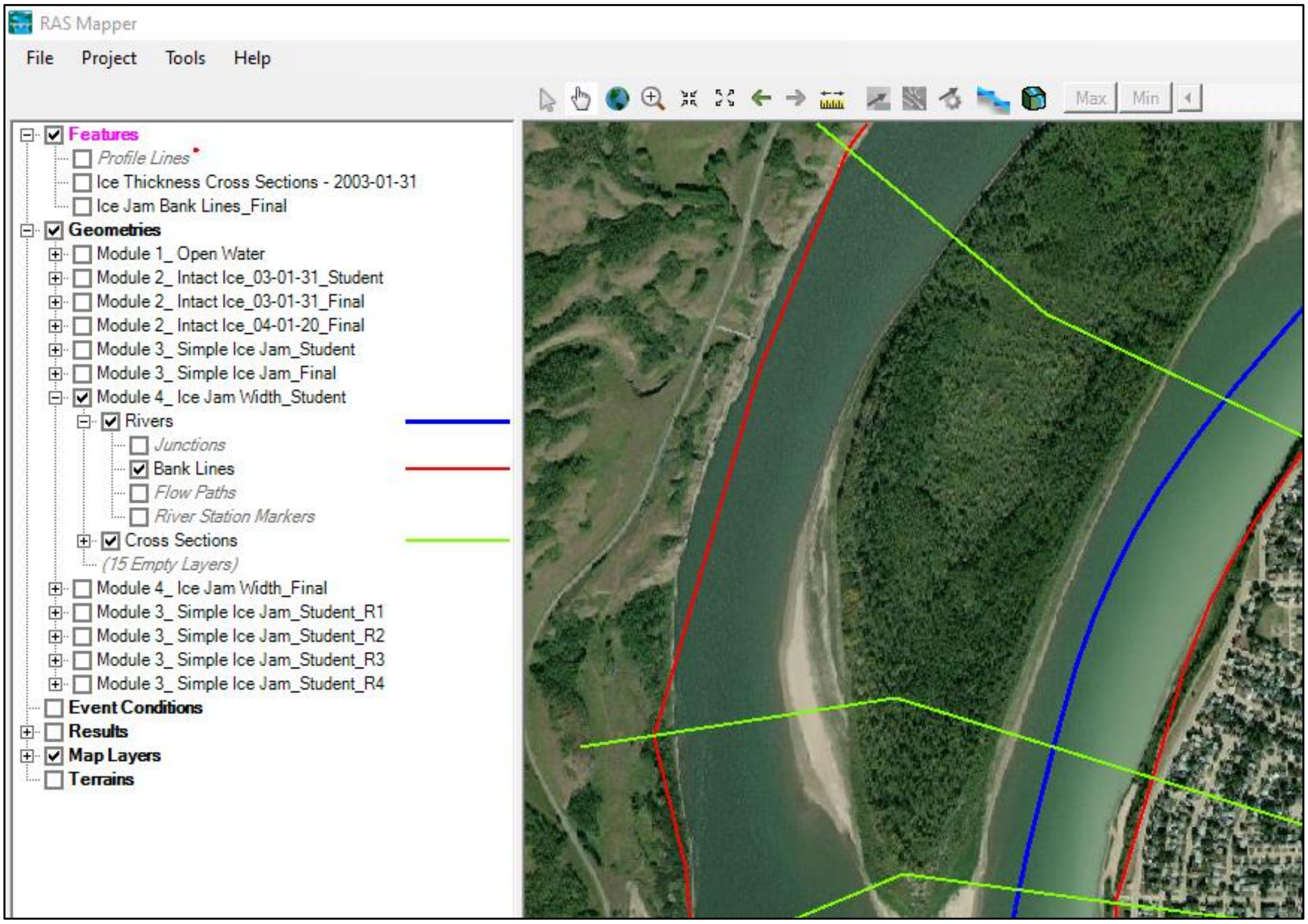
Therefore, we will model:
- Active width on one side of the island

(Task 4A: modify bank stations)

- Equally thick and rough ice on both sides of the island
- (*Task 4B: define ice thickness in overbank*)

Task 4A Instructions: Modify Channel Bank Stations

1. Open the ‘Geometric Data’ window by clicking the in the main interface. Go to File and click ‘*Open Geometry Data …*’. Pick the **Geometry File** called **“Module 4: Ice Jam Width_Student”**. Click OK.
2. Click on in the main interface to open the ‘Steady Flow Data’ window. Go to File and click ‘*Open Flow Data ...*’. Pick the **Steady Flow File** called “**Module 3: Simple Ice Jam**”. Click OK. We will continue to use the same steady flow information that we used in Module 3.
3. Close the ‘Steady Flow Data’ window by clicking the ×
4. In the main interface window, open the ‘RAS Mapper’ window.
5. In the pane on the left, expand the “**Module 4_Ice Jam Width_Student**” layer. Turn on ‘*Cross Sections*’. Expand ‘*Rivers*’, and turn on ‘*Bank Lines*’. Make sure all other layers are turned off, except for the ‘*Map Layers*’ base layer.

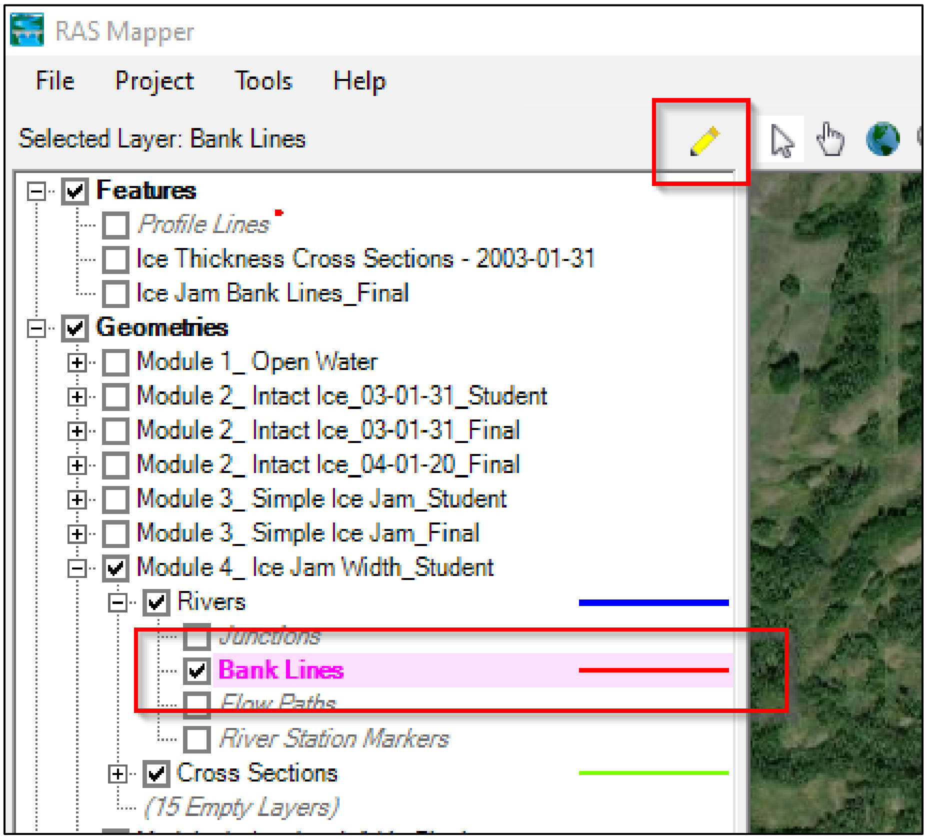


The red bank lines shown on the map are generated from the open water geometry. They are straight lines that intersect each cross-section at the bank station defined in the geometry file.

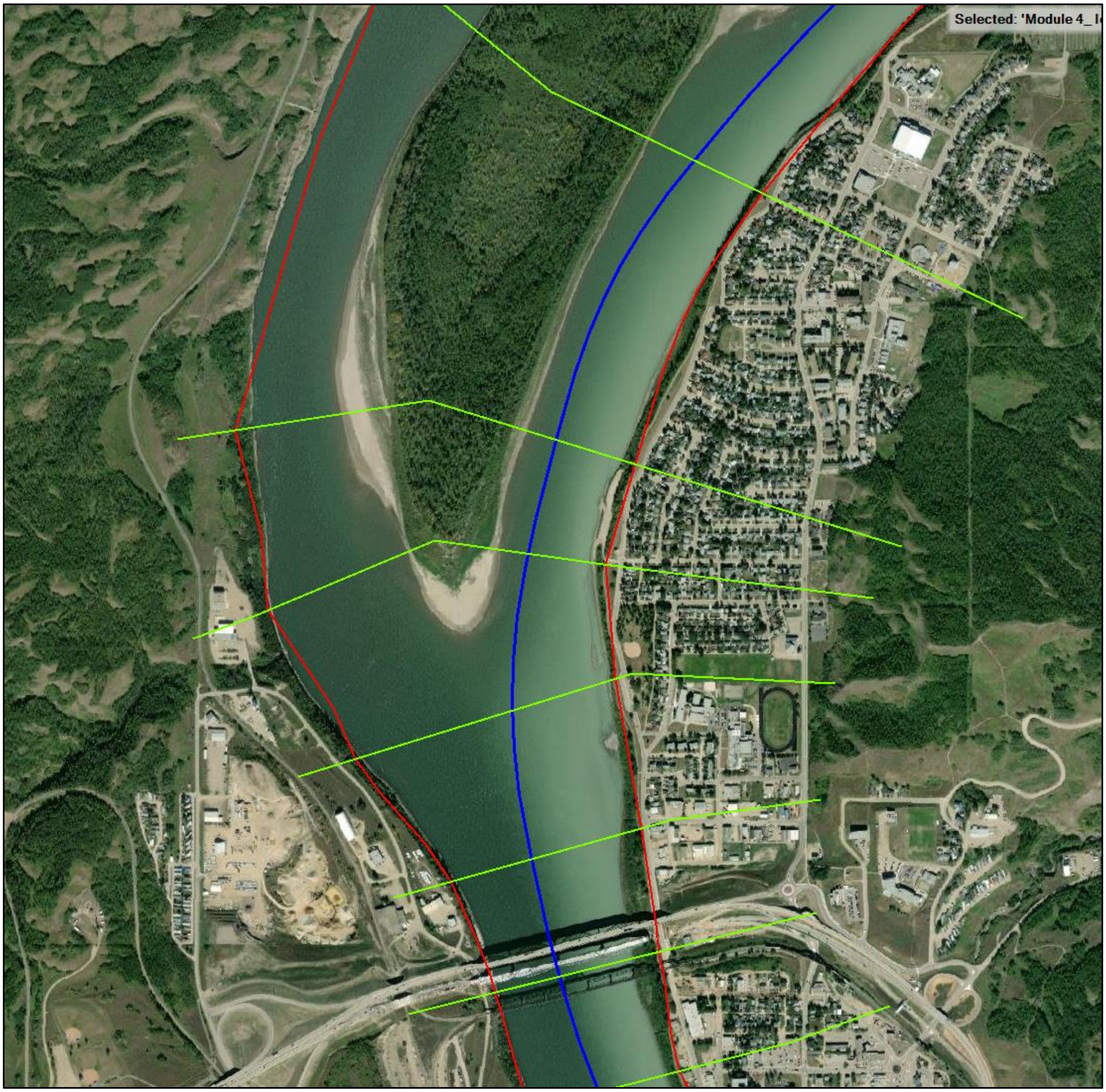
The bank lines will be edited to reflect the active ice jam width instead of the open channel width. In this case study, the ice jam was found to shove along one side of the island at a time. Therefore, assuming that the entire river width on both sides of the island contributes to the active ice jam would be unrealistic.

We will start by editing the bank lines from the Hwy 2 bridge to around Beweley Island.

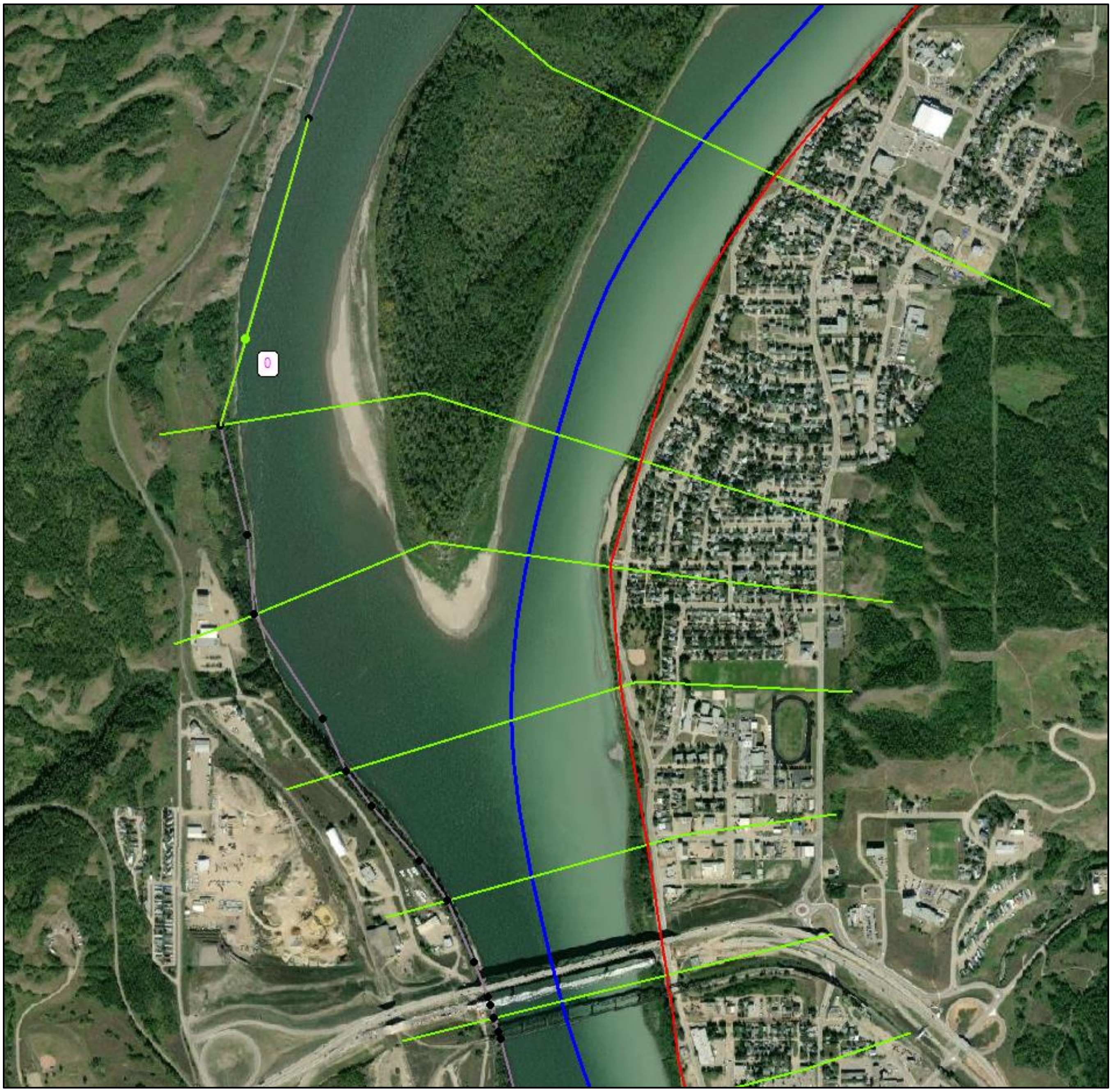
6. Start editing the Bank Lines feature under “**Module 4_Ice Jam Width_Student**”. Select the ‘*Bank Lines feature*’ (it will turn pink), then choose the ✎ icon on top of the left pane.



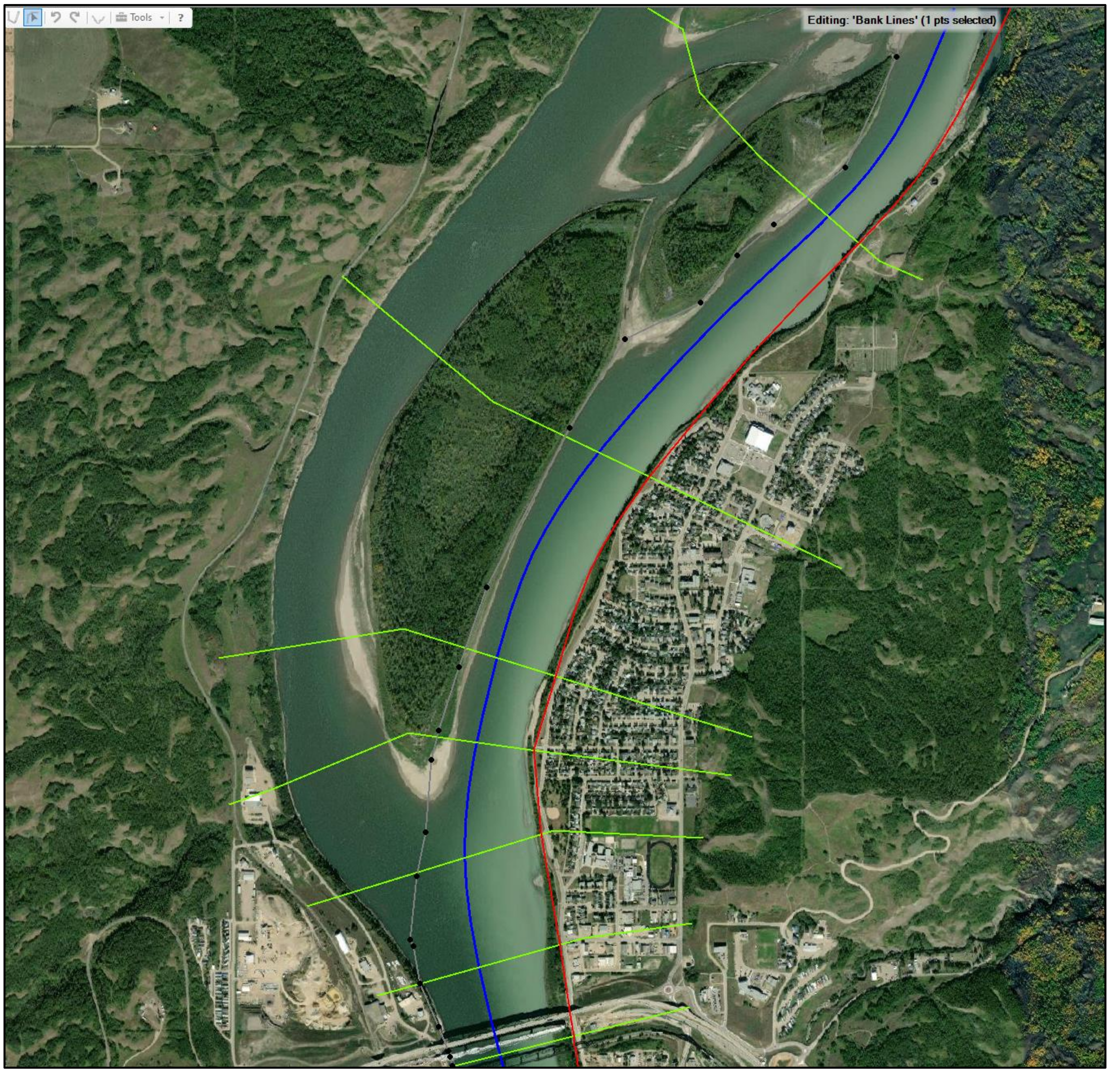
7. Pan to the area downstream of the Hwy 2 and CN Rail Bridges using the *pan tool* ☝. We will start editing the bank lines downstream of the bridges and along Beweley Island.



8. Using the *arrow tool* , double click on the red bank line on the left bank. This will reveal the vertices of the bank line:


0

9. Using the *arrow tool*, move and re-draw the bank line so that the channel is defined only on the river right side of Beweley Island. Helpful tools and procedures include:
    - *Move vertex:* click on existing vertex and drag to new location
    - *Add new vertex:* click on the line between two vertices, the new vertex can then be moved
    - *Delete vertex:* click on the vertex and press delete
    - *Undo last edit:* press Ctrl + Z
    - You can use the pan tool while editing, but you must switch back to the arrow tool to continue editing.

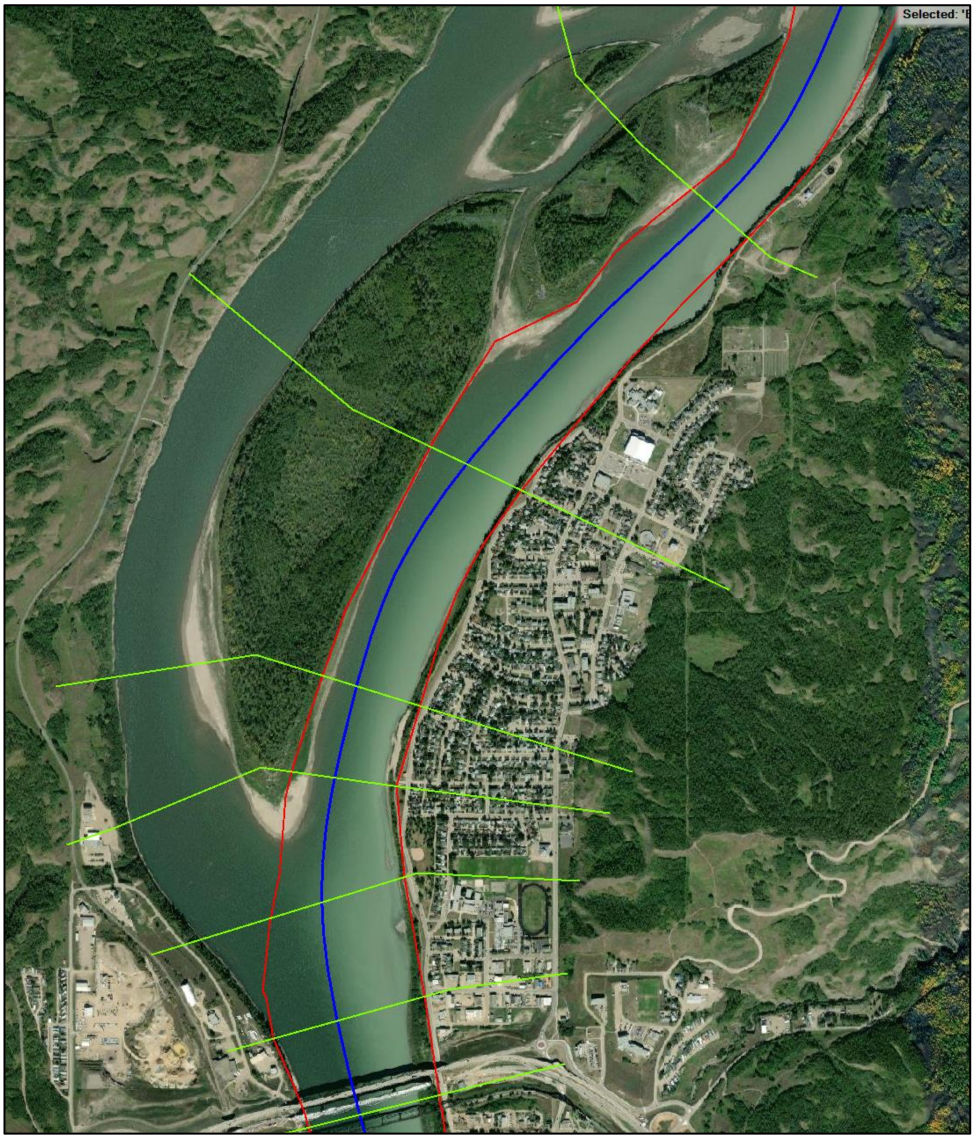


Editing: 'Bank Lines' (1 pts selected)

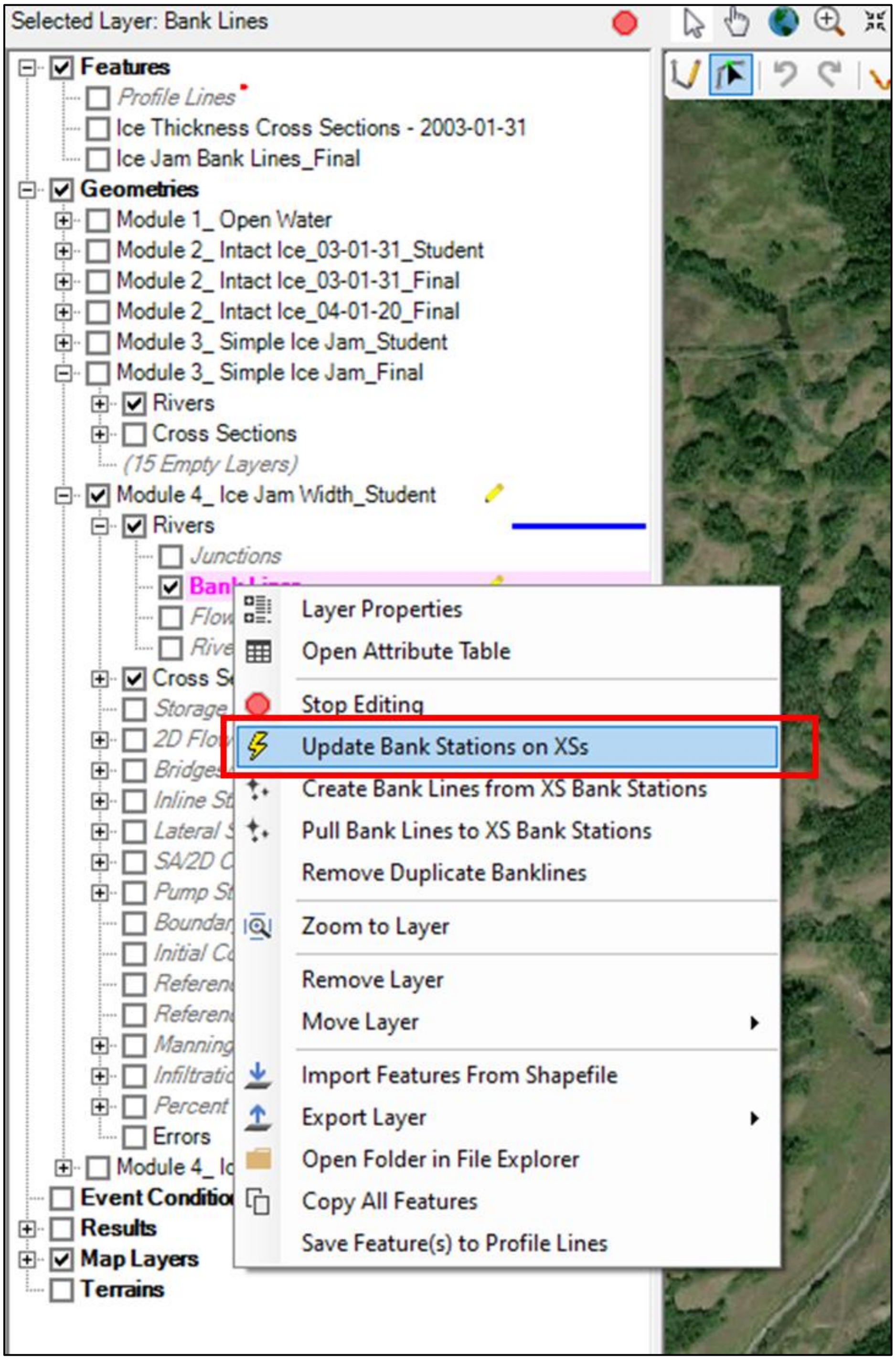
There are several ways to choose where to place the new bank lines:

- Along the edge of the large, permanent vegetation (trees, not shrubs). The assumption here is that ice movement prevents the establishment of large trees
- Using a digital terrain file, and identifying the topographic feature that resembles a geomorphic top of bank
- Using field observations (aerial photographs) of actual ice jams in this area to determine where the active channel is and the extents of the active channel in a multi-channel environment.
- In all cases, care should be taken to ensure that the active width does not rapidly expand or contract, and that changes in width are gradual from cross-section to cross-section.

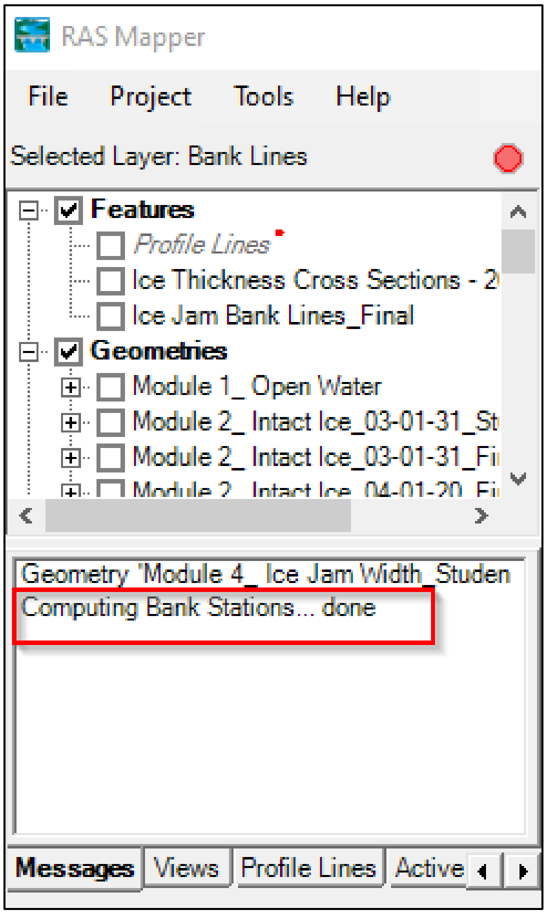
10. Save your changes to the bank lines feature by clicking on the stop sign 🛑 above the left panel, and clicking Yes in the next dialog box. The bank lines will turn back to red.



11. Now, the new bank stations must be updated in the cross-sections in the **Geometry** File. Start editing the bank lines by clicking on the pencil icon ✏. Right click on the '*Bank Lines*' layer and select '*Update Bank Stations on XSs*'

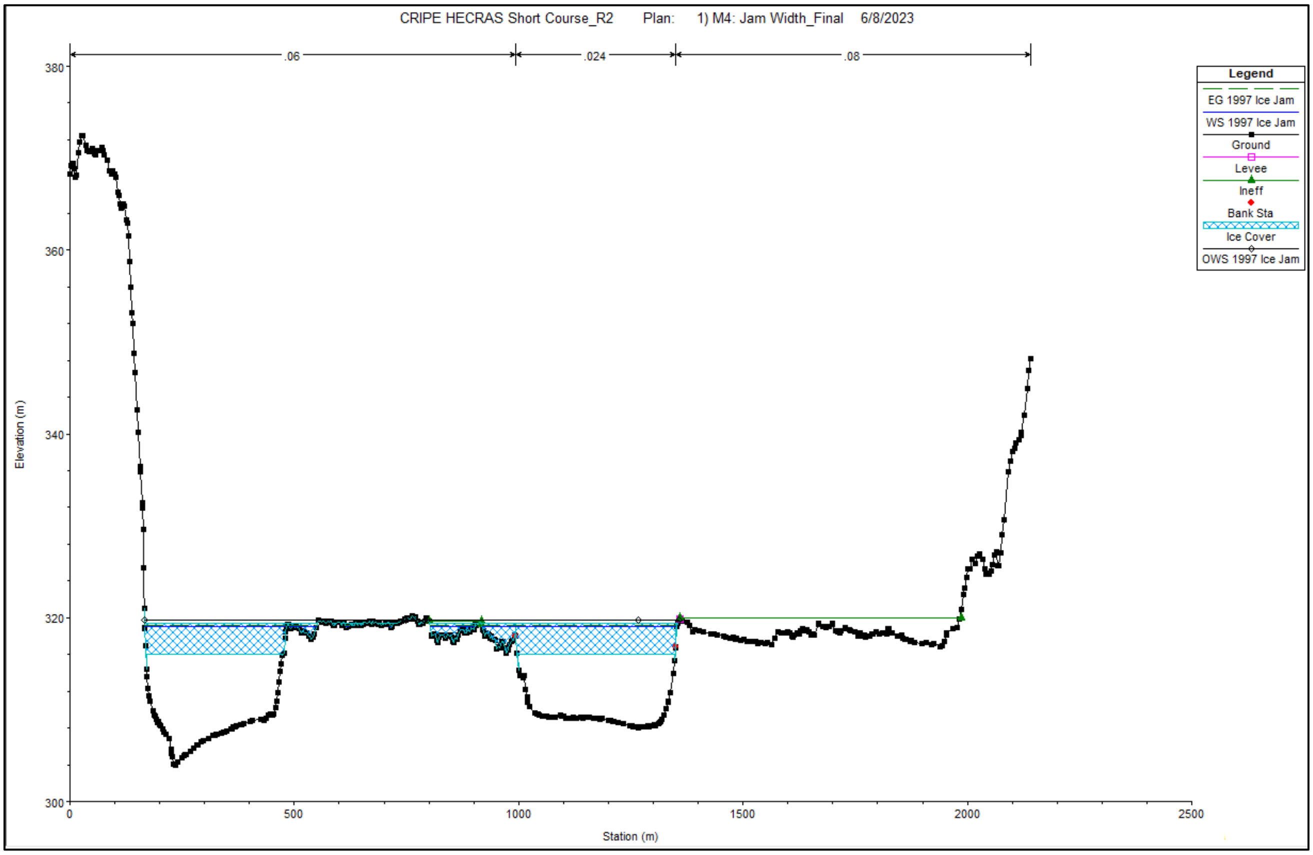


When the bank stations have been computed, there will be a note in the message box at the bottom of the left panel:



Geometry 'Module 4_ Ice Jam Width_Studen
Computing Bank Stations... done

12. Stop editing and save the bank stations by clicking the stop sign ● and then clicking Yes. Note the note in the Messages box, indicating that the geometry has been saved.
13. Verify that the new bank stations have been incorporated into the model cross-sections. In the Geometric Data window, click on the 'Cross Section Data' icon Cross Section.
14. Navigate to *XS #19*, which intersects Beweley Island in its middle:



Now the channel (the section between the two red square dots) is defined only on the right side of the island, instead of including the middle island area and the left channel as well:

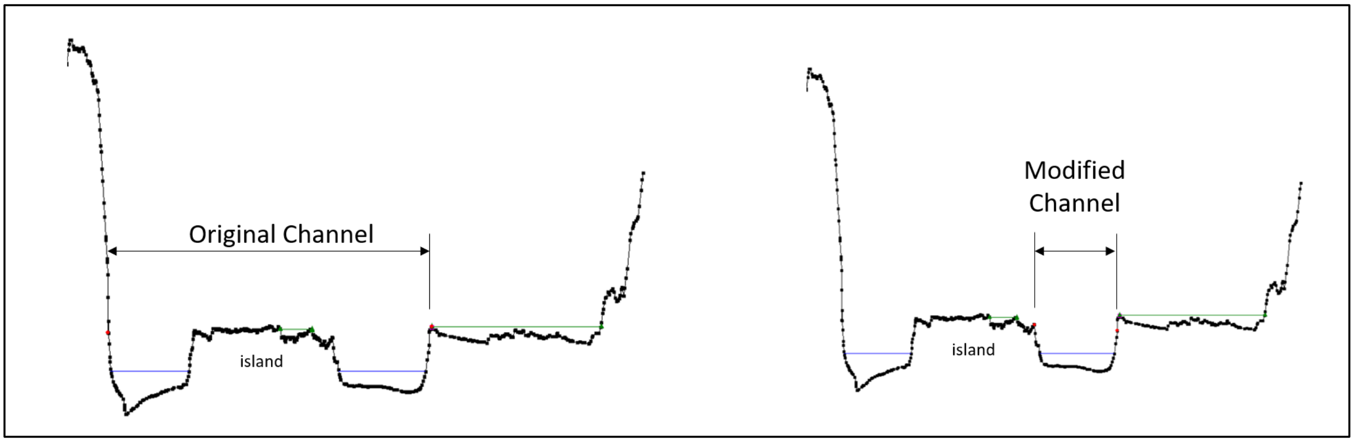
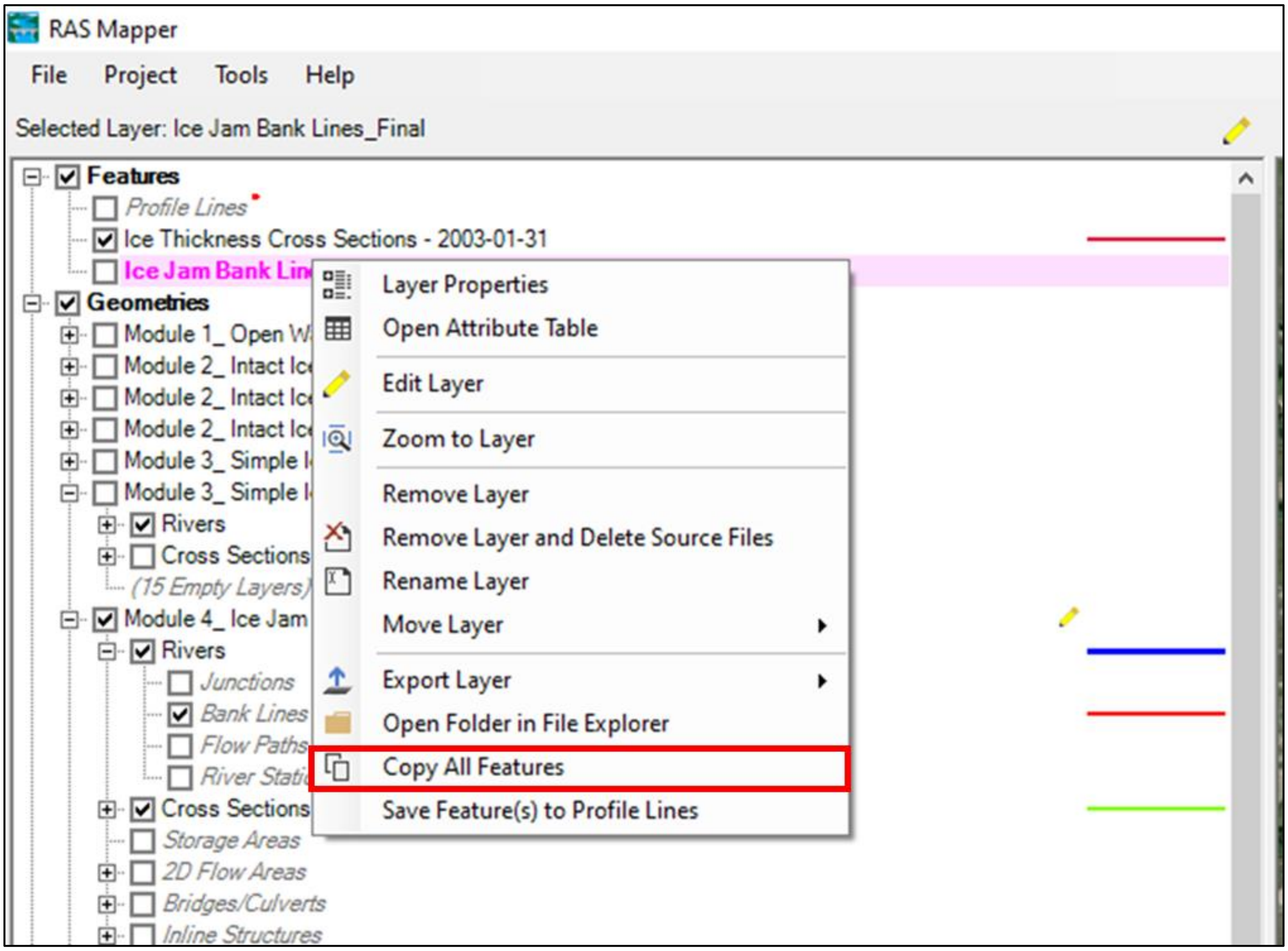


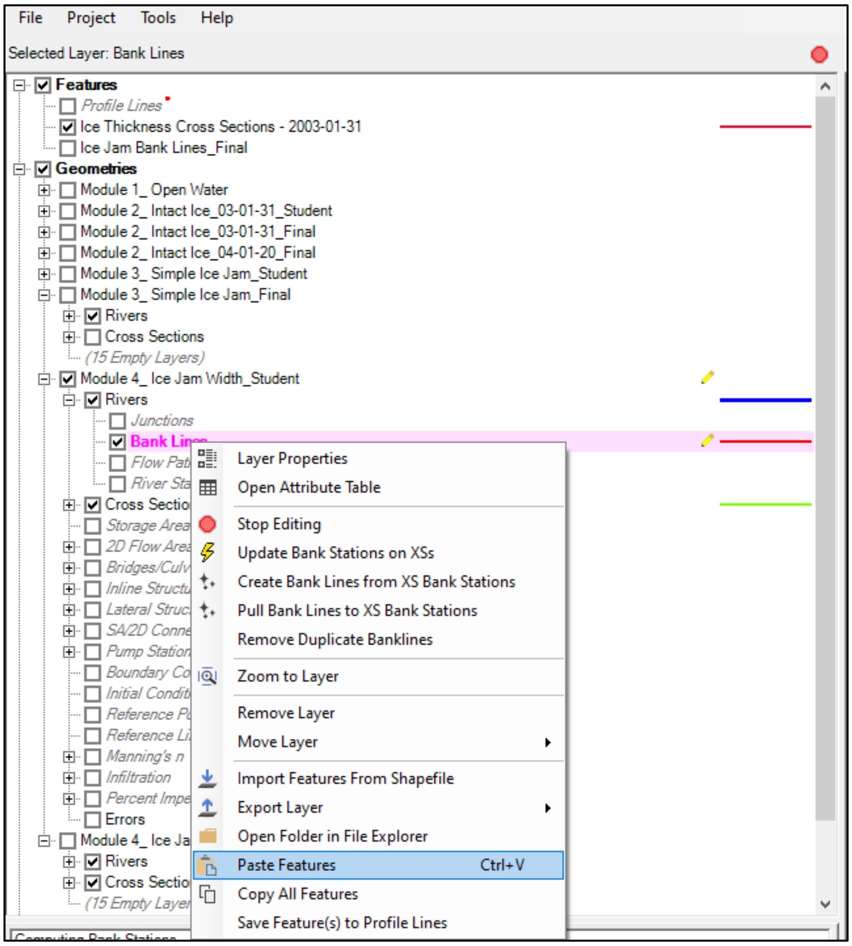
Figure 3: Schematic of original channel and modified channel at XS #19

Manually drawing accurate bank lines can be a long and tedious process in RAS Mapper, but there is a way to copy the bank lines from an existing polyline. For example, one you have imported from a GIS or CAD program. We will try that method next.

15. Start by editing the ‘*Bank Lines*’ feature under “**Module 4_Ice Jam Width_Student**”. Click on the layer and then choose the pencil icon ✎.
16. Delete the existing two bank lines by clicking on each of the two bank lines and then pressing ‘Delete’ on your keyboard.
17. The “Final bank lines” to copy into our model are located under the ‘Features’ heading at the top of the pane on the left. Right click on that feature (‘*Ice Jam Bank Lines_Final*’), and choose ‘*Copy All Features*’



18. Copy the new “Final” bank lines into the model bank line. Right click on the ‘*Bank Lines*’ layer in the Module 4 geometry, and choose ‘*Paste Features*’.



19. Copy the new final bank stations to the Geometry File by right clicking on the '*Bank Lines*' layer and select '*Update Bank Stations on XSs*'

20. Stop editing by clicking on the stop sign ● at the top of the left pane.

21. Pan through the new "Final" bank stations and see how the channel is defined around islands.

22. Save the RAS Mapper data by choosing File and selecting '*Save*'.

QUESTION: Does having a smaller ice jam top width result in a thinner or a thicker computed ice jam? Does this result in higher or lower computed water levels?

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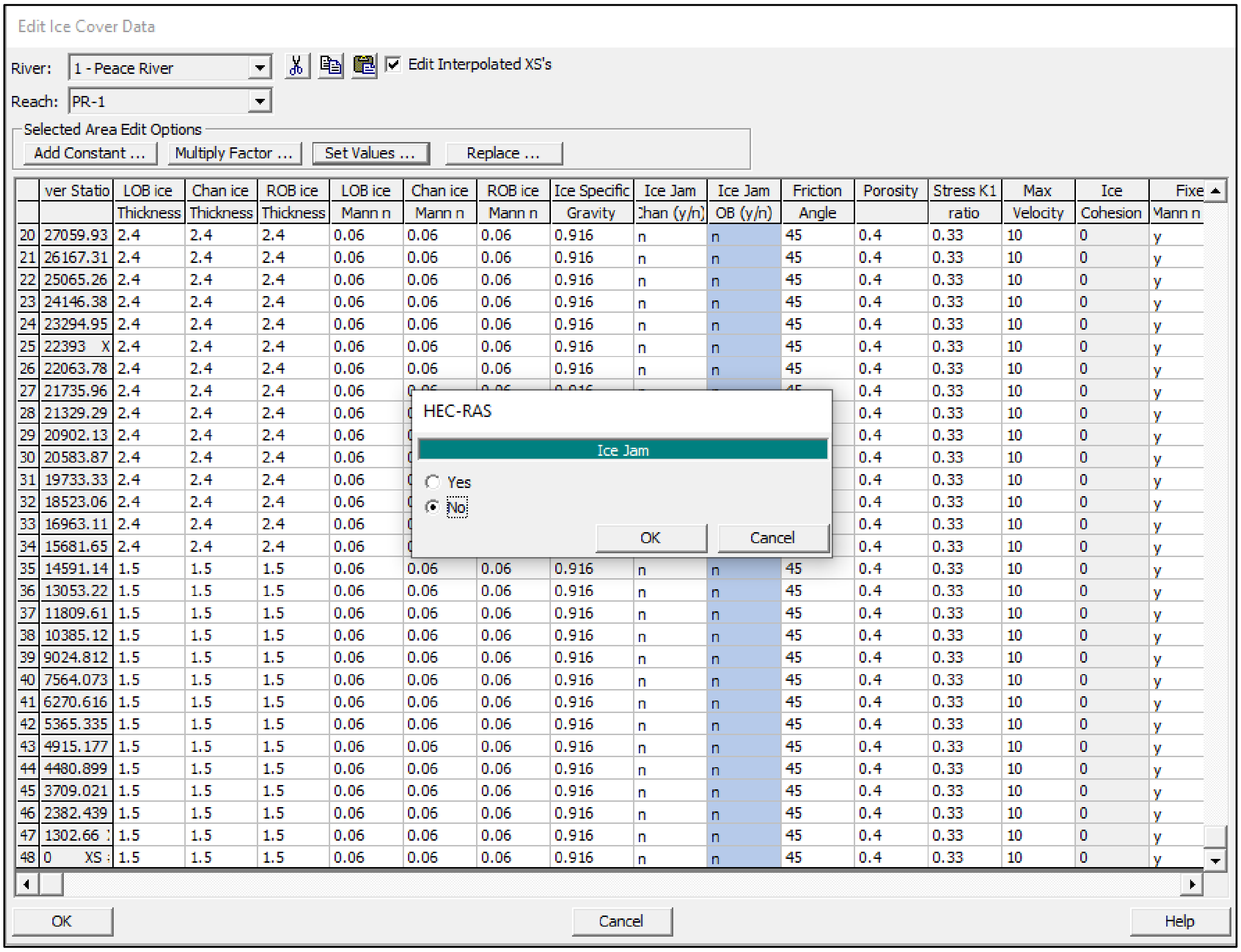
Task 4B Instructions: Define the Ice Thicknesses in the Overbank Areas

1. Click on the in the main interface to open the 'Geometric Data' window.
2. Go to Tables and select '*Ice Cover*'.
3. Make sure the ice jam is in the geometry file. Ensure all cross-sections from 15681.65 to 52544.35 have the values of '*Ice Jam Chan (y/n)*' column set to '*y*'. Fix this if it is not set to '*y*'. Depending on how the geometry file was saved, it may need to be fixed.
4. Select all values the '*Ice Jam OB (y/n)*' column and choose '*no*'. Then click OK. Make sure to not change the 'Ice Jam Chan (y/n)' column.



River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

	ver Statio	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam :han (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity	Ice Cohesion	Fixe Mann n
20	27059.93	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
21	26167.31	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
22	25065.26	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
23	24146.38	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
24	23294.95	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
25	22393 X	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
26	22063.78	2.4	2.4	2.4	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
27	21735.96	2.4	2.4	2.4	0.06							0.4	0.33	10	0	y
28	21329.29	2.4	2.4	2.4	0.06							0.4	0.33	10	0	y
29	20902.13	2.4	2.4	2.4	0.06							0.4	0.33	10	0	y
30	20583.87	2.4	2.4	2.4	0.06							0.4	0.33	10	0	y
31	19733.33	2.4	2.4	2.4	0.06							0.4	0.33	10	0	y
32	18523.06	2.4	2.4	2.4	0.06							0.4	0.33	10	0	y
33	16963.11	2.4	2.4	2.4	0.06							0.4	0.33	10	0	y
34	15681.65	2.4	2.4	2.4	0.06							0.4	0.33	10	0	y
35	14591.14	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
36	13053.22	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
37	11809.61	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
38	10385.12	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
39	9024.812	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
40	7564.073	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
41	6270.616	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
42	5365.335	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
43	4915.177	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
44	4480.899	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
45	3709.021	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
46	2382.439	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
47	1302.66 :	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
48	0 XS :	1.5	1.5	1.5	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y

HEC-RAS

Ice Jam

○ Yes
● No

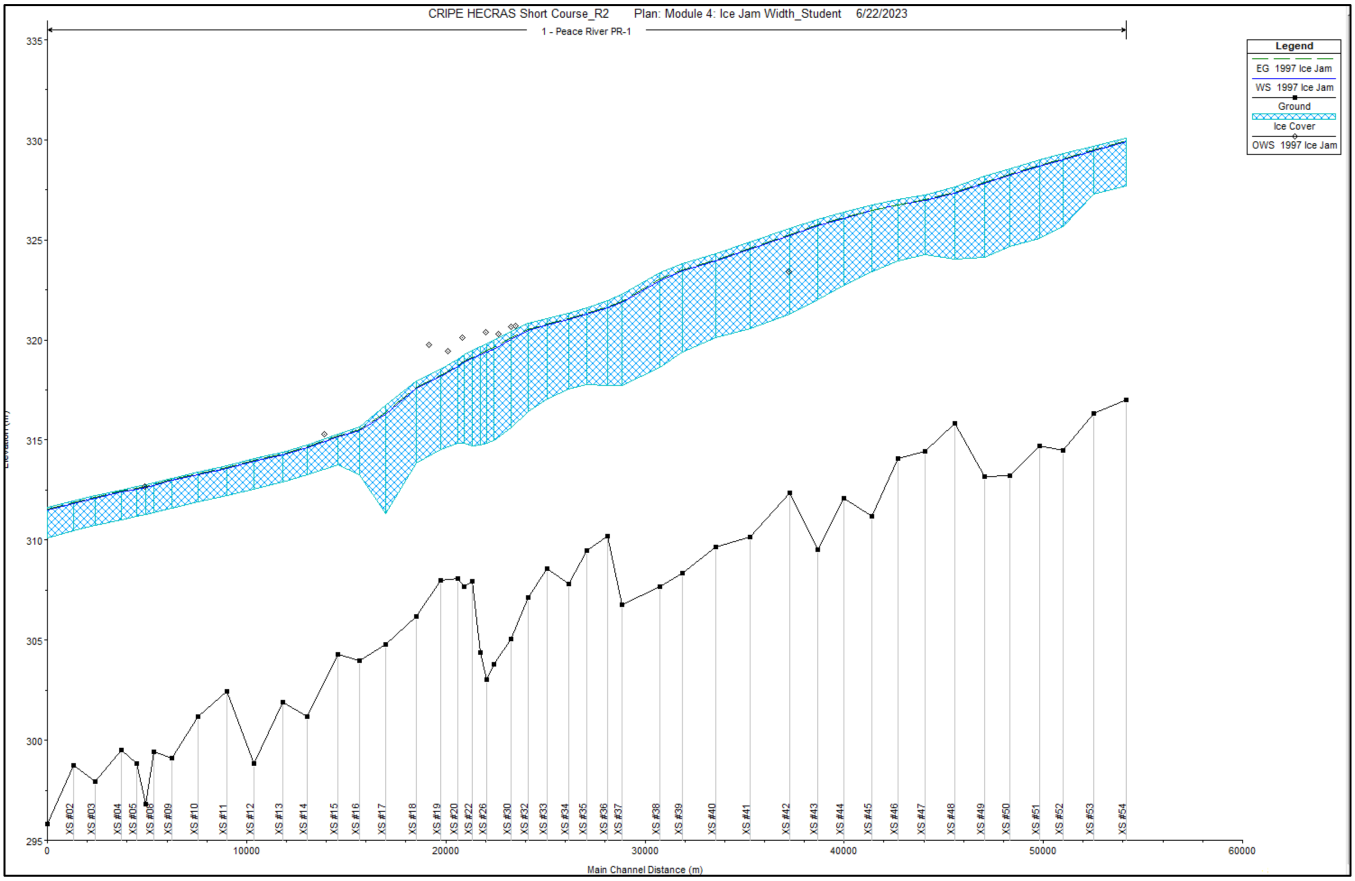
5. Close the 'Ice Cover Data' window by clicking OK.
6. Click on in the main interface to open the 'Steady Flow Analysis' window.
7. Go to File and select '*Open Plan …*'. Do not save other plans. Choose "**Module 4: Ice Jam Width_Student**". Click OK. Verify that the **Geometry** and **Steady Flow** files are correct:

Table 14: Model Files Used for HEC-RAS Module 4 - Task 4B

File Type	Filename
Plan	“Module 4: Ice Jam Width_Student”
Geometry	“Module 4: Ice Jam Width_Student”
Steady Flow	“Module 3: Simple Ice Jam”

8. Click Compute.

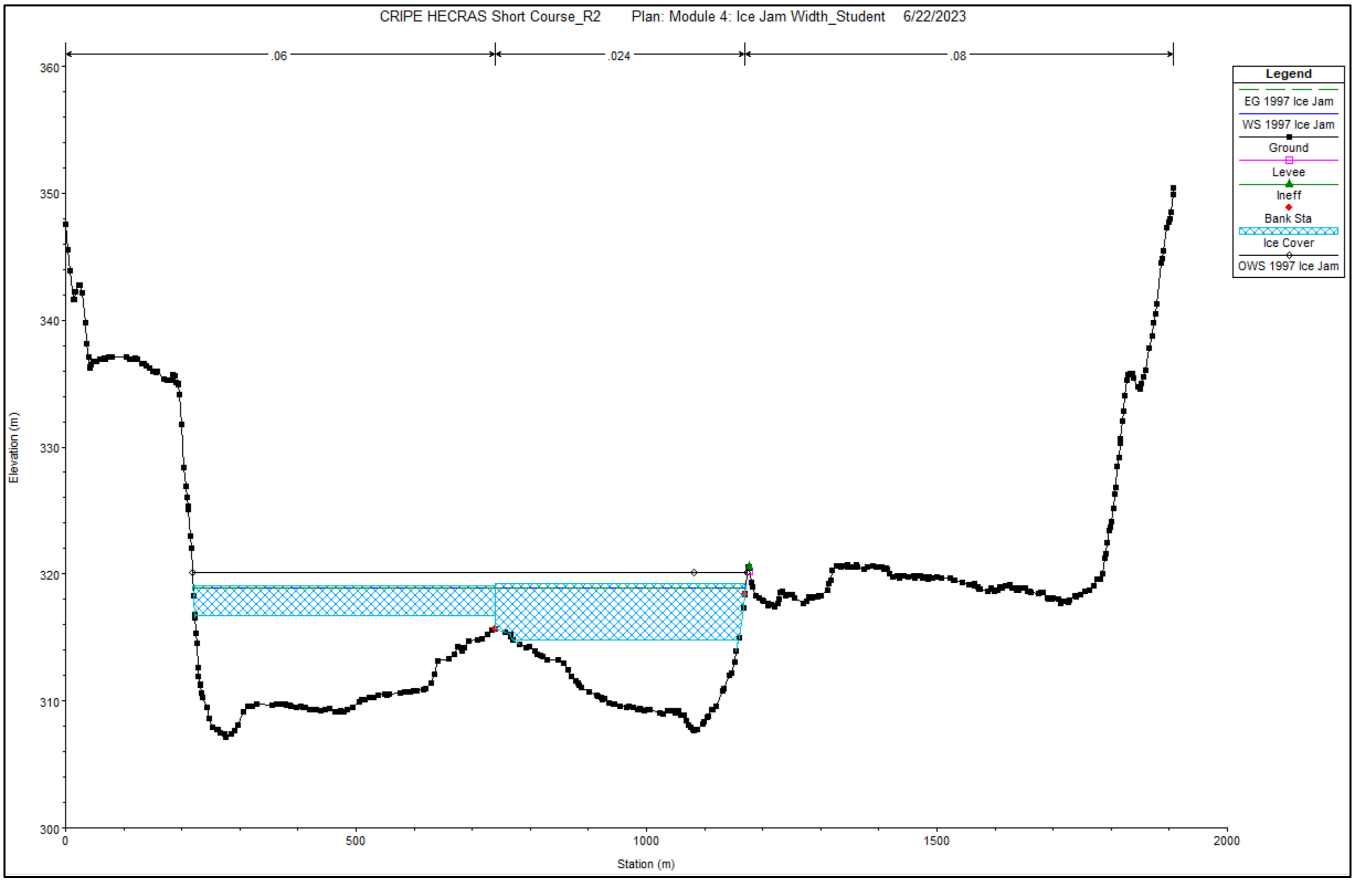
9. First, review the results in the profile plot .



Notice that the computed water surface is again below the observed water surface elevations. Let’s do some investigating to find out why, and then make some changes to the model.

10. Review the results by opening the cross-section viewer Cross Section in the 'Geometry Data' window .

11. Take a look at cross-section '*XS #21'* as an example, by choosing this cross-section from the drop-down menu.

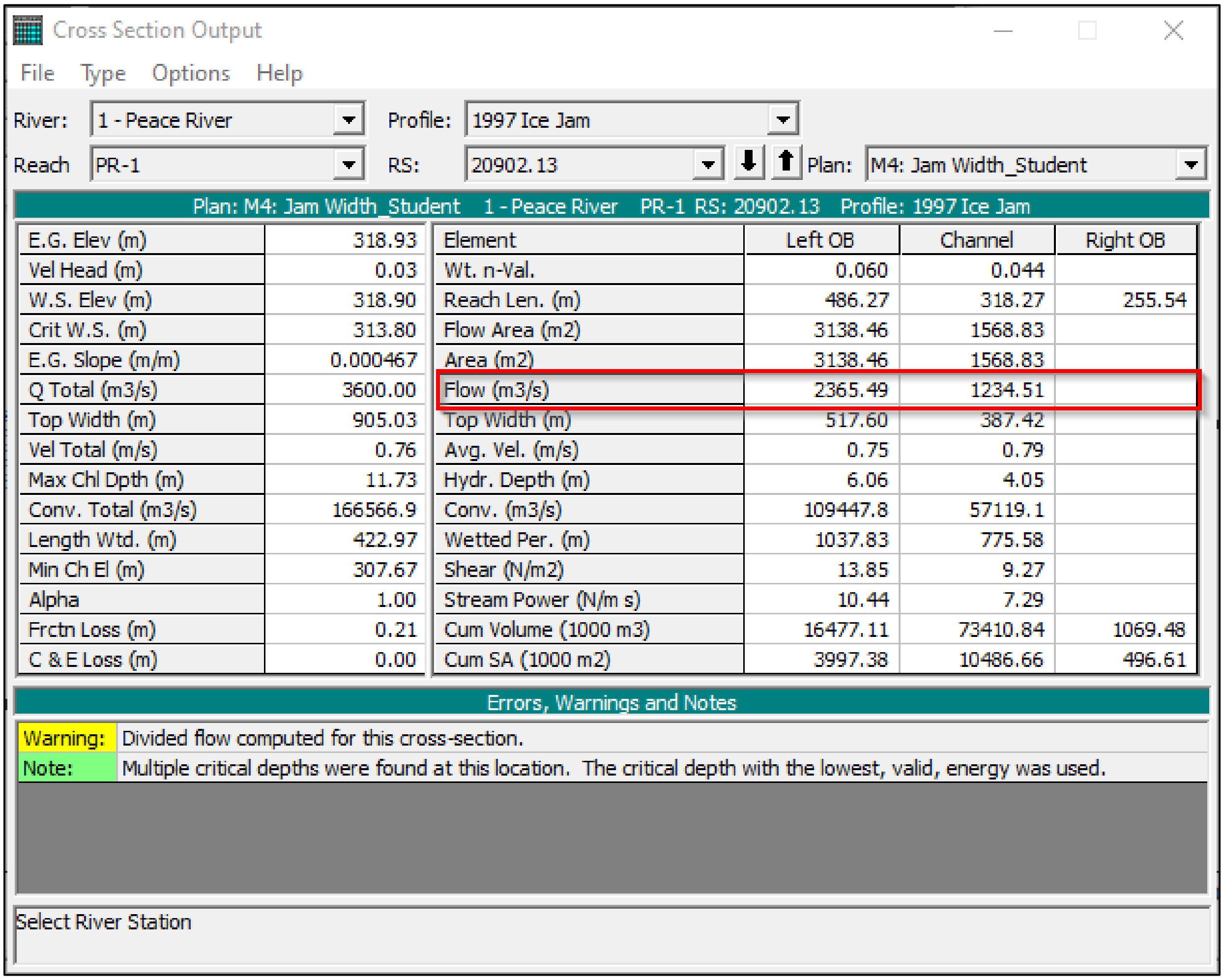


Notice: That the ice cover is thicker in the channel portion of the cross-section. The overbank section has the default starting thickness (2.4 m) that we added to the geometry file earlier. However, the channel has the ice jam thickness that was computed by HEC-RAS using the ice jam stability equation. As the thickness in the channel increases, more discharge is being calculated in the overbank, where the conveyance is higher.

This "redistribution" of the discharge be seen in the computation detailed summary table.

12. Click on the detailed output icon in the main interface. (This is different than the Profile Output Table, which looks like this:)

13. View RS 20902.13 XS #21, by choosing it from the dropdown menu:



River: 1 - Peace River
Profile: 1997 Ice Jam
Reach PR-1
RS: 20902.13
Plan: M4: Jam Width_Student

Plan: M4: Jam Width_Student 1 - Peace River PR-1 RS: 20902.13 Profile: 1997 Ice Jam

E.G. Elev (m)	318.93
Vel Head (m)	0.03
W.S. Elev (m)	318.90
Crit W.S. (m)	313.80
E.G. Slope (m/m)	0.000467
Q Total (m3/s)	3600.00
Top Width (m)	905.03
Vel Total (m/s)	0.76
Max Chl Dpth (m)	11.73
Conv. Total (m3/s)	166566.9
Length Wtd. (m)	422.97
Min Ch El (m)	307.67
Alpha	1.00
Frctn Loss (m)	0.21
C & E Loss (m)	0.00

Element	Left OB	Channel	Right OB
Wt. n-Val.	0.060	0.044	
Reach Len. (m)	486.27	318.27	255.54
Flow Area (m2)	3138.46	1568.83	
Area (m2)	3138.46	1568.83	
Flow (m3/s)	2365.49	1234.51	
Top Width (m)	517.60	387.42	
Avg. Vel. (m/s)	0.75	0.79	
Hydr. Depth (m)	6.06	4.05	
Conv. (m3/s)	109447.8	57119.1	
Wetted Per. (m)	1037.83	775.58	
Shear (N/m2)	13.85	9.27	
Stream Power (N/m s)	10.44	7.29	
Cum Volume (1000 m3)	16477.11	73410.84	1069.48
Cum SA (1000 m2)	3997.38	10486.66	496.61

Errors, Warnings and Notes

Warning: Divided flow computed for this cross-section.

Note: Multiple critical depths were found at this location. The critical depth with the lowest, valid, energy was used.

Select River Station

Notice that the flow in the left overbank is *almost twice* the flow in the channel. This condition does not match observations of ice jam formation at the Town of Peace River. For the Peace River, ice jams have been observed to shove down one side of Beweley Island, and then shove down the other side. As modellers, we have interpreted these observations and made the following model choices/model goals:

- Have the active ice jam width (the part used in the ice jam stability equation) be only on one side of Beweley Island.
- Have the remainder of the wetted width (the overbanks) have an ice thickness equal to the computed ice jam thickness in the channel.

This highlights that it is up to the modeller to specify the ice conditions in the overbank. Effort should be focused on simulating a realistic ice configuration based on observations or expected ice jam behaviour. In different situations, overbank ice conditions could include:

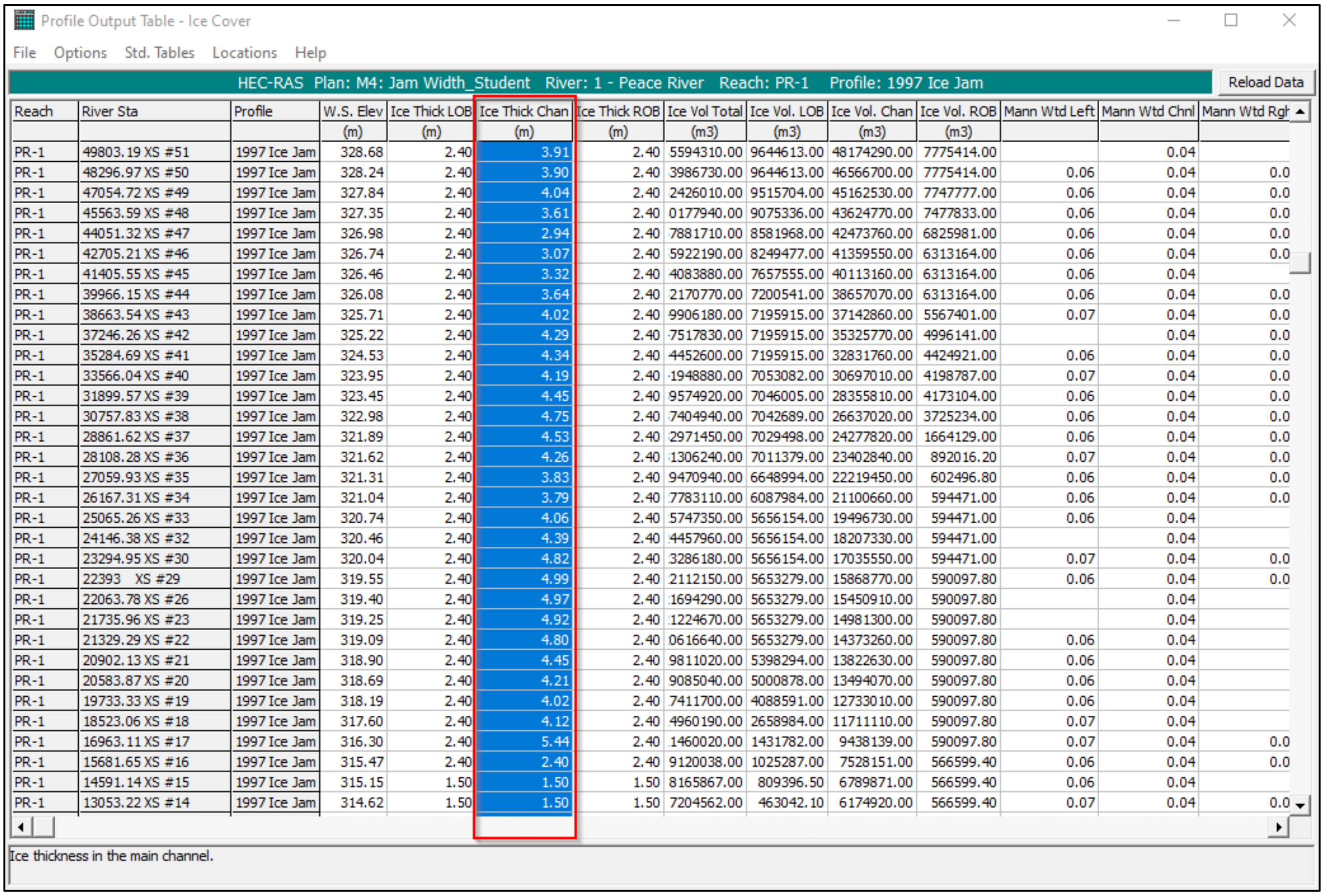
- No water or ice (for example, where the water levels doesn't reach high enough into the overbank area)
- Open water conditions (for example where trees prevent ice escaping into the floodplains)
- Smoother, intact (i.e. non-ice jam) ice cover (for example where an ice jam has only pushed and formed in the channel are but not the over bank)

- Ice jam conditions that are not part of the ice jam stability computation
- Ice jam conditions that are part of the ice jam stability computation

We will next change the ice thickness in the overbank so that it is equal to the ice jam thickness in the channel, which is consistent with the observed ice jam behaviour. This must be done iteratively, because each time the ice thickness is changed, the flow partitioning changes and the computed ice jam thickness in the channel changes as well. In a real life, care should be taken to develop a model that has consistent flow along the same flow path. However, this is not always achievable with a 1D model, and complicated flow situations may be better simulated by a network (i.e. multi-channel) model or a two-dimensional model.

Based on experience, the most efficient way to make adjustments to the overbank ice thickness is to start with too large a thickness value and then iteratively make adjustments thinner. The goal is to have the same thickness in the overbank as in the ice jam. First we will make the overbank ice artificially think.

14. View the current computed ice jam thicknesses the 'Profile Output Table' by clicking on the ▦ in the main interface. Choose Std. Tables and select '*Ice Cover*'.
15. Highlight and copy (Ctrl + C) the column '*Ice Thick Chan (m)*'. Keep this window open.



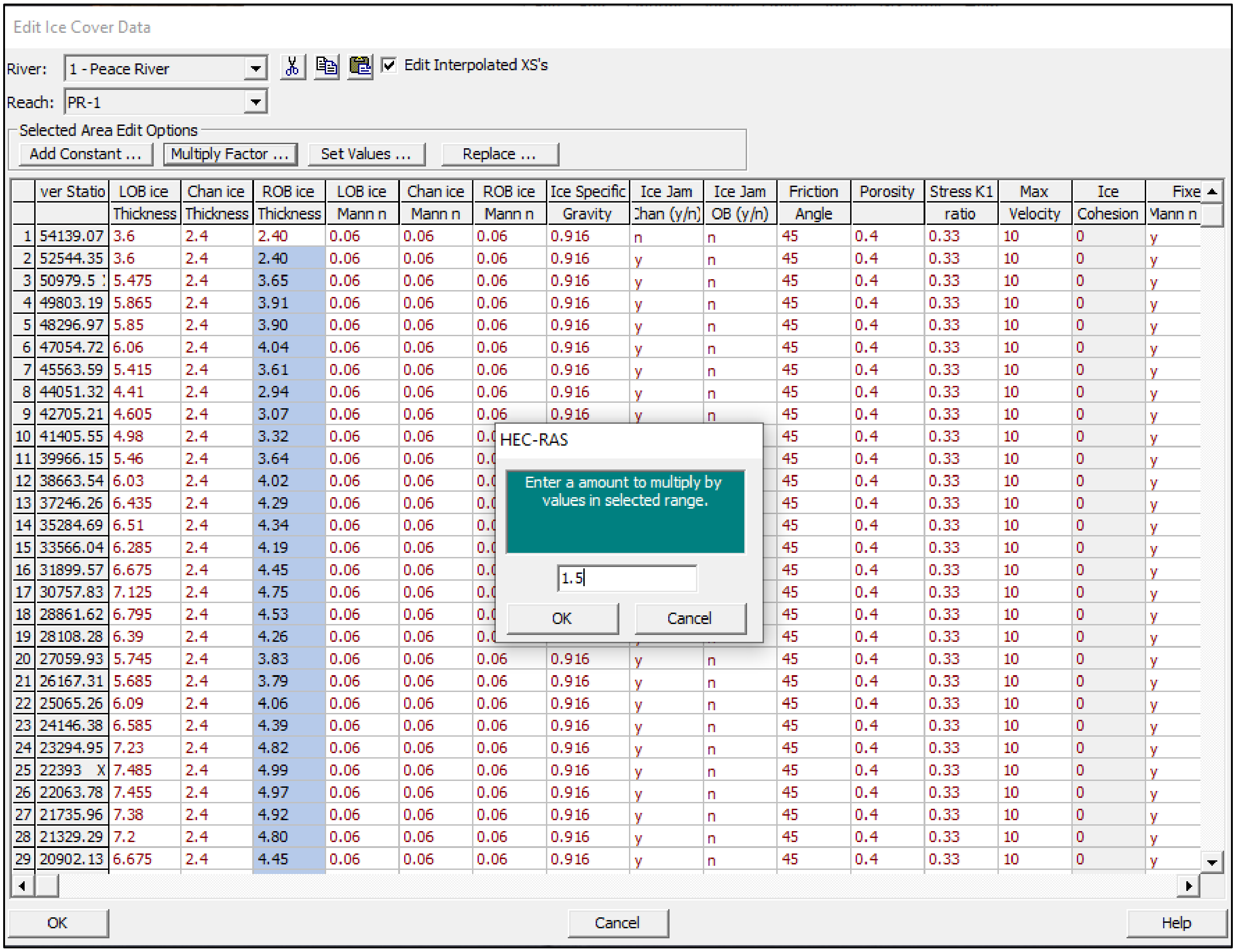
HEC-RAS Plan: M4: Jam Width_Student River: 1 - Peace River Reach: PR-1 Profile: 1997 Ice Jam

Reach	River Sta	Profile	W.S. Elev	Ice Thick LOB	Ice Thick Chan	Ice Thick ROB	Ice Vol Total	Ice Vol. LOB	Ice Vol. Chan	Ice Vol. ROB	Mann Wtd Left	Mann Wtd Chnl	Mann Wtd Rgh
			(m)	(m)	(m)	(m)	(m3)	(m3)	(m3)	(m3)			
PR-1	49803.19 XS #51	1997 Ice Jam	328.68	2.40	3.91	2.40	5594310.00	9644613.00	48174290.00	7775414.00		0.04	
PR-1	48296.97 XS #50	1997 Ice Jam	328.24	2.40	3.90	2.40	3986730.00	9644613.00	46566700.00	7775414.00	0.06	0.04	0.0
PR-1	47054.72 XS #49	1997 Ice Jam	327.84	2.40	4.04	2.40	2426010.00	9515704.00	45162530.00	7747777.00	0.06	0.04	0.0
PR-1	45563.59 XS #48	1997 Ice Jam	327.35	2.40	3.61	2.40	0177940.00	9075336.00	43624770.00	7477833.00	0.06	0.04	0.0
PR-1	44051.32 XS #47	1997 Ice Jam	326.98	2.40	2.94	2.40	7881710.00	8581968.00	42473760.00	6825981.00	0.06	0.04	0.0
PR-1	42705.21 XS #46	1997 Ice Jam	326.74	2.40	3.07	2.40	5922190.00	8249477.00	41359550.00	6313164.00	0.06	0.04	0.0
PR-1	41405.55 XS #45	1997 Ice Jam	326.46	2.40	3.32	2.40	4083880.00	7657555.00	40113160.00	6313164.00	0.06	0.04	
PR-1	39966.15 XS #44	1997 Ice Jam	326.08	2.40	3.64	2.40	2170770.00	7200541.00	38657070.00	6313164.00	0.06	0.04	0.0
PR-1	38663.54 XS #43	1997 Ice Jam	325.71	2.40	4.02	2.40	9906180.00	7195915.00	37142860.00	5567401.00	0.07	0.04	0.0
PR-1	37246.26 XS #42	1997 Ice Jam	325.22	2.40	4.29	2.40	7517830.00	7195915.00	35325770.00	4996141.00		0.04	0.0
PR-1	35284.69 XS #41	1997 Ice Jam	324.53	2.40	4.34	2.40	4452600.00	7195915.00	32831760.00	4424921.00	0.06	0.04	0.0
PR-1	33566.04 XS #40	1997 Ice Jam	323.95	2.40	4.19	2.40	1948880.00	7053082.00	30697010.00	4198787.00	0.07	0.04	0.0
PR-1	31899.57 XS #39	1997 Ice Jam	323.45	2.40	4.45	2.40	9574920.00	7046005.00	28355810.00	4173104.00	0.06	0.04	0.0
PR-1	30757.83 XS #38	1997 Ice Jam	322.98	2.40	4.75	2.40	7404940.00	7042689.00	26637020.00	3725234.00	0.06	0.04	0.0
PR-1	28861.62 XS #37	1997 Ice Jam	321.89	2.40	4.53	2.40	2971450.00	7029498.00	24277820.00	1664129.00	0.06	0.04	0.0
PR-1	28108.28 XS #36	1997 Ice Jam	321.62	2.40	4.26	2.40	1306240.00	7011379.00	23402840.00	892016.20	0.07	0.04	0.0
PR-1	27059.93 XS #35	1997 Ice Jam	321.31	2.40	3.83	2.40	9470940.00	6648994.00	22219450.00	602496.80	0.06	0.04	0.0
PR-1	26167.31 XS #34	1997 Ice Jam	321.04	2.40	3.79	2.40	7783110.00	6087984.00	21100660.00	594471.00	0.06	0.04	0.0
PR-1	25065.26 XS #33	1997 Ice Jam	320.74	2.40	4.06	2.40	5747350.00	5656154.00	19496730.00	594471.00	0.06	0.04	
PR-1	24146.38 XS #32	1997 Ice Jam	320.46	2.40	4.39	2.40	4457960.00	5656154.00	18207330.00	594471.00		0.04	
PR-1	23294.95 XS #30	1997 Ice Jam	320.04	2.40	4.82	2.40	3286180.00	5656154.00	17035550.00	594471.00	0.07	0.04	0.0
PR-1	22393 XS #29	1997 Ice Jam	319.55	2.40	4.99	2.40	2112150.00	5653279.00	15868770.00	590097.80	0.06	0.04	0.0
PR-1	22063.78 XS #26	1997 Ice Jam	319.40	2.40	4.97	2.40	1694290.00	5653279.00	15450910.00	590097.80		0.04	
PR-1	21735.96 XS #23	1997 Ice Jam	319.25	2.40	4.92	2.40	1224670.00	5653279.00	14981300.00	590097.80		0.04	
PR-1	21329.29 XS #22	1997 Ice Jam	319.09	2.40	4.80	2.40	0616640.00	5653279.00	14373260.00	590097.80	0.06	0.04	
PR-1	20902.13 XS #21	1997 Ice Jam	318.90	2.40	4.45	2.40	9811020.00	5398294.00	13822630.00	590097.80	0.06	0.04	
PR-1	20583.87 XS #20	1997 Ice Jam	318.69	2.40	4.21	2.40	9085040.00	5000878.00	13494070.00	590097.80	0.06	0.04	
PR-1	19733.33 XS #19	1997 Ice Jam	318.19	2.40	4.02	2.40	7411700.00	4088591.00	12733010.00	590097.80	0.06	0.04	
PR-1	18523.06 XS #18	1997 Ice Jam	317.60	2.40	4.12	2.40	4960190.00	2658984.00	11711110.00	590097.80	0.07	0.04	
PR-1	16963.11 XS #17	1997 Ice Jam	316.30	2.40	5.44	2.40	1460020.00	1431782.00	9438139.00	590097.80	0.07	0.04	0.0
PR-1	15681.65 XS #16	1997 Ice Jam	315.47	2.40	2.40	2.40	9120038.00	1025287.00	7528151.00	566599.40	0.06	0.04	0.0
PR-1	14591.14 XS #15	1997 Ice Jam	315.15	1.50	1.50	1.50	8165867.00	809396.50	6789871.00	566599.40	0.06	0.04	
PR-1	13053.22 XS #14	1997 Ice Jam	314.62	1.50	1.50	1.50	7204562.00	463042.10	6174920.00	566599.40	0.07	0.04	0.0

Ice thickness in the main channel.

16. Open the 'Geometry Data' window ⊠ from the main interface.

17. Choose Tables and select ‘*Ice Cover …*’
18. Highlight all the rows in the column ‘*LOB ice Thickness*’, paste (Ctrl+V) the values into this column. With the column still highlighted, choose Multiply Factor ..., enter *1.5*, click OK.
19. Repeat the above step for the column ‘*ROB ice Thickness*’.



Edit Ice Cover Data

River: 1 - Peace River

Reach: PR-1

☑ Edit Interpolated XS's

Selected Area Edit Options

	ver Statio	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam han (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity	Ice Cohesion	Fixe Mann n
1	54139.07	3.6	2.4	2.40	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0	y
2	52544.35	3.6	2.4	2.40	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
3	50979.5 :	5.475	2.4	3.65	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
4	49803.19	5.865	2.4	3.91	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
5	48296.97	5.85	2.4	3.90	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
6	47054.72	6.06	2.4	4.04	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
7	45563.59	5.415	2.4	3.61	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
8	44051.32	4.41	2.4	2.94	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
9	42705.21	4.605	2.4	3.07	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
10	41405.55	4.98	2.4	3.32	0.06	0.06	0.0				45	0.4	0.33	10	0	y
11	39966.15	5.46	2.4	3.64	0.06	0.06	0.0				45	0.4	0.33	10	0	y
12	38663.54	6.03	2.4	4.02	0.06	0.06	0.0				45	0.4	0.33	10	0	y
13	37246.26	6.435	2.4	4.29	0.06	0.06	0.0				45	0.4	0.33	10	0	y
14	35284.69	6.51	2.4	4.34	0.06	0.06	0.0				45	0.4	0.33	10	0	y
15	33566.04	6.285	2.4	4.19	0.06	0.06	0.0				45	0.4	0.33	10	0	y
16	31899.57	6.675	2.4	4.45	0.06	0.06	0.0				45	0.4	0.33	10	0	y
17	30757.83	7.125	2.4	4.75	0.06	0.06	0.0				45	0.4	0.33	10	0	y
18	28861.62	6.795	2.4	4.53	0.06	0.06	0.0				45	0.4	0.33	10	0	y
19	28108.28	6.39	2.4	4.26	0.06	0.06	0.0				45	0.4	0.33	10	0	y
20	27059.93	5.745	2.4	3.83	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
21	26167.31	5.685	2.4	3.79	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
22	25065.26	6.09	2.4	4.06	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
23	24146.38	6.585	2.4	4.39	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
24	23294.95	7.23	2.4	4.82	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
25	22393 X	7.485	2.4	4.99	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
26	22063.78	7.455	2.4	4.97	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
27	21735.96	7.38	2.4	4.92	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
28	21329.29	7.2	2.4	4.80	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y
29	20902.13	6.675	2.4	4.45	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0	y

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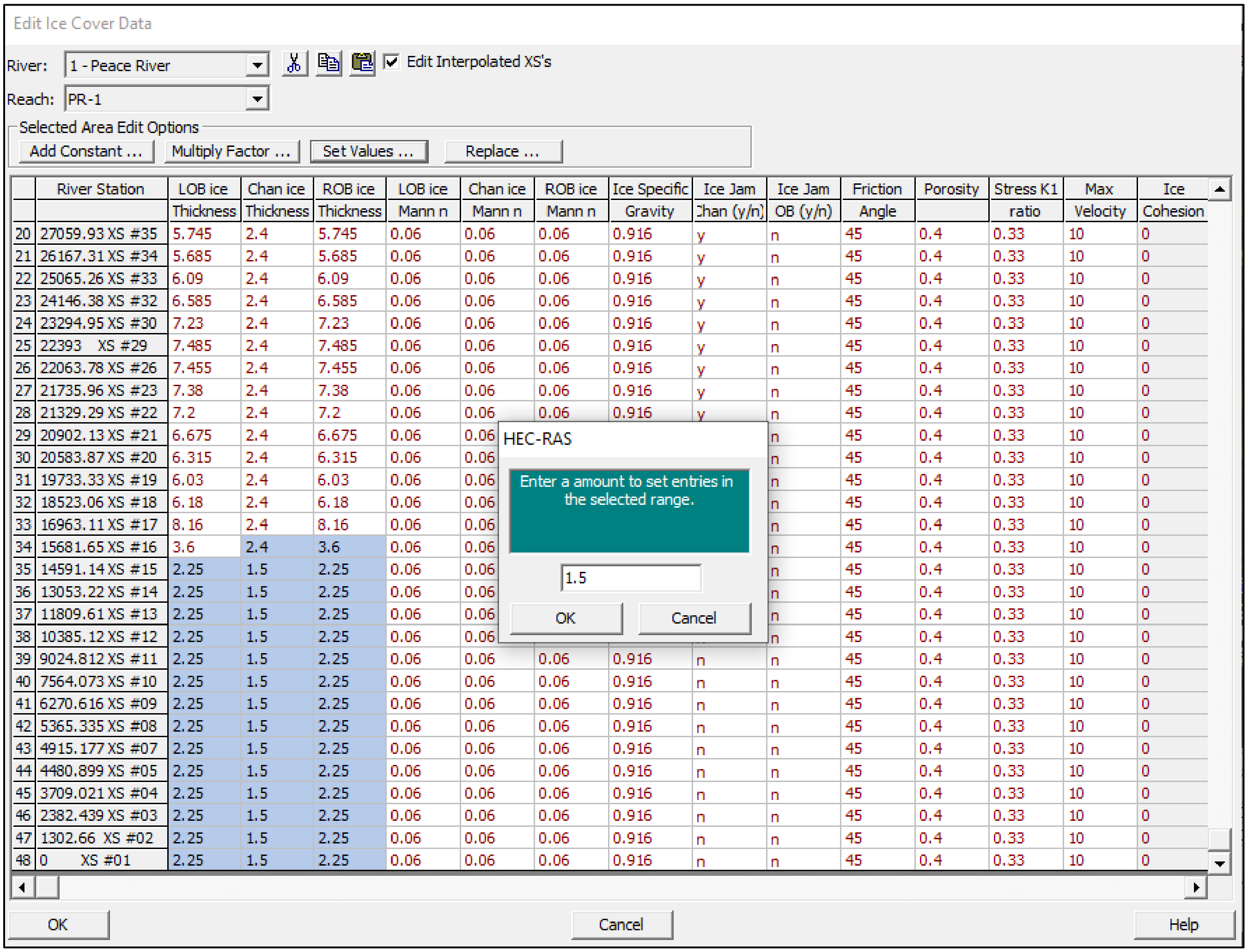
Enter a amount to multiply by values in selected range.

1.5

20. Select the ice 3 thickness columns for the cross-sections downstream of the ice jam toe (*XS #01* to *XS #15*), choose Set Values ..., enter *1.5* then click OK.



	River Station	LOB ice Thickness	Chan ice Thickness	ROB ice Thickness	LOB ice Mann n	Chan ice Mann n	ROB ice Mann n	Ice Specific Gravity	Ice Jam han (y/n)	Ice Jam OB (y/n)	Friction Angle	Porosity	Stress K1 ratio	Max Velocity	Ice Cohesion
20	27059.93 XS #35	5.745	2.4	5.745	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
21	26167.31 XS #34	5.685	2.4	5.685	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
22	25065.26 XS #33	6.09	2.4	6.09	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
23	24146.38 XS #32	6.585	2.4	6.585	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
24	23294.95 XS #30	7.23	2.4	7.23	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
25	22393 XS #29	7.485	2.4	7.485	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
26	22063.78 XS #26	7.455	2.4	7.455	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
27	21735.96 XS #23	7.38	2.4	7.38	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
28	21329.29 XS #22	7.2	2.4	7.2	0.06	0.06	0.06	0.916	y	n	45	0.4	0.33	10	0
29	20902.13 XS #21	6.675	2.4	6.675	0.06	0.06				n	45	0.4	0.33	10	0
30	20583.87 XS #20	6.315	2.4	6.315	0.06	0.06				n	45	0.4	0.33	10	0
31	19733.33 XS #19	6.03	2.4	6.03	0.06	0.06				n	45	0.4	0.33	10	0
32	18523.06 XS #18	6.18	2.4	6.18	0.06	0.06				n	45	0.4	0.33	10	0
33	16963.11 XS #17	8.16	2.4	8.16	0.06	0.06				n	45	0.4	0.33	10	0
34	15681.65 XS #16	3.6	2.4	3.6	0.06	0.06				n	45	0.4	0.33	10	0
35	14591.14 XS #15	2.25	1.5	2.25	0.06	0.06				n	45	0.4	0.33	10	0
36	13053.22 XS #14	2.25	1.5	2.25	0.06	0.06				n	45	0.4	0.33	10	0
37	11809.61 XS #13	2.25	1.5	2.25	0.06	0.06				n	45	0.4	0.33	10	0
38	10385.12 XS #12	2.25	1.5	2.25	0.06	0.06				n	45	0.4	0.33	10	0
39	9024.812 XS #11	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
40	7564.073 XS #10	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
41	6270.616 XS #09	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
42	5365.335 XS #08	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
43	4915.177 XS #07	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
44	4480.899 XS #05	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
45	3709.021 XS #04	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
46	2382.439 XS #03	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
47	1302.66 XS #02	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0
48	0 XS #01	2.25	1.5	2.25	0.06	0.06	0.06	0.916	n	n	45	0.4	0.33	10	0

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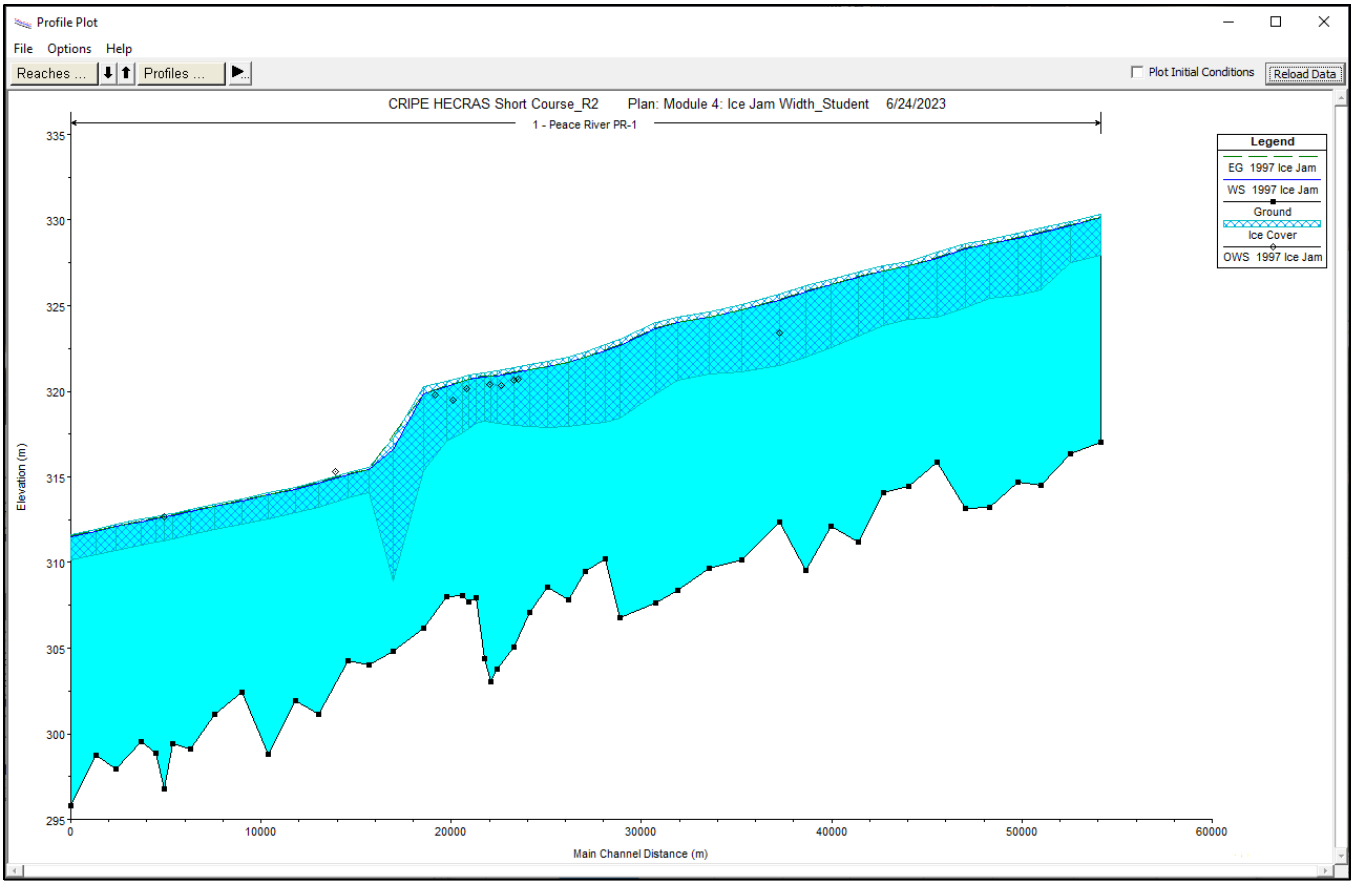
Enter a amount to set entries in the selected range.

1.5

21. Close the 'Edit Ice Cover' window by clicking OK.
22. Choose File and select '*Save Geometry Data'* in the 'Geometric Data' window.
23. Open the 'Steady Flow Analysis' window from the main interface. Click Compute
24. View the model results in the 'Profile Plot' window.



Notice that the computed water surface is above the observed water surface elevations.

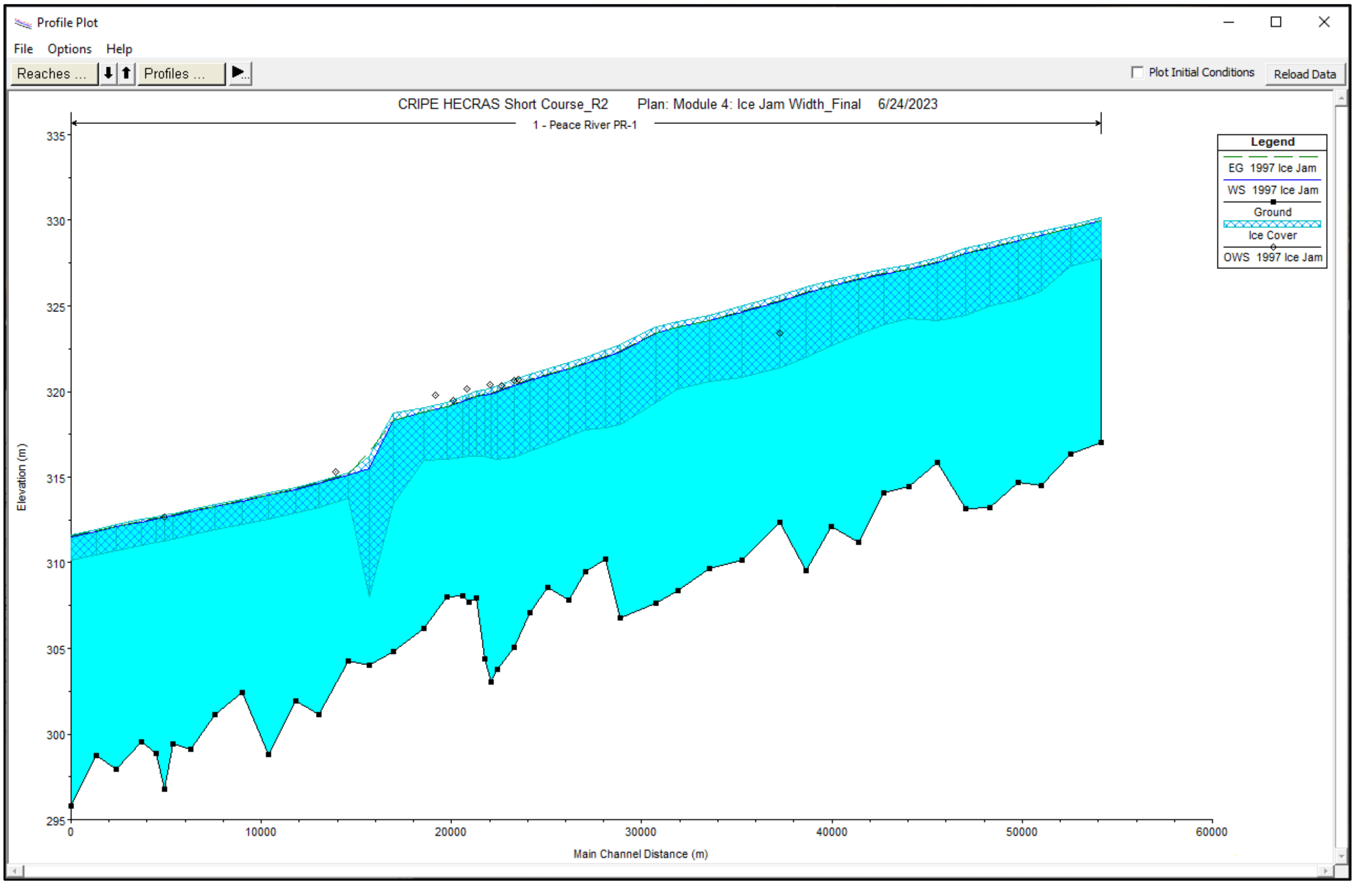
QUESTION: Why has the computed water surface increased? How can you tell?

We will now continue our iterative procedure by replacing the overbank ice thickness with the new computed ice jam thickness (instead of 1.5 times the ice jam thickness). After 3 or 4 iterations, the overbank ice jam thickness should match the computed ice jam thickness (within ~ 0.02 m). Follow these steps for each iteration:

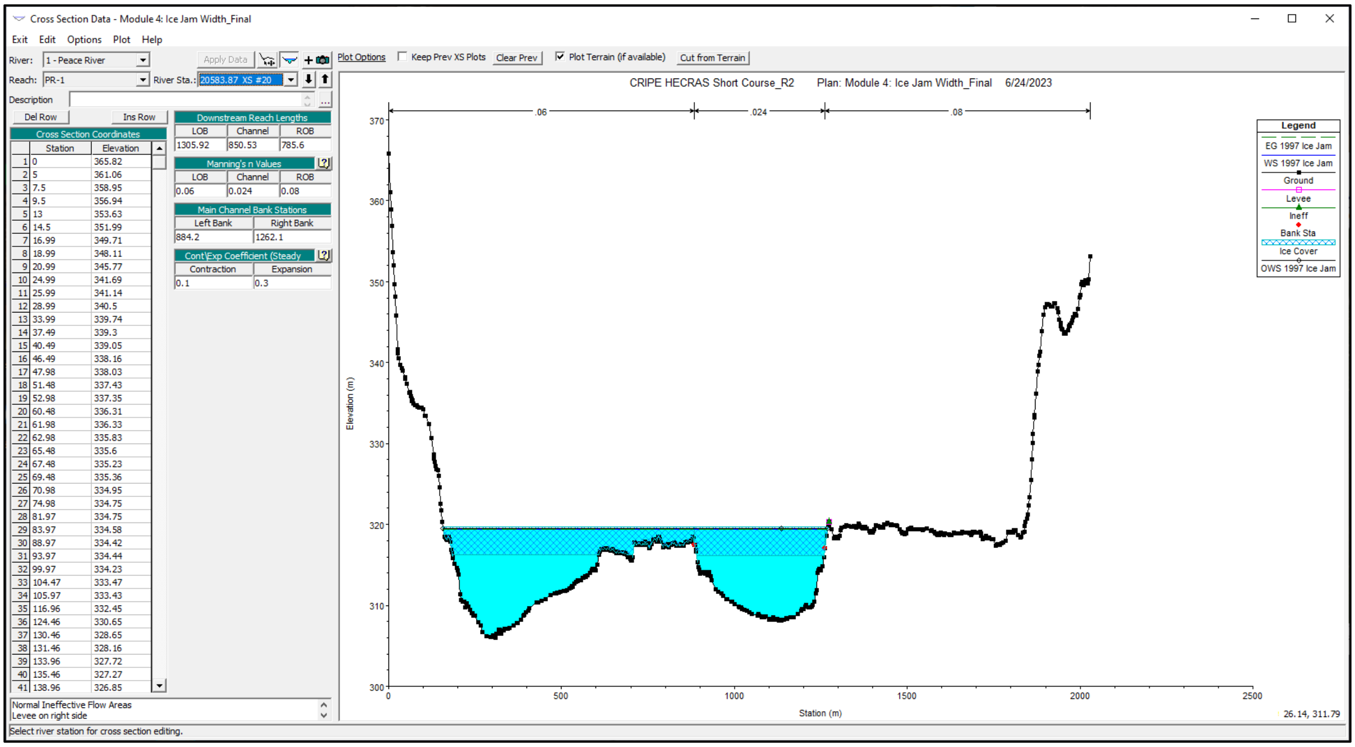
25. View the current computed ice jam thicknesses the ‘Profile Output Table’ by clicking on the ▦ in the main interface. Go to Std. Tables and select ‘*Ice Cover*’.
26. Highlight and copy (Ctrl + C) the column ‘*Ice Thick Chan (m)*’. Keep this window open.

27. Open the ‘Geometry Data’ window from the main interface.
28. Choose Tables and select ‘*Ice Cover …*’.
29. Highlight all the rows in the column ‘*LOB ice Thickness’*, paste (Ctrl+V) the values into this column.
30. Repeat the above step for the column ‘*ROB ice Thickness*’.
31. Close the ‘Edit Ice Cover window’ by clicking OK.
32. Choose File and select ‘*Save Geometry Data*’ in the ‘Geometric Data’ window.
33. Open the ‘Steady Flow Analysis’ window from the main interface. Click Compute
34. View the model results in the ‘Profile Plot’ window.

The final calibrated profile will look like this:



35. Check the ice thickness results for Cross-Section *XS #21* in the 'Geometry Data' window and the 'Profile Output Table' for Ice Cover:



Cross Section Data - Module 4: Ice Jam Width_Final

River: 1 - Peace River

Reach: PR-1

River Sta.: 20583.87 XS #20

Description:

Downstream Reach Lengths

LOB	Channel	ROB
1305.92	850.53	785.6

Manning's n Values

LOB	Channel	ROB
0.06	0.024	0.08

Main Channel Bank Stations

Left Bank	Right Bank
884.2	1262.1

Cont\Exp Coefficient (Steady

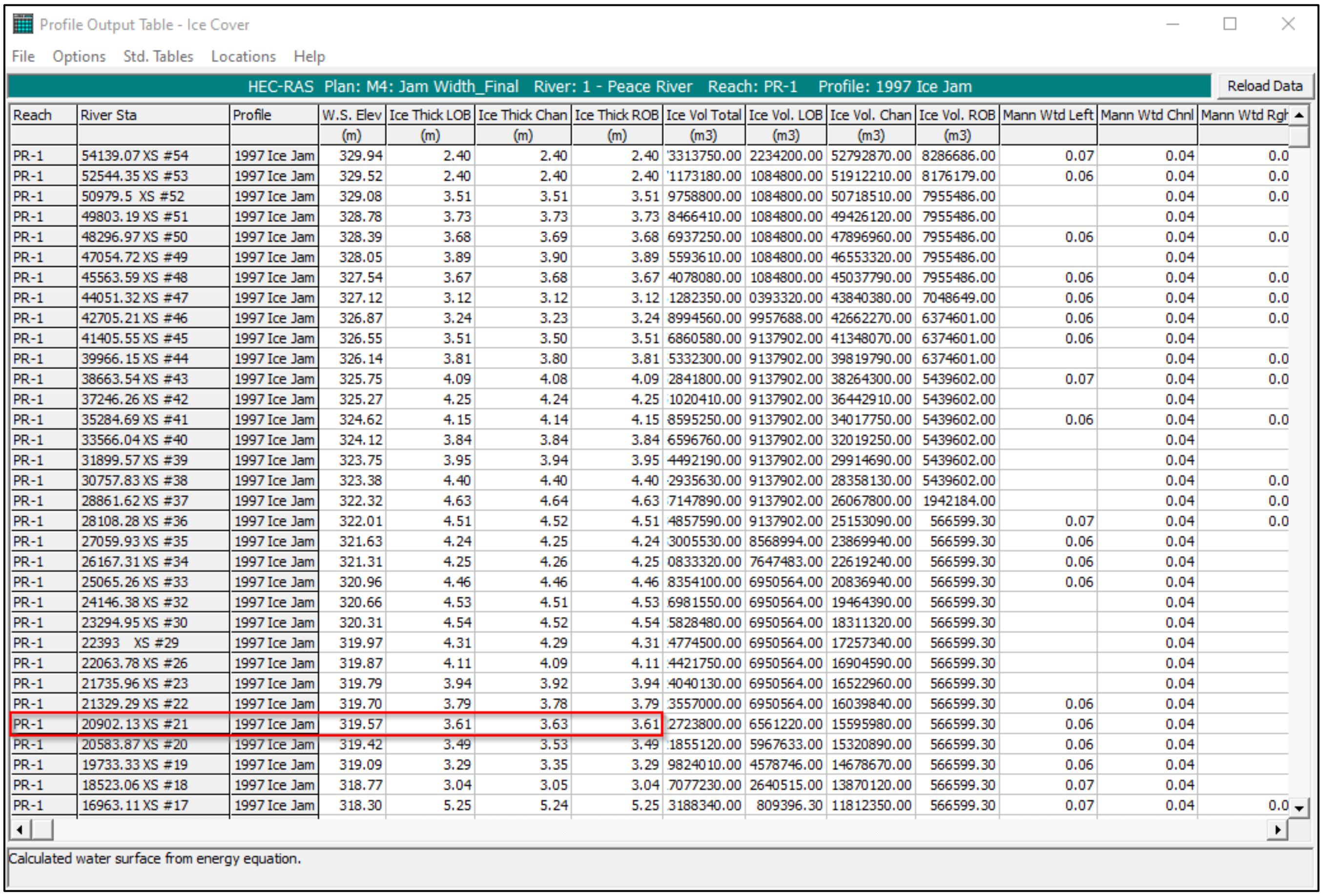
Contraction	Expansion
0.1	0.3

Cross Section Coordinates

	Station	Elevation
1	0	365.82
2	5	361.06
3	7.5	358.95
4	9.5	356.94
5	13	353.63
6	14.5	351.99
7	16.99	349.71
8	18.99	348.11
9	20.99	345.77
10	24.99	341.69
11	25.99	341.14
12	28.99	340.5
13	33.99	339.74
14	37.49	339.3
15	40.49	339.05
16	46.49	338.16
17	47.98	338.03
18	51.48	337.43
19	52.98	337.35
20	60.48	336.31
21	61.98	336.33
22	62.98	335.83
23	65.48	335.6
24	67.48	335.23
25	69.48	335.36
26	70.98	334.95
27	74.98	334.75
28	81.97	334.75
29	83.97	334.58
30	88.97	334.42
31	93.97	334.44
32	99.97	334.23
33	104.47	333.47
34	105.97	333.43
35	116.96	332.45
36	124.46	330.65
37	130.46	328.65
38	131.46	328.16
39	133.96	327.72
40	135.46	327.27
41	138.96	326.85

Normal Ineffective Flow Areas
Levee on right side

Select river station for cross section editing.



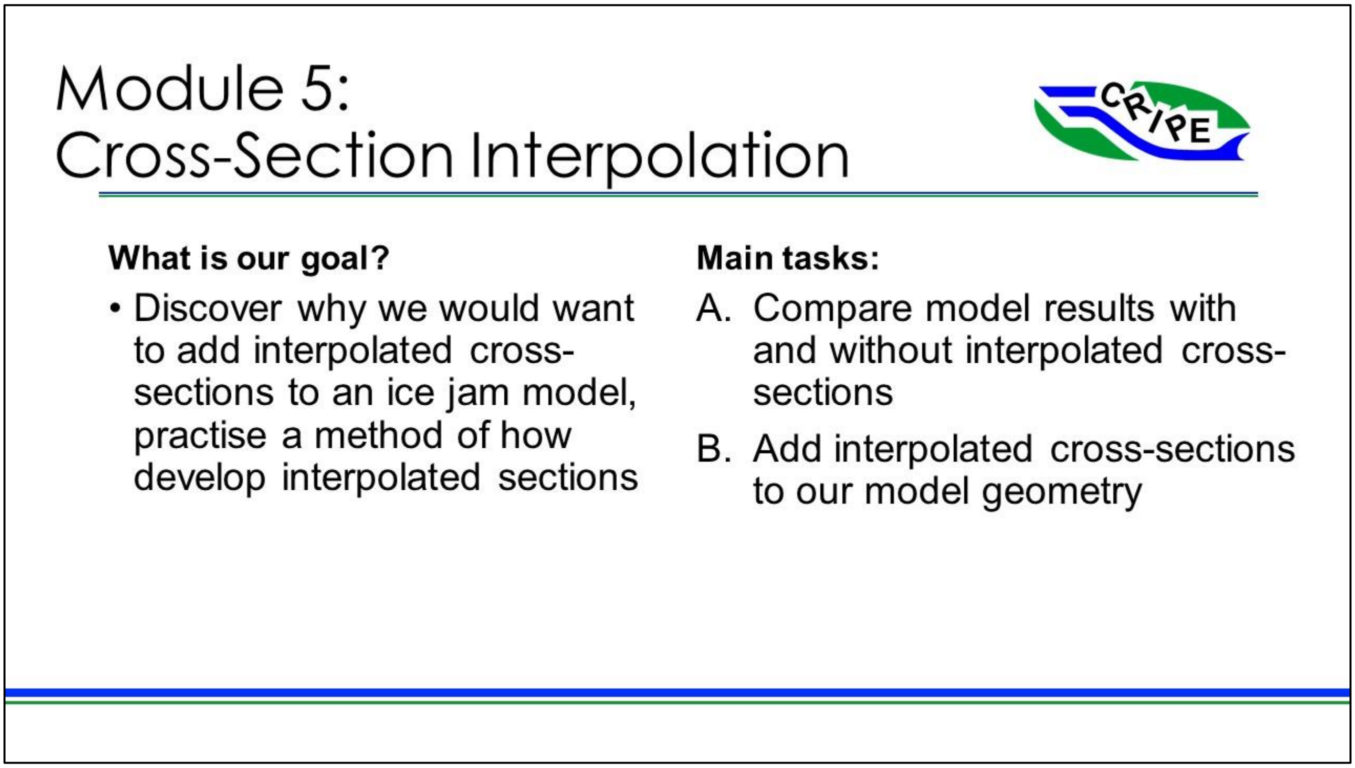
HEC-RAS Plan: M4: Jam Width_Final River: 1 - Peace River Reach: PR-1 Profile: 1997 Ice Jam

Reach	River Sta	Profile	W.S. Elev	Ice Thick LOB	Ice Thick Chan	Ice Thick ROB	Ice Vol Total	Ice Vol. LOB	Ice Vol. Chan	Ice Vol. ROB	Mann Wtd Left	Mann Wtd Chnl	Mann Wtd Rgh
			(m)	(m)	(m)	(m)	(m3)	(m3)	(m3)	(m3)			
PR-1	54139.07 XS #54	1997 Ice Jam	329.94	2.40	2.40	2.40	3313750.00	2234200.00	52792870.00	8286686.00	0.07	0.04	0.0
PR-1	52544.35 XS #53	1997 Ice Jam	329.52	2.40	2.40	2.40	1173180.00	1084800.00	51912210.00	8176179.00	0.06	0.04	0.0
PR-1	50979.5 XS #52	1997 Ice Jam	329.08	3.51	3.51	3.51	9758800.00	1084800.00	50718510.00	7955486.00		0.04	0.0
PR-1	49803.19 XS #51	1997 Ice Jam	328.78	3.73	3.73	3.73	8466410.00	1084800.00	49426120.00	7955486.00		0.04	
PR-1	48296.97 XS #50	1997 Ice Jam	328.39	3.68	3.69	3.68	6937250.00	1084800.00	47896960.00	7955486.00	0.06	0.04	0.0
PR-1	47054.72 XS #49	1997 Ice Jam	328.05	3.89	3.90	3.89	5593610.00	1084800.00	46553320.00	7955486.00		0.04	
PR-1	45563.59 XS #48	1997 Ice Jam	327.54	3.67	3.68	3.67	4078080.00	1084800.00	45037790.00	7955486.00	0.06	0.04	0.0
PR-1	44051.32 XS #47	1997 Ice Jam	327.12	3.12	3.12	3.12	1282350.00	0393320.00	43840380.00	7048649.00	0.06	0.04	0.0
PR-1	42705.21 XS #46	1997 Ice Jam	326.87	3.24	3.23	3.24	8994560.00	9957688.00	42662270.00	6374601.00	0.06	0.04	0.0
PR-1	41405.55 XS #45	1997 Ice Jam	326.55	3.51	3.50	3.51	6860580.00	9137902.00	41348070.00	6374601.00	0.06	0.04	
PR-1	39966.15 XS #44	1997 Ice Jam	326.14	3.81	3.80	3.81	5332300.00	9137902.00	39819790.00	6374601.00		0.04	0.0
PR-1	38663.54 XS #43	1997 Ice Jam	325.75	4.09	4.08	4.09	2841800.00	9137902.00	38264300.00	5439602.00	0.07	0.04	0.0
PR-1	37246.26 XS #42	1997 Ice Jam	325.27	4.25	4.24	4.25	1020410.00	9137902.00	36442910.00	5439602.00		0.04	
PR-1	35284.69 XS #41	1997 Ice Jam	324.62	4.15	4.14	4.15	8595250.00	9137902.00	34017750.00	5439602.00	0.06	0.04	0.0
PR-1	33566.04 XS #40	1997 Ice Jam	324.12	3.84	3.84	3.84	6596760.00	9137902.00	32019250.00	5439602.00		0.04	
PR-1	31899.57 XS #39	1997 Ice Jam	323.75	3.95	3.94	3.95	4492190.00	9137902.00	29914690.00	5439602.00		0.04	
PR-1	30757.83 XS #38	1997 Ice Jam	323.38	4.40	4.40	4.40	2935630.00	9137902.00	28358130.00	5439602.00		0.04	0.0
PR-1	28861.62 XS #37	1997 Ice Jam	322.32	4.63	4.64	4.63	7147890.00	9137902.00	26067800.00	1942184.00		0.04	0.0
PR-1	28108.28 XS #36	1997 Ice Jam	322.01	4.51	4.52	4.51	4857590.00	9137902.00	25153090.00	566599.30	0.07	0.04	0.0
PR-1	27059.93 XS #35	1997 Ice Jam	321.63	4.24	4.25	4.24	3005530.00	8568994.00	23869940.00	566599.30	0.06	0.04	
PR-1	26167.31 XS #34	1997 Ice Jam	321.31	4.25	4.26	4.25	0833320.00	7647483.00	22619240.00	566599.30	0.06	0.04	
PR-1	25065.26 XS #33	1997 Ice Jam	320.96	4.46	4.46	4.46	8354100.00	6950564.00	20836940.00	566599.30	0.06	0.04	
PR-1	24146.38 XS #32	1997 Ice Jam	320.66	4.53	4.51	4.53	6981550.00	6950564.00	19464390.00	566599.30		0.04	
PR-1	23294.95 XS #30	1997 Ice Jam	320.31	4.54	4.52	4.54	5828480.00	6950564.00	18311320.00	566599.30		0.04	
PR-1	22393 XS #29	1997 Ice Jam	319.97	4.31	4.29	4.31	4774500.00	6950564.00	17257340.00	566599.30		0.04	
PR-1	22063.78 XS #26	1997 Ice Jam	319.87	4.11	4.09	4.11	4421750.00	6950564.00	16904590.00	566599.30		0.04	
PR-1	21735.96 XS #23	1997 Ice Jam	319.79	3.94	3.92	3.94	4040130.00	6950564.00	16522960.00	566599.30		0.04	
PR-1	21329.29 XS #22	1997 Ice Jam	319.70	3.79	3.78	3.79	3557000.00	6950564.00	16039840.00	566599.30	0.06	0.04	
PR-1	20902.13 XS #21	1997 Ice Jam	319.57	3.61	3.63	3.61	2723800.00	6561220.00	15595980.00	566599.30	0.06	0.04	
PR-1	20583.87 XS #20	1997 Ice Jam	319.42	3.49	3.53	3.49	1855120.00	5967633.00	15320890.00	566599.30	0.06	0.04	
PR-1	19733.33 XS #19	1997 Ice Jam	319.09	3.29	3.35	3.29	9824010.00	4578746.00	14678670.00	566599.30	0.06	0.04	
PR-1	18523.06 XS #18	1997 Ice Jam	318.77	3.04	3.05	3.04	7077230.00	2640515.00	13870120.00	566599.30	0.07	0.04	
PR-1	16963.11 XS #17	1997 Ice Jam	318.30	5.25	5.24	5.25	3188340.00	809396.30	11812350.00	566599.30	0.07	0.04	0.0

Calculated water surface from energy equation.

36. Close all windows except for the main interface.

Module 5: Cross-Section Interpolation



Module 5: Cross-Section Interpolation

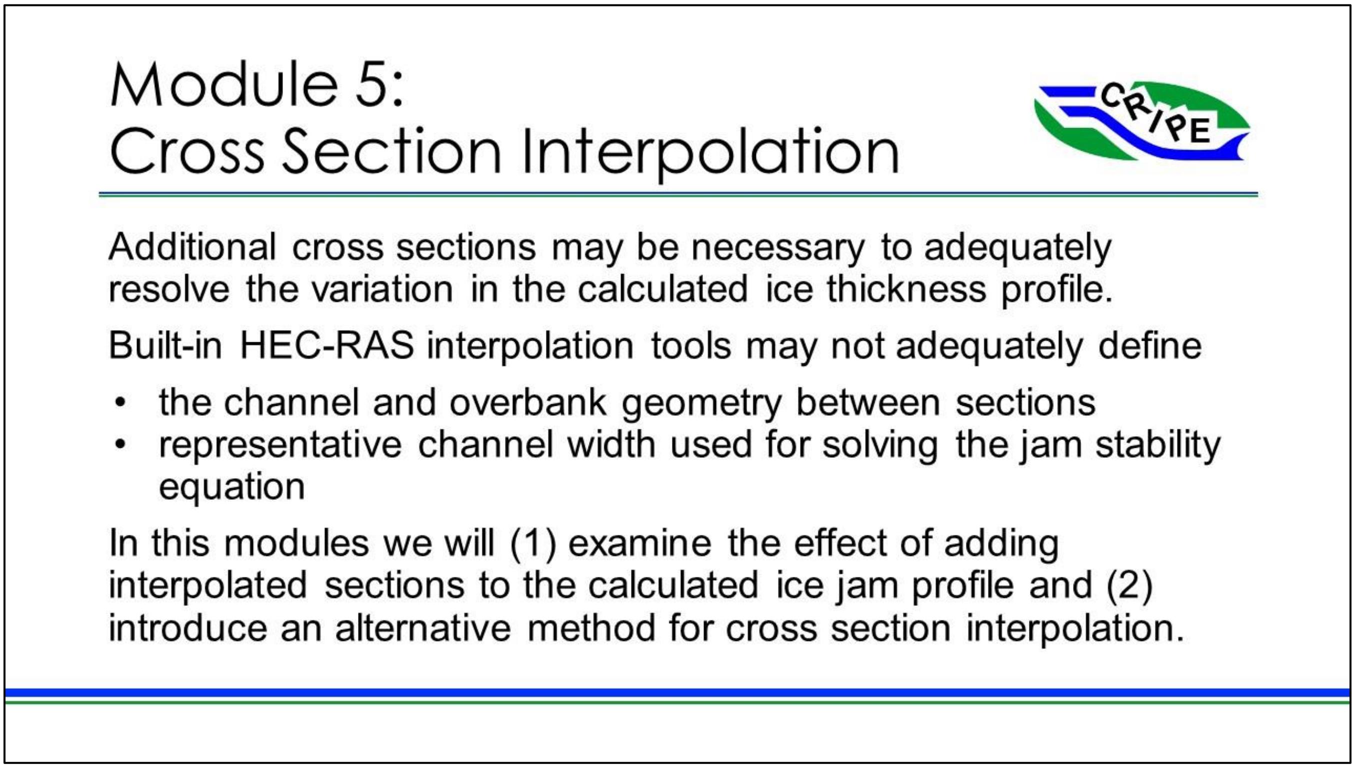
What is our goal?

- Discover why we would want to add interpolated cross-sections to an ice jam model, practise a method of how develop interpolated sections

Main tasks:

A. Compare model results with and without interpolated cross-sections

B. Add interpolated cross-sections to our model geometry



Module 5: Cross Section Interpolation

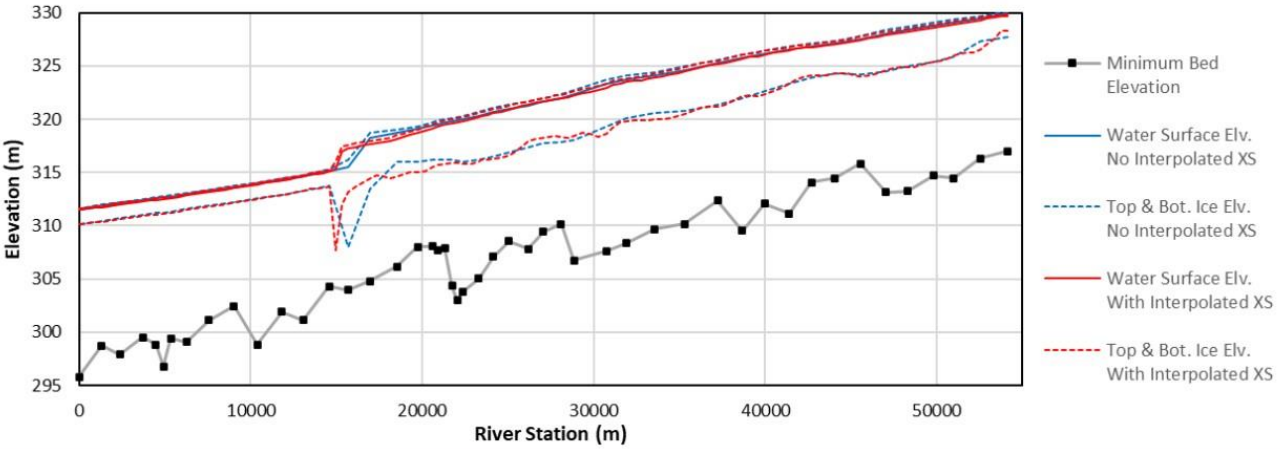
Additional cross sections may be necessary to adequately resolve the variation in the calculated ice thickness profile.

Built-in HEC-RAS interpolation tools may not adequately define

- the channel and overbank geometry between sections
- representative channel width used for solving the jam stability equation

In this modules we will (1) examine the effect of adding interpolated sections to the calculated ice jam profile and (2) introduce an alternative method for cross section interpolation.

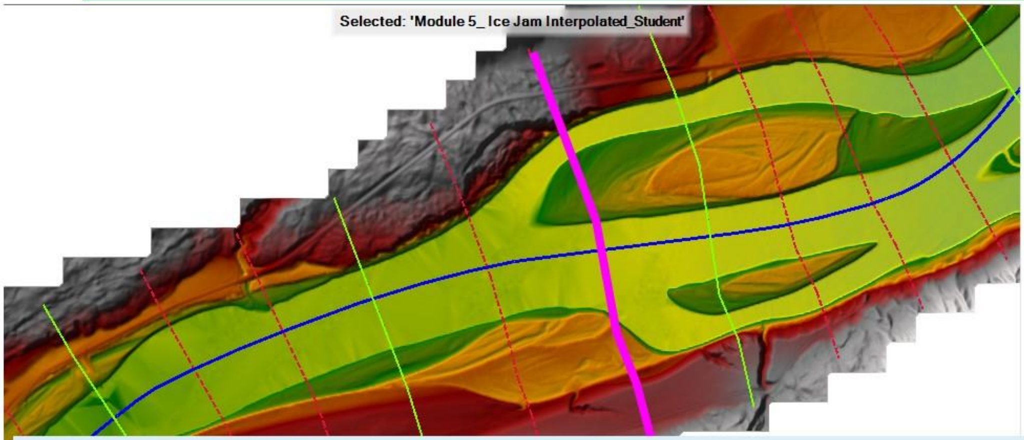
Effect of adding interpolated cross sections



An alternative method for cross section interpolation

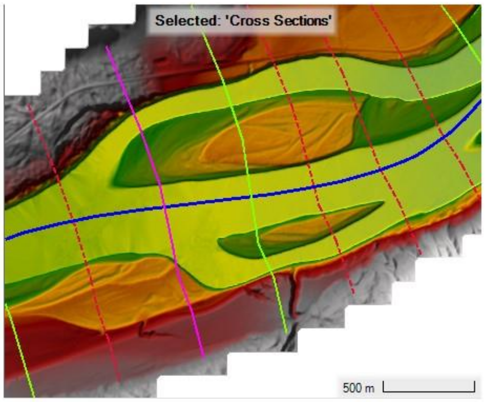
- Establish the alignment of the interpolated cross section between neighbouring sections - denoted as a “cut-line”.
- Use Terrain to inform elevations along the alignment of the interpolated cross section - “cut” a profile from the Terrain.
- Update channel elevation data based on neighbouring channel geometry.

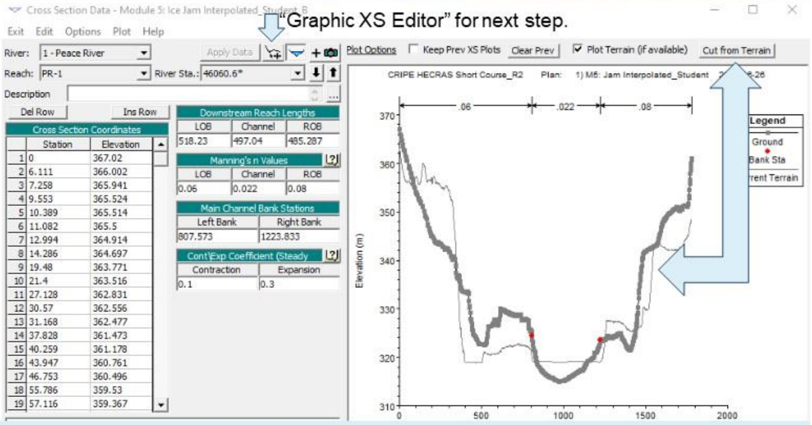
An alternative method for cross section interpolation



1. Use the “XS Interpolation Tool” to help align the interpolated cross section “cut-line”.

An alternative method for cross section interpolation





“Graphic XS Editor” for next step.

River: 1 - Peace River

Reach: PR-1

River Sta.: 46060.6*

Description

☐ Keep Prev XS Plots

☑ Plot Terrain (if available)

Cross Section Coordinates

	Station	Elevation
1	0	367.02
2	6.111	366.002
3	7.258	365.941
4	9.553	365.524
5	10.389	365.514
6	11.082	365.5
7	12.994	364.914
8	14.286	364.697
9	19.48	363.771
10	21.4	363.516
11	27.128	362.831
12	30.57	362.556
13	31.168	362.477
14	37.828	361.473
15	40.259	361.178
16	43.947	360.761
17	46.753	360.496
18	55.786	359.53
19	57.116	359.367

Downstream Reach Lengths

LOB	Channel	ROB
518.23	497.04	485.287

Manning's n Values

LOB	Channel	ROB
0.06	0.022	0.08

Main Channel Bank Stations

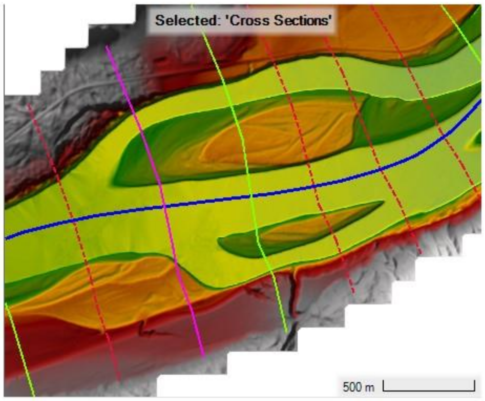
Left Bank	Right Bank
807.573	1223.833

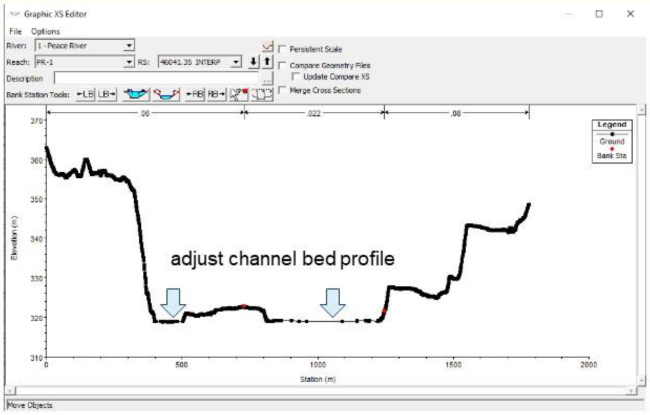
Cont\Exp Coefficient (Steady

Contraction	Expansion
0.1	0.3

2. Use the “Cross Section Data” editor to *cut* profile from the Terrain.

An alternative method for cross section interpolation





Graphic XS Editor

River: 1 - Peace River
Reach: PR-1
RS: 46041.35 INTERP
Description:

☐ Persistent Scale
☐ Compare Geometry Files
☐ Update Compare XS
☐ Merge Cross Sections

adjust channel bed profile

3. Use the “Graphic XS Editor” to inform the channel bed profile from neighbouring sections and manual adjustments.

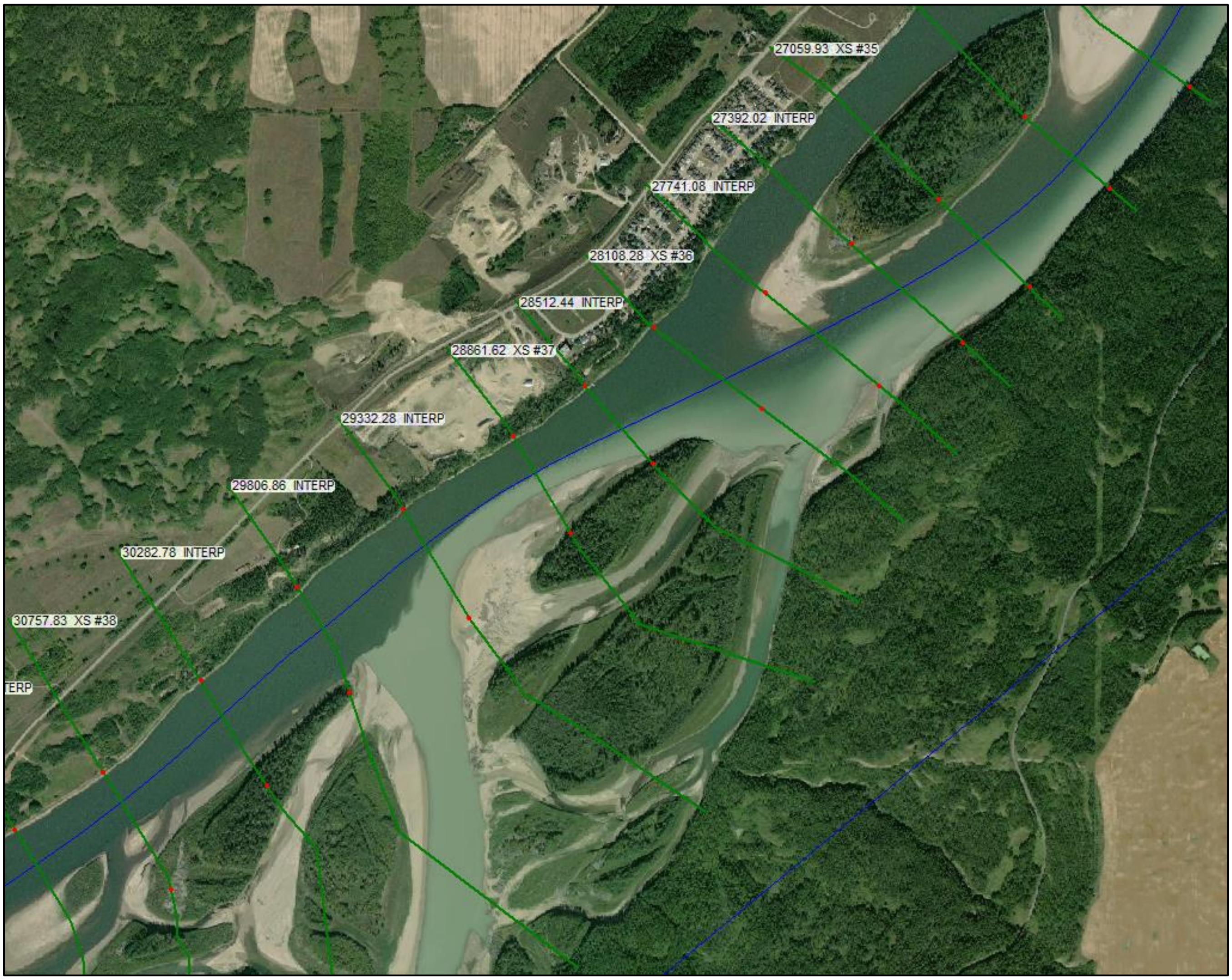
Task 5A Instructions: Compare Model Results with and without Interpolated Cross-Sections

1. Open the 'Steady Flow Analysis' window by clicking on the in the main interface window.
2. Go to File and select the '*Open Plan …*' option and choose the "**Module 5: Ice Jam Interpolated_Final**" plan. In this plan interpolated cross sections have been developed throughout the study reach. As part of the interpolation process, the overbank ice thicknesses were assigned the same as was done in Module 4. Verify that the correct files have been selected:

Table 15: Model Files Used for HEC-RAS Module 5 - Task 5A

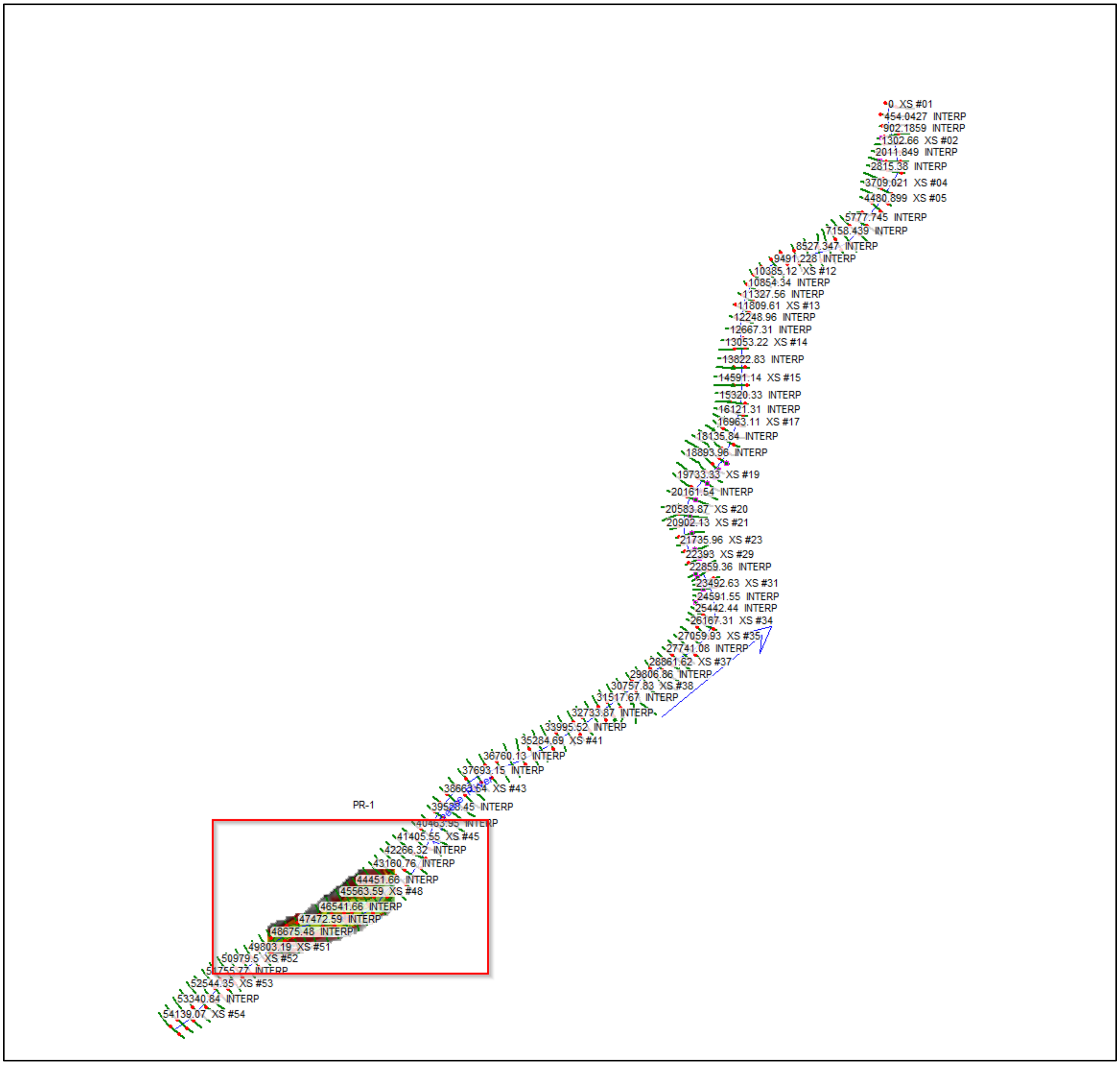
File Type	Filename
Plan	"Module 5: Ice Jam Interpolated_Final"
Geometry	"Module 5: Ice Jam Interpolated_Final"
Steady Flow	"Module 3: Simple Ice Jam"

3. Close this window by clicking on the ×
4. Open the 'Geometric Data' window by clicking on the in the main interface window.
5. Zoom in on any section of the model in plan view. Either use the scroll button on your mouse, or choose View and select '*Zoom In*'.



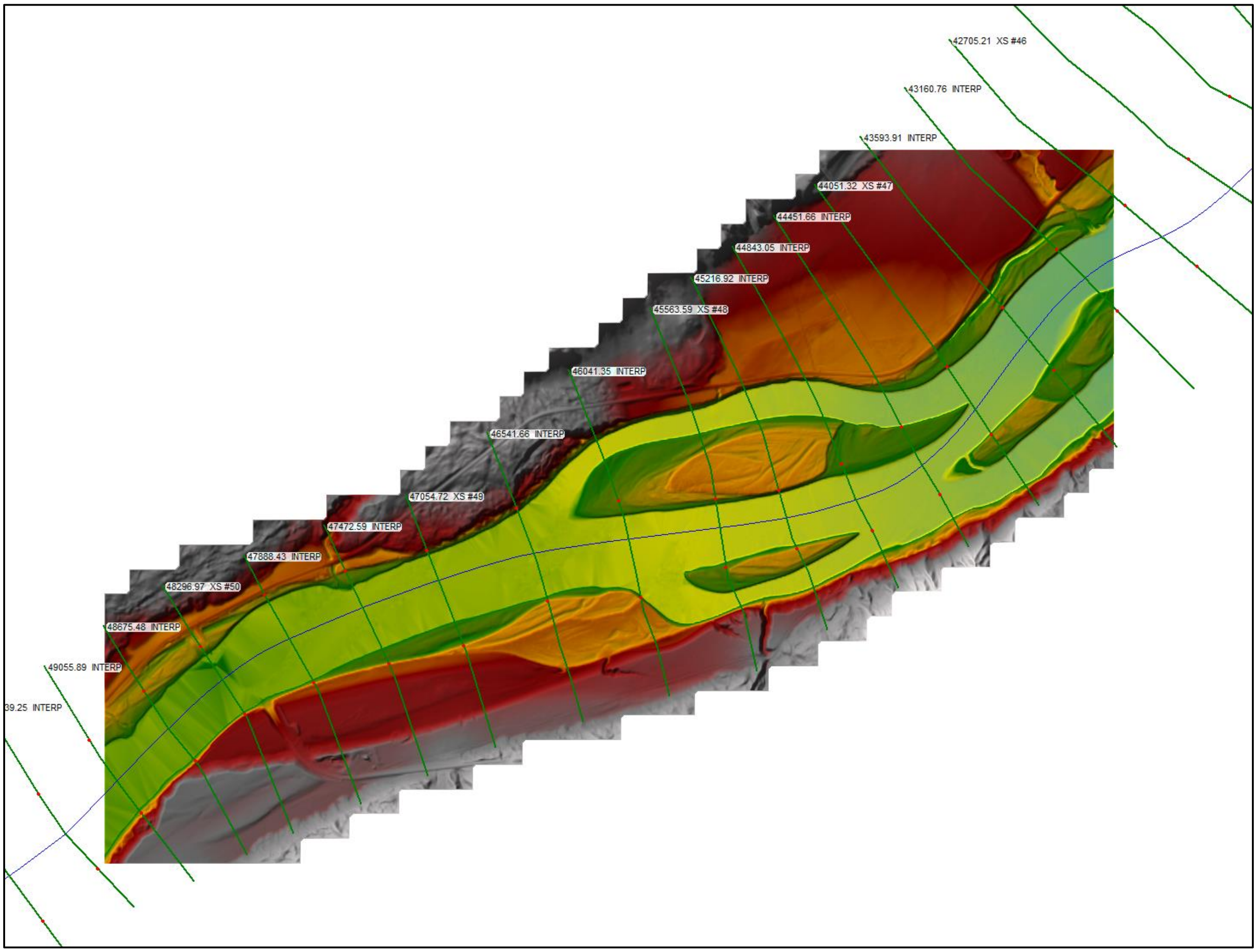
Notice that there are many more cross-sections than we saw previously. Cross sections have been interpolated between the surveyed cross sections and have been labelled INTERP for easier identification. Note that the INTERP label was added manually and is not the default HEC-RAS label for interpolated cross sections, which is a “*” (eg. 36182.2*). By manually changing the label of the interpolated cross sections, the HEC-RAS interface treats these sections differently (the user is not able to delete them with the interpolated cross section tool).

6. Pan around the plan view of the model (hold down the SHIFT key to pan, or choose View and select ‘*Pan (shift key)*’). Take a look at the bank stations for the interpolated cross-sections (marked), and compare their location to the background imagery.
7. Go to View and select ‘*Full Plot*’. To bring the zoom back to the model domain.
8. Click on the on the top bar in the ‘Geometric Data’ window
9. Uncheck *‘ArcGIS World Imagery’* and make sure ‘*Plot Terrain*’ is checked. Click Close.

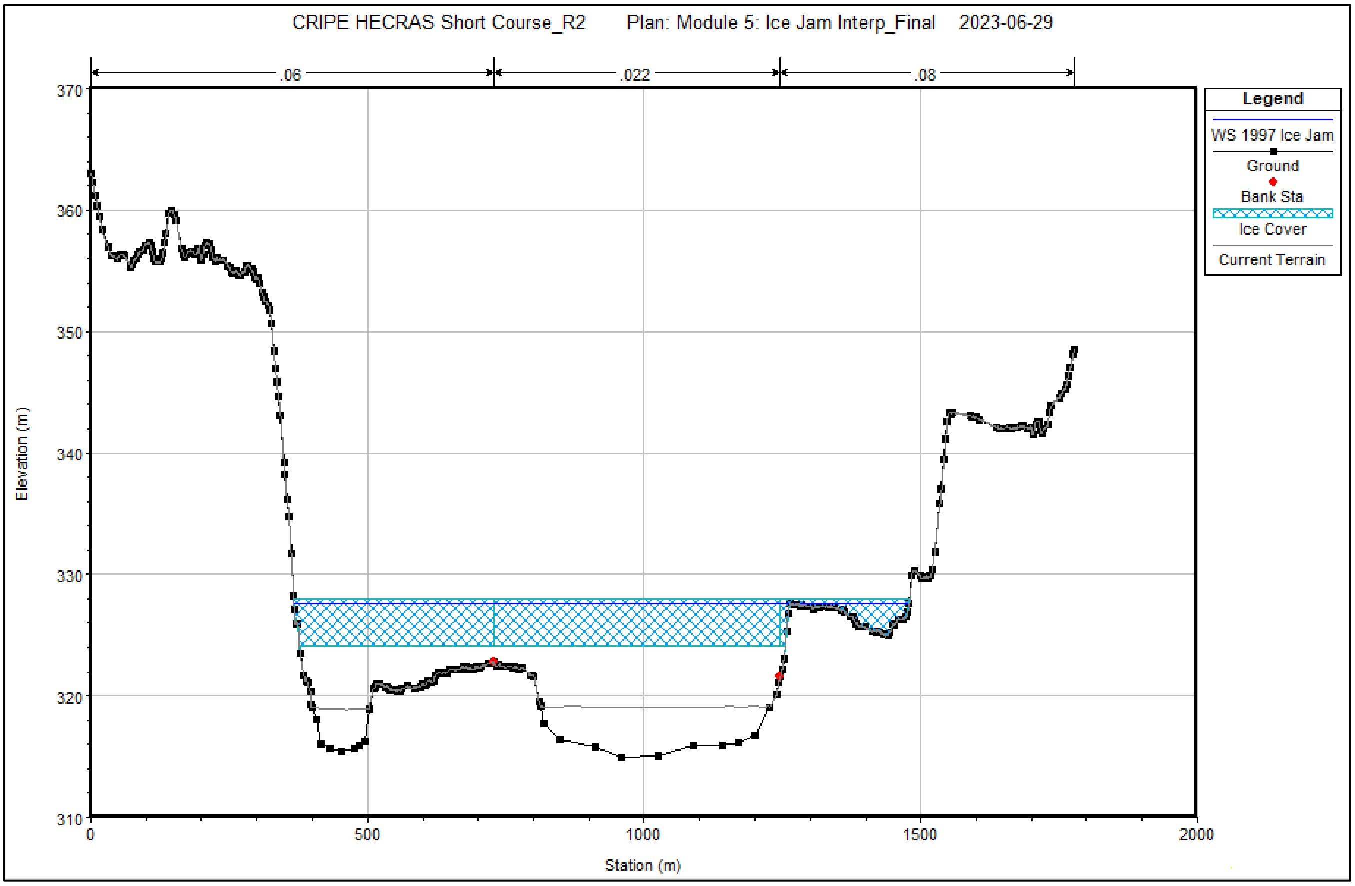


We have a small section of "Terrain" loaded into this model. This is a high-resolution digital elevation model showing the ground elevations. The data was collected using airborne LiDAR and verified with a third-party on-site survey. The terrain data has been "hydro-flattened", meaning that the area below the normal water surface is flat. The real life model has a terrain file that covers the entire model domain.

10. Zoom into the area where the terrain file is located. Choose View and select '*Zoom In*'.

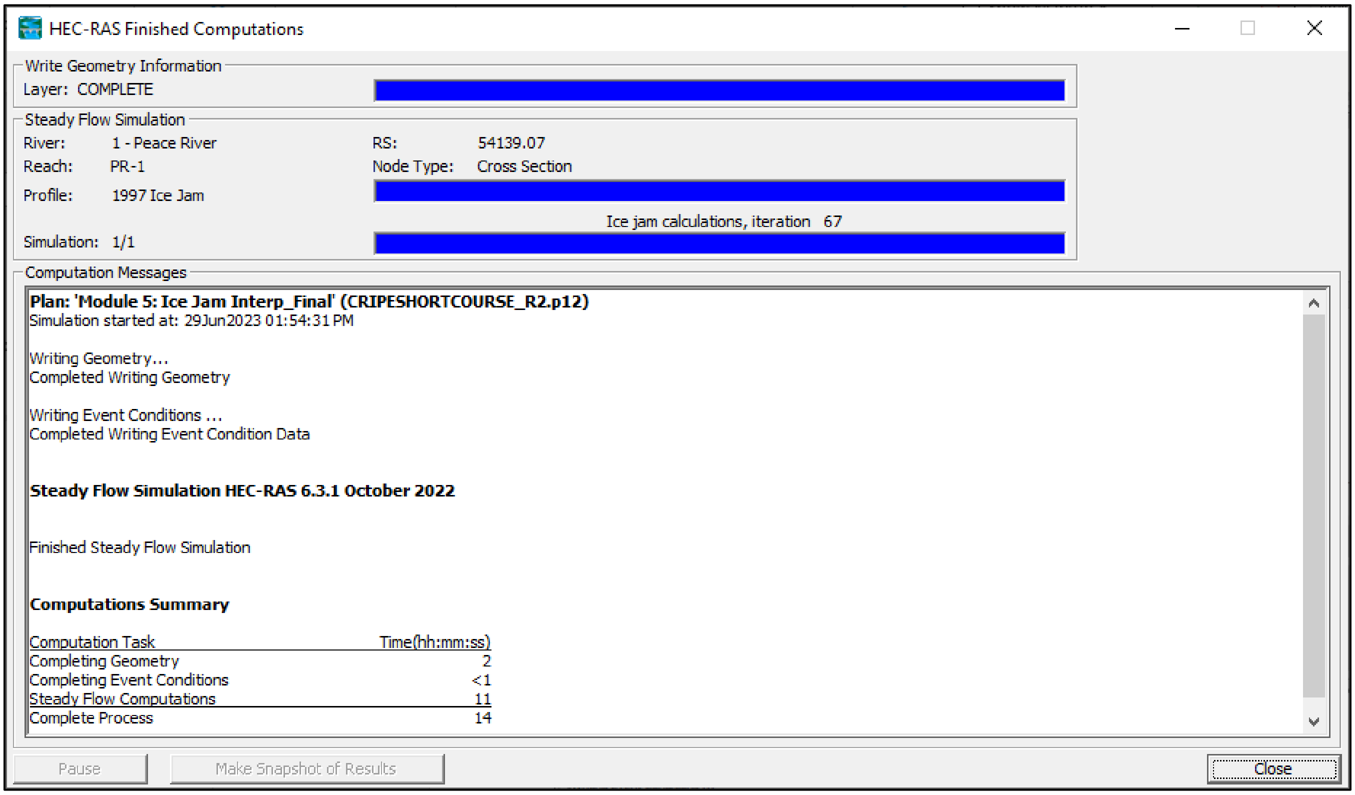


11. Click on the Cross Section to open the ‘Cross Section Data’ window. Choose a cross-section in the region where the terrain file is, such as ‘*47472.59 INTERP*’ from the ‘*River Sta.:*’ dropdown menu.



This cross section was developed from a combination of the DEM in the overbank and on the island and an interpolated cross section in the wetted portion of the channel. Notice how the ‘Current Terrain’ line follows the ‘Ground” line in the overbank and on the island but is nearly flat in both channels where the DEM has been hydroflattened.

12. Open the ‘Steady Flow Analysis’ window by clicking on the in the main interface window.
13. Check that the “**Module 5: Ice Jam Interpolated_Final**” plan is still active. Click Compute .



Layer: COMPLETE

River: 1 - Peace River
RS: 54139.07
Reach: PR-1
Node Type: Cross Section
Profile: 1997 Ice Jam
Ice jam calculations, iteration 67
Simulation: 1/1

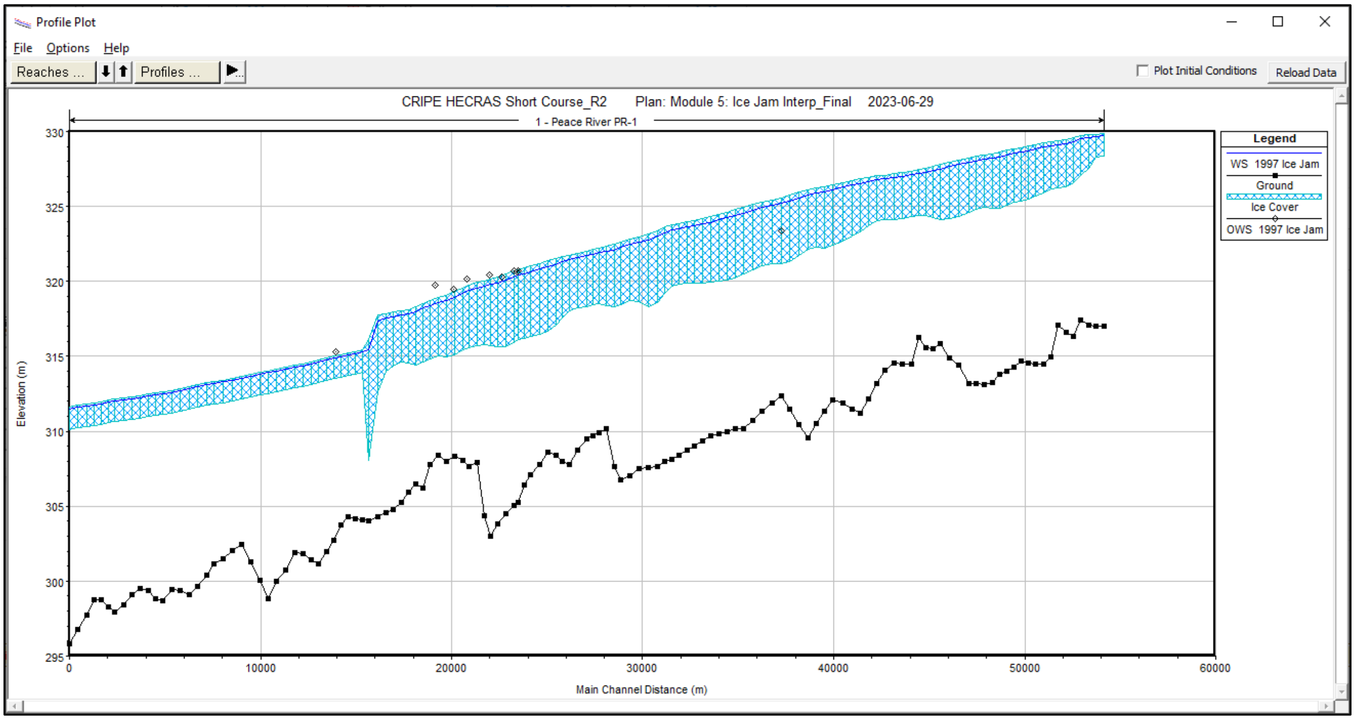
```
Plan: 'Module 5: Ice Jam Interp_Final' (CRIPESHORTCOURSE_R2.p12)
Simulation started at: 29Jun2023 01:54:31 PM

Writing Geometry...
Completed Writing Geometry

Writing Event Conditions ...
Completed Writing Event Condition Data


Steady Flow Simulation HEC-RAS 6.3.1 October 2022


Finished Steady Flow Simulation


Computations Summary

Computation Task                      Time(hh:mm:ss)
Completing Geometry                                2
Completing Event Conditions                       <1
Steady Flow Computations                          11
Complete Process                                  14
```

Notice how many iterations it took for the ice jam simulation to run. In the above window, it took 67 iterations to converge.

14. Click Close.

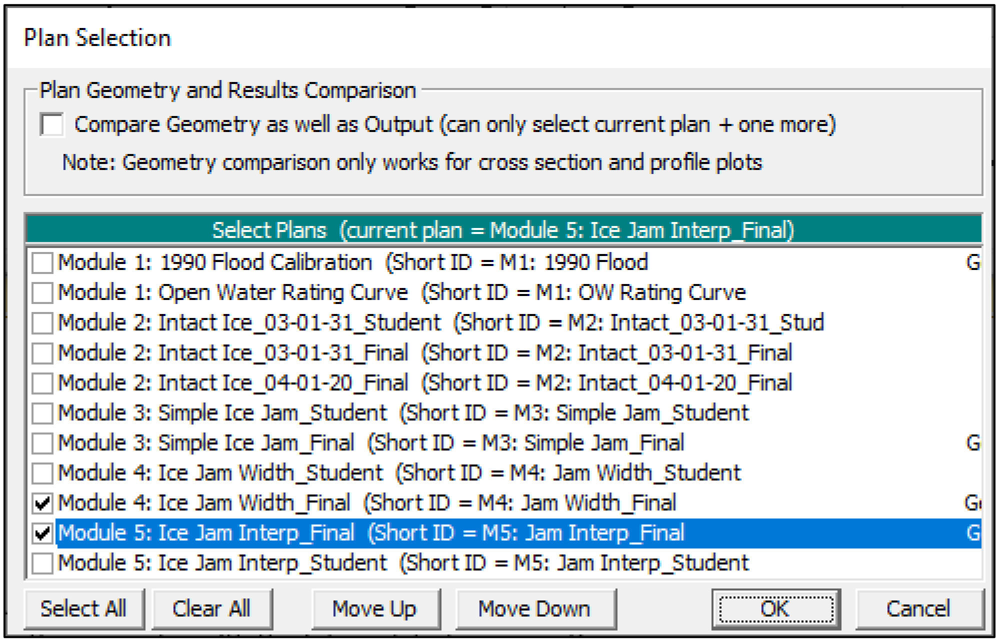
15. Close the 'Steady Flow Analysis' window by clicking on the ×

16. Open the 'Profile Plot' window by clicking on the 📈 in the main interface.



17. Open additional plans to compare against this one by go to Options and select ‘*Plans*’. Make sure the following 2 plans are selected:

- **“Module 4: Ice Jam Width_Final”**
- **“Module 5: Ice Jam Interp_Final”**



Plan Selection

Plan Geometry and Results Comparison

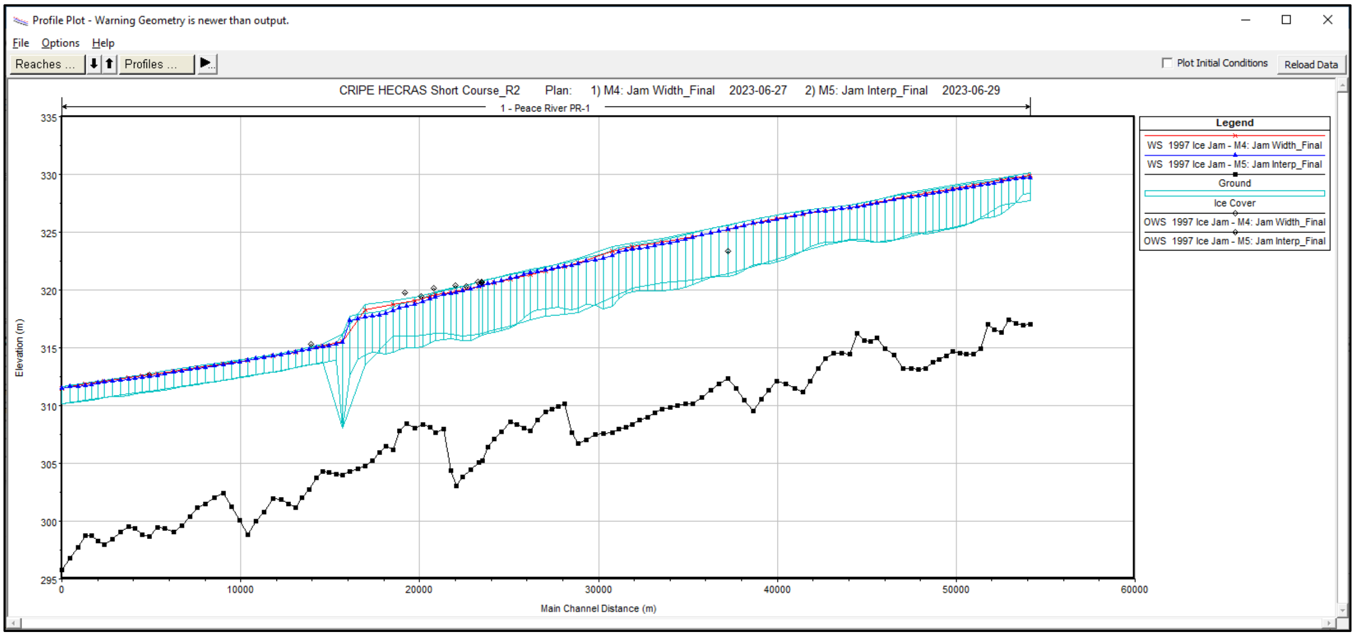
☐ Compare Geometry as well as Output (can only select current plan + one more)

Note: Geometry comparison only works for cross section and profile plots

Select Plans (current plan = Module 5: Ice Jam Interp_Final)

☐ Module 1: 1990 Flood Calibration (Short ID = M1: 1990 Flood G
☐ Module 1: Open Water Rating Curve (Short ID = M1: OW Rating Curve
☐ Module 2: Intact Ice_03-01-31_Student (Short ID = M2: Intact_03-01-31_Stud
☐ Module 2: Intact Ice_03-01-31_Final (Short ID = M2: Intact_03-01-31_Final
☐ Module 2: Intact Ice_04-01-20_Final (Short ID = M2: Intact_04-01-20_Final
☐ Module 3: Simple Ice Jam_Student (Short ID = M3: Simple Jam_Student
☐ Module 3: Simple Ice Jam_Final (Short ID = M3: Simple Jam_Final G
☐ Module 4: Ice Jam Width_Student (Short ID = M4: Jam Width_Student
☑ Module 4: Ice Jam Width_Final (Short ID = M4: Jam Width_Final G
☑ Module 5: Ice Jam Interp_Final (Short ID = M5: Jam Interp_Final G
☐ Module 5: Ice Jam Interp_Student (Short ID = M5: Jam Interp_Student

18. Click OK



The following table describes how each of the plans was generated. You can turn the plans on and off to see the various features better using Options and selecting '*Plans*'. You can also zoom in using your mouse scroll or use Options and click '*Zoom In*', etc.

Table 16: Description of plan files

Plan	Description	Notes
Module 4: Ice Jam Width_Final	Model developed in Module 4. There are no interpolated cross-sections so the ave/max/min XS spacing in the jam is 1163 m/1962 m/318 m, respectively.	Toe area is longer (in the streamwise direction) and has a greater ice volume.
Module 5: Ice Jam Interpolated_Final	Interpolated cross sections have been developed to resolve the ice plan profile, particularly the toe, in higher detail. The ave/max/min XS spacing in the jam is 413 m/513 m/198 m	The water level rise in the toe is much steeper and there is more variation is the thickness of the ice jam

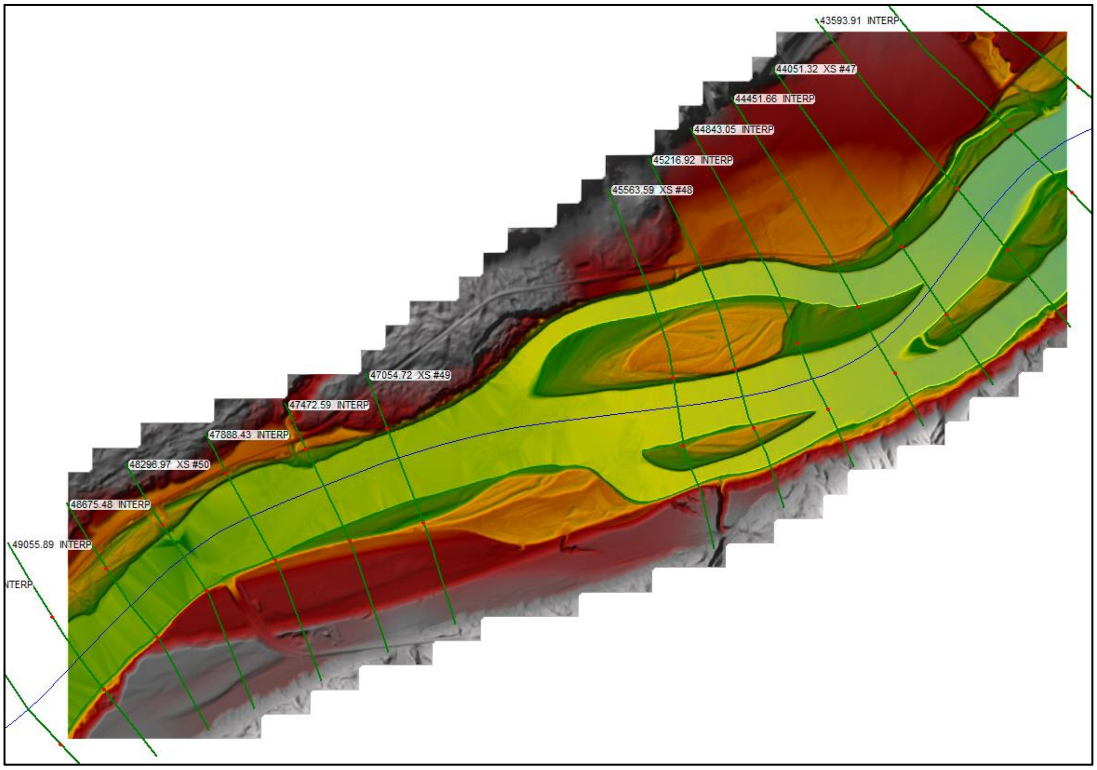
19. Close the profile plot by clicking on the by clicking on the ×

Task 5B Instructions: Add In New Interpolated Cross-Sections

1. Open the ‘Steady Flow Analysis’ window by clicking on the in the main interface window.
2. Go to File and select ‘*Open Plan …*’ to choose the “**Module 5: Ice Jam Interpolated_Student**” plan. Verify that the correct files have been selected:
3. Open the ‘Geometric Data’ window by clicking on the in the main interface window. The geometry file that is opened should be “**Module 5: Ice Jam Interpolated_Studen**t”. Click OK.

This geometry file is the same as we used in Task 5A, except two cross-sections have been removed between XS #48 and XS #49. We will be creating new interpolated sections for this area.

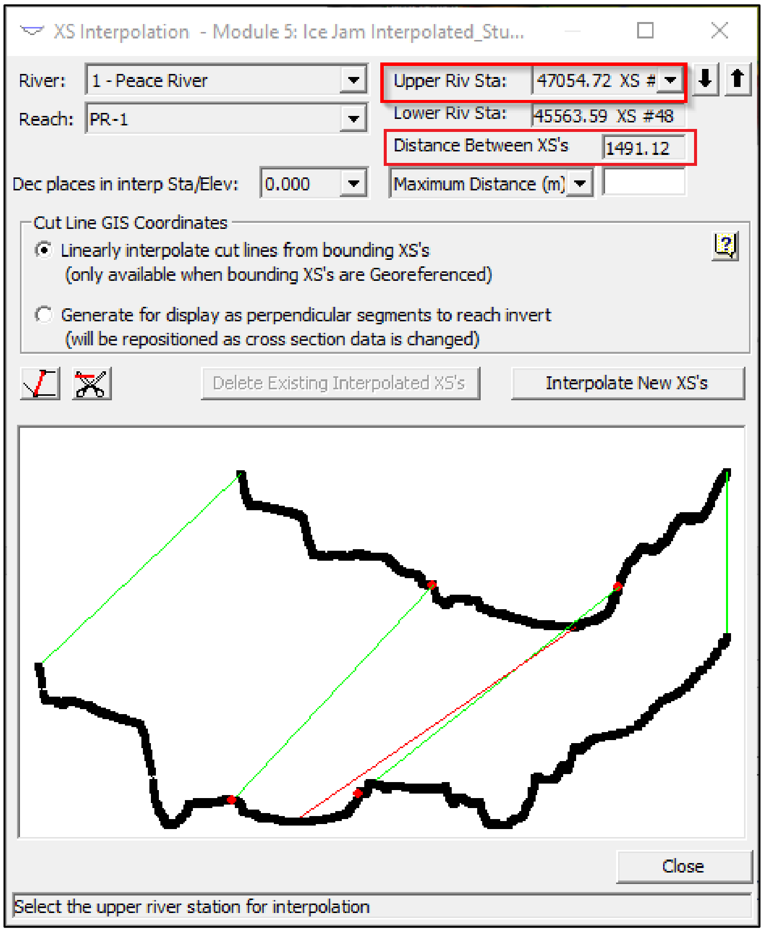
4. Zoom into the area where the terrain file coverage is located, like we did in Task 5A. Make sure that the ArcGIS World Imagery layer is turned off by clicking on in the top bar in the ‘Geometric Data’ window. Uncheck ‘*ArcGIS World Imagery*’ and make sure ‘*Plot Terrain*’ is checked. Click Close.



Notice the area missing interpolated cross-sections between XS #48 and XS #49.

5. Go to Tools, select ‘*XS Interpolation*’, and then select ‘*Between 2 XS’s*’.

6. Choose '*47054.72 XS #49*' from the dropdown menu beside 'Upper Riv Sta:'. The 'Lower Riv Sta:' box will automatically populate with XS #48.



XS Interpolation - Module 5: Ice Jam Interpolated_Stu...

River: 1 - Peace River

Reach: PR-1

Upper Riv Sta: 47054.72 XS #

Lower Riv Sta: 45563.59 XS #48

Distance Between XS's 1491.12

Dec places in interp Sta/Elev: 0.000

Maximum Distance (m)

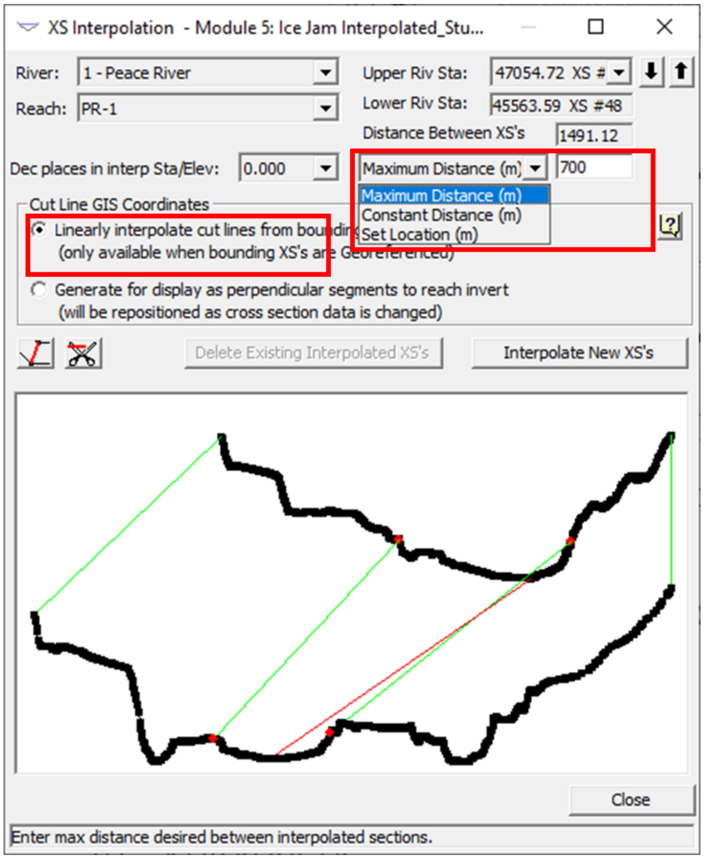
Cut Line GIS Coordinates

● Linearly interpolate cut lines from bounding XS's
(only available when bounding XS's are Georeferenced)

○ Generate for display as perpendicular segments to reach invert
(will be repositioned as cross section data is changed)

Select the upper river station for interpolation

7. The current distance between cross sections is 1491.12 m. The intent is to add two interpolated cross sections, dividing the space between the existing sections into thirds. Choose a 'Maximum Distance (m)' of *500 m* in the dropdown menu, and choose the "*Linearly interpolate cut lines from bounding XS's*" radio button.



River: 1 - Peace River

Reach: PR-1

Upper Riv Sta: 47054.72 XS #

Lower Riv Sta: 45563.59 XS #48

Distance Between XS's 1491.12

Dec places in interp Sta/Elev: 0.000

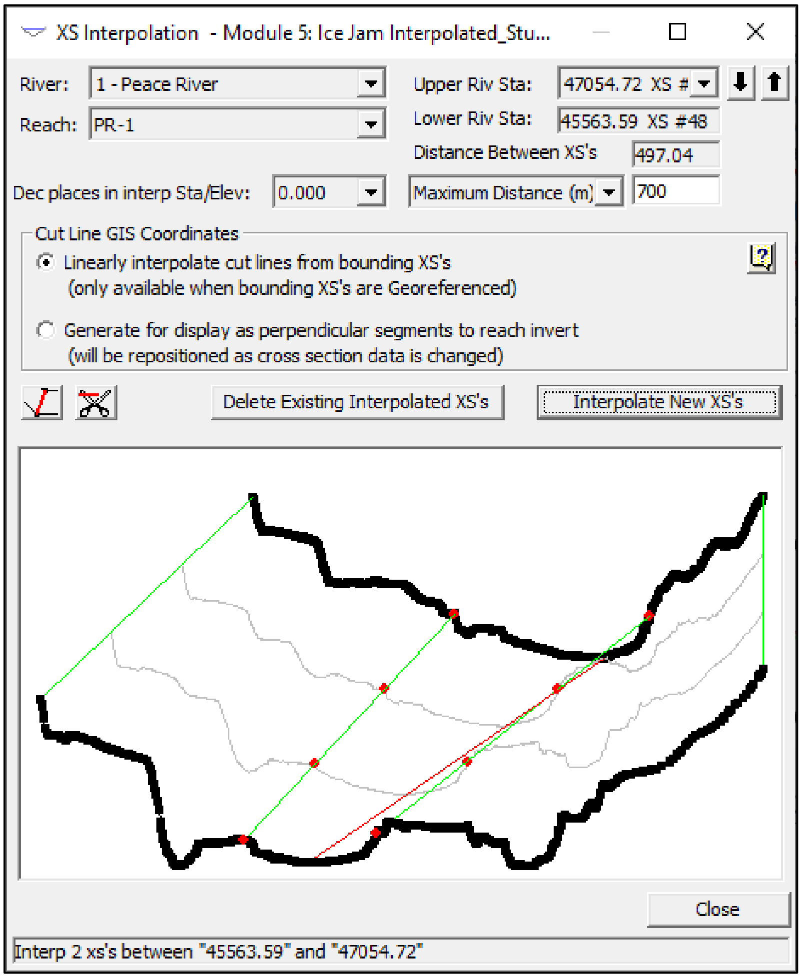
Maximum Distance (m) 700

● Linearly interpolate cut lines from bounding XS's (only available when bounding XS's are Georeferenced)

○ Generate for display as perpendicular segments to reach invert (will be repositioned as cross section data is changed)

Enter max distance desired between interpolated sections.

8. Click Interpolate New XS's. Note how the 'Distance Between XS's' updates to 497.04 m.


XS Interpolation - Module 5: Ice Jam Interpolated_Stu...

River: 1 - Peace River

Reach: PR-1

Upper Riv Sta: 47054.72 XS #

Lower Riv Sta: 45563.59 XS #48

Distance Between XS's 497.04

Dec places in interp Sta/Elev: 0.000

Maximum Distance (m) 700

Cut Line GIS Coordinates

● Linearly interpolate cut lines from bounding XS's (only available when bounding XS's are Georeferenced)

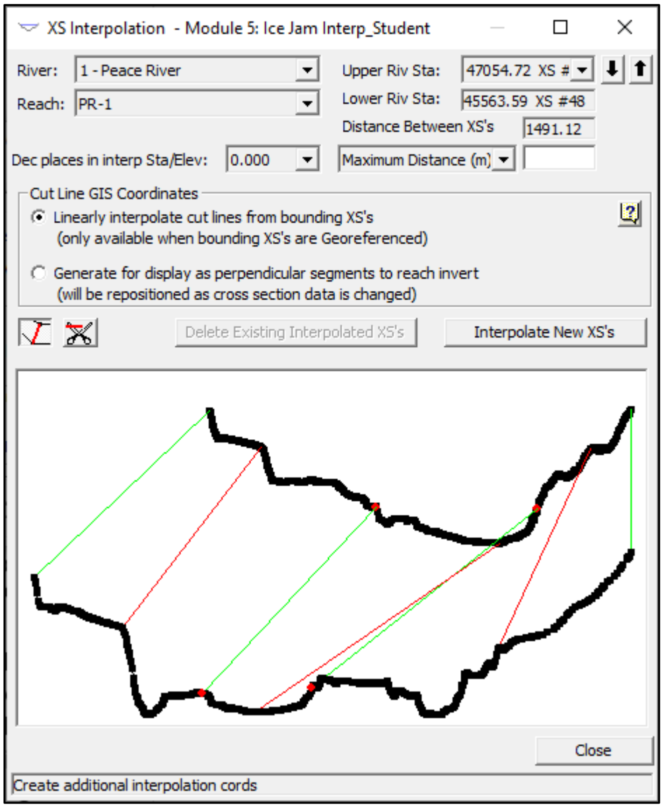
○ Generate for display as perpendicular segments to reach invert (will be repositioned as cross section data is changed)

Interp 2 xs's between "45563.59" and "47054.72"

The new cross-sections show up as grey lines in the preview window.

9. OPTIONAL: experiment with different ways to generate interpolated cross-sections. The Constant Distance (m) option interpolates cross sections at constant distance starting at the upstream cross section. The Set Location (m) option interpolates a cross section at the specified distance downstream of the upstream cross section. As long as you **don't click** Close, you can trial different ways. Before moving on to the next step, make sure you have generated two new cross-sections that are a maximum of 500 m apart, as shown above.

10. OPTIONAL: Additional cords can be added to the interpolation using this button. To add a cord, click on one cross-section and drag and release at the other cross section. Added cords connect points for interpolation and cords cannot intersect. There are default cords between the bank stations and the end of the cross sections (shown in green) that cannot be removed with the cut cord button. Keen students may recognize that because we are working with a geometry file where the bank stations have been adjusted, we are not able to do a reasonable interpolation to the split channels in XS 48.



XS Interpolation - Module 5: Ice Jam Interp_Student

River: 1 - Peace River

Reach: PR-1

Upper Riv Sta: 47054.72 XS #

Lower Riv Sta: 45563.59 XS #48

Distance Between XS's 1491.12

Dec places in interp Sta/Elev: 0.000

Maximum Distance (m)

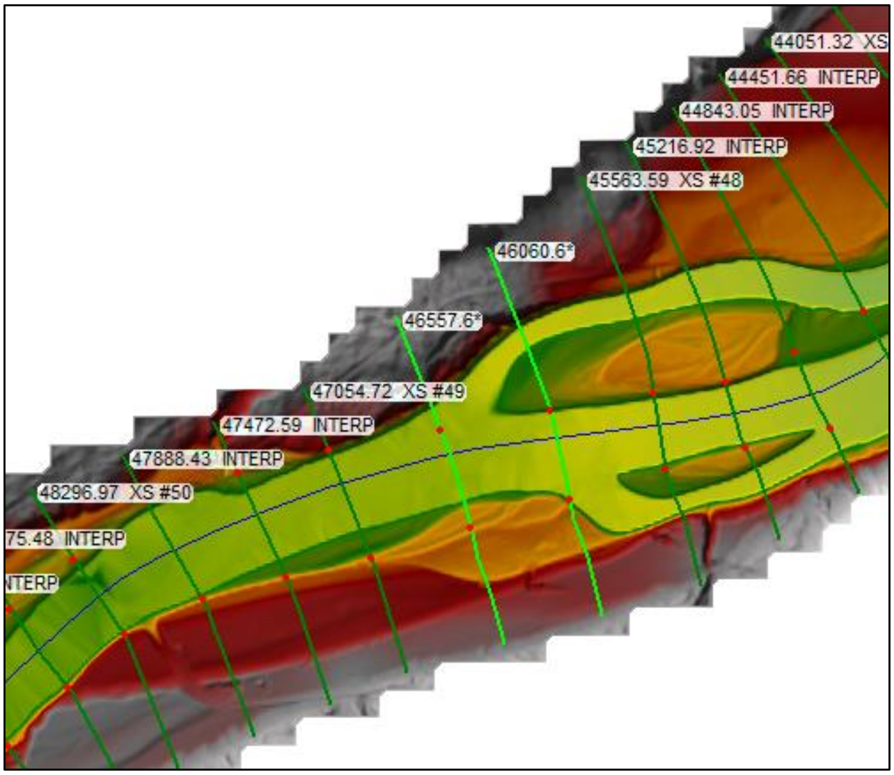
Cut Line GIS Coordinates

● Linearly interpolate cut lines from bounding XS's
(only available when bounding XS's are Georeferenced)

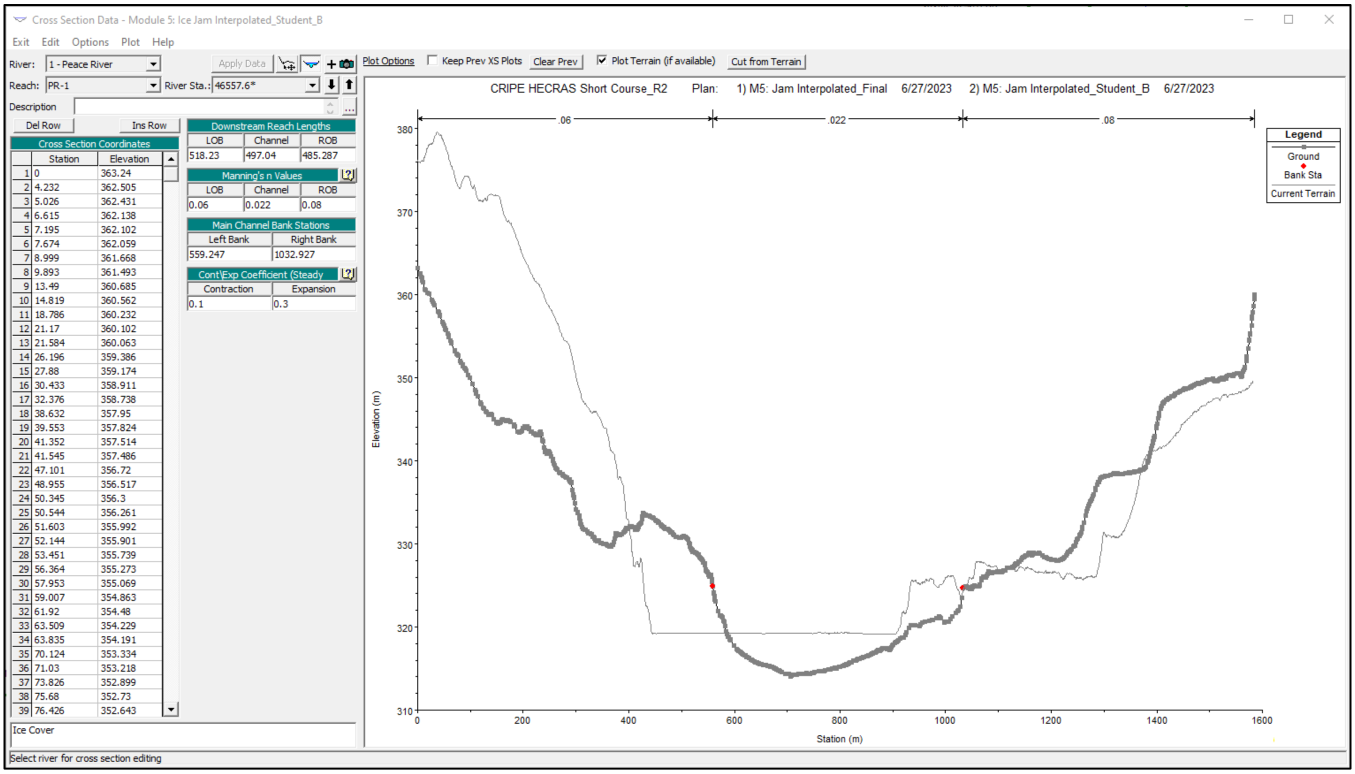
○ Generate for display as perpendicular segments to reach invert
(will be repositioned as cross section data is changed)

Create additional interpolation cords

11. Click Close. The new cross-sections will appear in the Geometric Data window. Note that they are labelled by their River Station and have an asterisk (*) beside the River Station, indicating that they have been interpolated.



12. Save the geometry file.
13. Click on the interpolated '*XS 46557.6**' in the 'Geometric Data' window. It will turn pink. Click again and choose '*Edit Cross Section*' to open the 'Cross Section Data' window for this cross-section.



River: 1 - Peace River

Reach: PR-1 River Sta.: 46557.6*

Description

Downstream Reach Lengths

LOB	Channel	ROB
518.23	497.04	485.287

Manning's n Values

LOB	Channel	ROB
0.06	0.022	0.08

Main Channel Bank Stations

Left Bank	Right Bank
559.247	1032.927

Cont\Exp Coefficient (Steady

Contraction	Expansion
0.1	0.3

Cross Section Coordinates

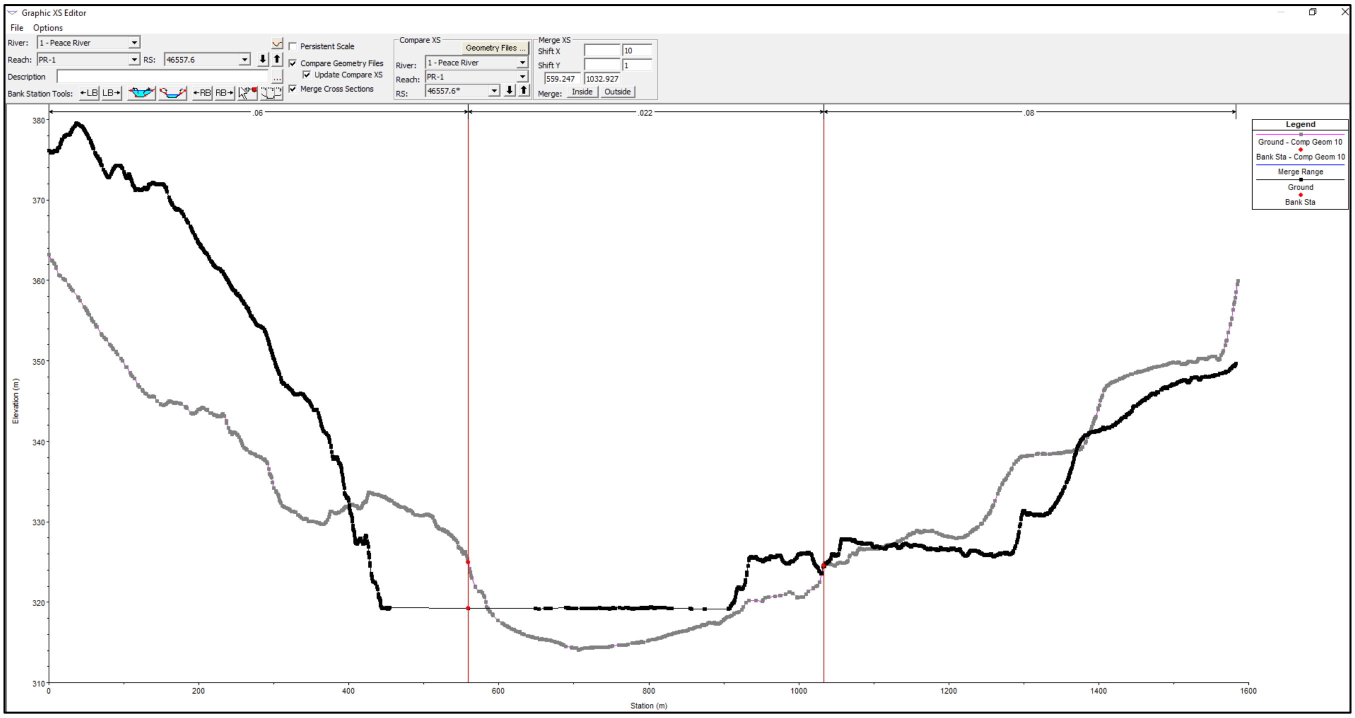
	Station	Elevation
1	0	363.24
2	4.232	362.505
3	5.026	362.431
4	6.615	362.138
5	7.195	362.102
6	7.674	362.059
7	8.999	361.668
8	9.893	361.493
9	13.49	360.685
10	14.819	360.562
11	18.786	360.232
12	21.17	360.102
13	21.584	360.063
14	26.196	359.386
15	27.88	359.174
16	30.433	358.911
17	32.376	358.738
18	38.632	357.95
19	39.553	357.824
20	41.352	357.514
21	41.545	357.486
22	47.101	356.72
23	48.955	356.517
24	50.345	356.3
25	50.544	356.261
26	51.603	355.992
27	52.144	355.901
28	53.451	355.739
29	56.364	355.273
30	57.953	355.069
31	59.007	354.863
32	61.92	354.48
33	63.509	354.229
34	63.835	354.191
35	70.124	353.334
36	71.03	353.218
37	73.826	352.899
38	75.68	352.73
39	76.426	352.643

Ice Cover

Select river for cross section editing

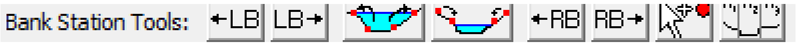
The interpolated cross-section is shown and compared with the DEM elevation (thin light gray line) along the alignment of the interpolated cross-section. The DEM cross-section is a better representation of the channel width. The next steps will look to combine the interpolated cross-section and the DEM cross-section.

14. Close the 'Cross Section Data' editor ×. In the 'Geometric Data' window, select File and click on '*Save As*'. Save the file as "**Module 5: Ice Jam Interp_Student_DEM"**.
15. Open the 'Cross Section data' editor again Cross Section and go to '*46557.6**'. Press Cut from Terrain to replace the cross section with the DEM elevations. Press Apply Data to see the updated cross section. Notice how the " * " is removed from the cross-section name. It is no longer coded in HEC-RAS as an interpolated cross section. Close the 'Cross Section editor' window.
16. In the 'Geometric Data editor' window, left click on the cross section and select '*Graphical Cross Section*' Editor. The 'Graphical Cross Section' Editor allows the user edit and combine cross sections visually.
17. Select '*RS: 46557.6*' from the drop down menu. Click on '*Compare Geometry Files*', then '*Update Compare XS*', and then '*Merge Cross Sections*'. Click the '*Geometry Files*' button and select "**10 Module 5: Ice Jam Interp_Student**". It will automatically select the River and Reach, but you will have to select '*46557.6**' in the RS drop down. This shows a comparison of the interpolated cross section and the DEM cross section.



River: 1 - Peace River
Reach: PR-1
RS: 46557.6
☐ Persistent Scale
☑ Compare Geometry Files
☑ Update Compare XS
☑ Merge Cross Sections
Compare XS
River: 1 - Peace River
Reach: PR-1
RS: 46557.6*
Merge XS
Shift X 10
Shift Y 1
559.247 1032.927

18. The ‘Graphical Cross Section’ Editor allows for assignment of the bank stations using the Bank Station Tools.

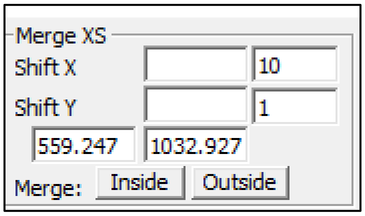


.

19. For example, the bank stations can be modified using the ‘*Set Bank Station*’ Button . Click on and then click on a point on the cross section and notice how the red bank station dots move. Notice as well how the Manning’s roughness coefficient bands change as the bank stations are changed. Note changes in the ‘Graphical Cross Section’ Editor can be undone by pressing Ctrl + Z. When you are done adjusting the bank stations, the button needs to be pressed again to turn it off.

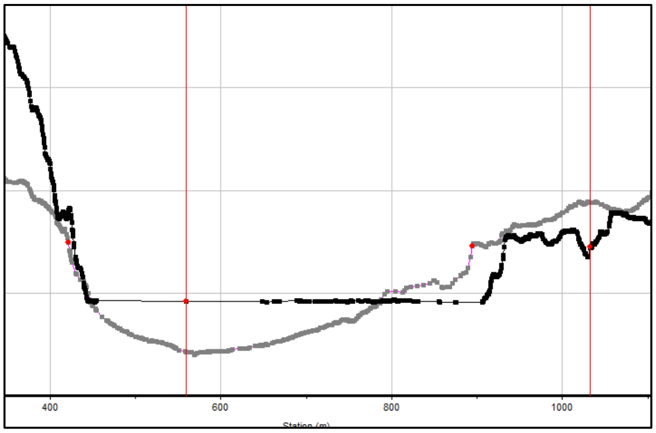
20. The cross section can be modified in several ways. Right click on the screen to bring up the different options including ‘Move Objects’, ‘Delete Objects’, ‘Add Sta/Elev Points’, etc. Select ‘*Move Objects’* and experiment with moving around points on the cross section. Any changes can be undone.

21. To merge portions of the interpolated and DEM cross sections we use the ‘*Merge XS*’ options. The Shift X and Shift Y boxes adjust the location of the light gray cross section.



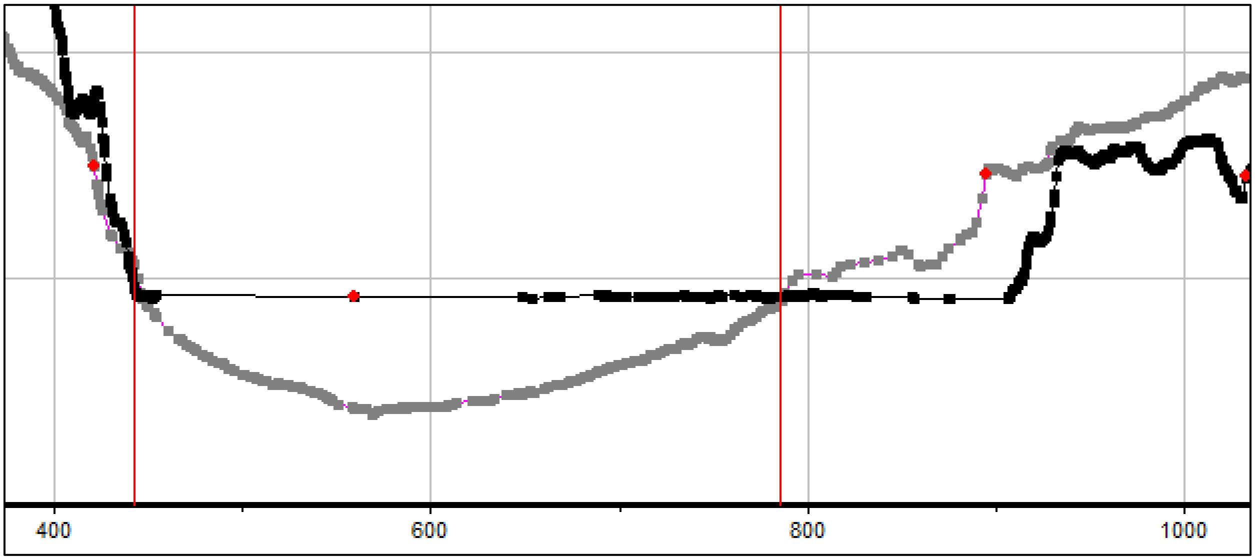
Merge XS
Shift X 10
Shift Y 1
559.247 1032.927
Merge: Inside Outside

22. Enter a value of *-138* in the Shift X field. This matches up the intersection of the left bank of both cross sections. Notice how the width of the interpolated cross section (light gray colour) is less than the DEM cross-section.

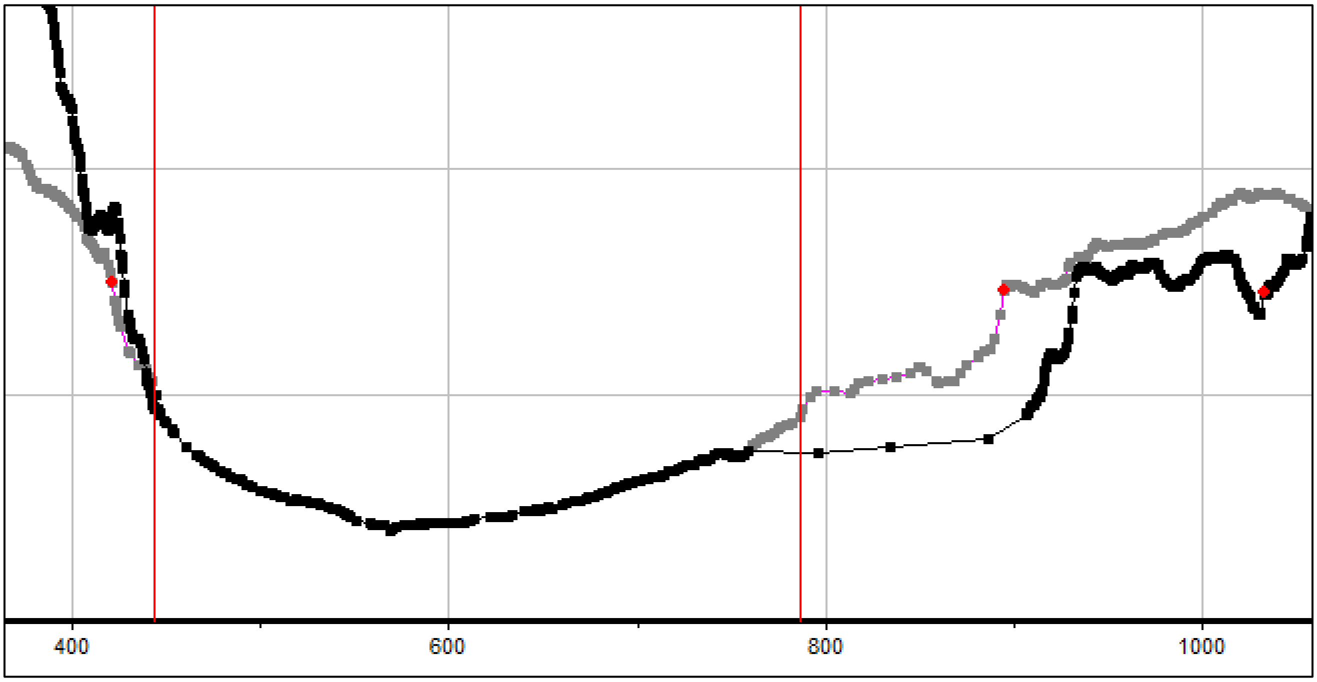


23. For the exercise, we will replace the hydro-flattened portion of the DEM cross section (black colour) with the interpolated cross section. Notice the vertical red lines which define the portions of the cross section that will be replaced. The cursor changes when you hover over these lines.

Drag the *left red line* to intersect with the *left intersection of the black and light grey lines* and the *right red line* to intersect with the *right intersection*. Click the '*Merge: Inside*' button Merge: Inside Outside. Notice how the data is replaced between the red lines. Remember that this change can be undone if you don't like how it has turned out.

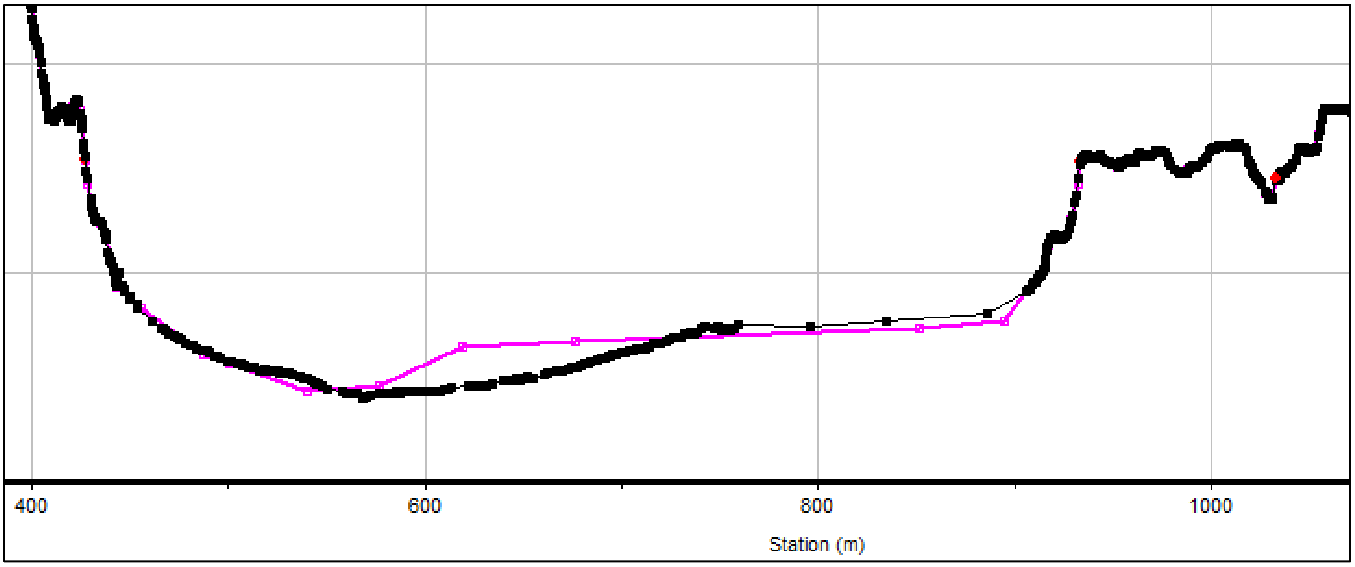


24. The hydro-flattened portion of the DEM cross section to the right of the red line can be modified using your engineering judgment. For example, we could assume that the right half of the channel is shallower and create a channel through a combination of deleting and adding points as shown in the image below. Deleting points can be done either one at a time or by selecting multiple in a selection box.

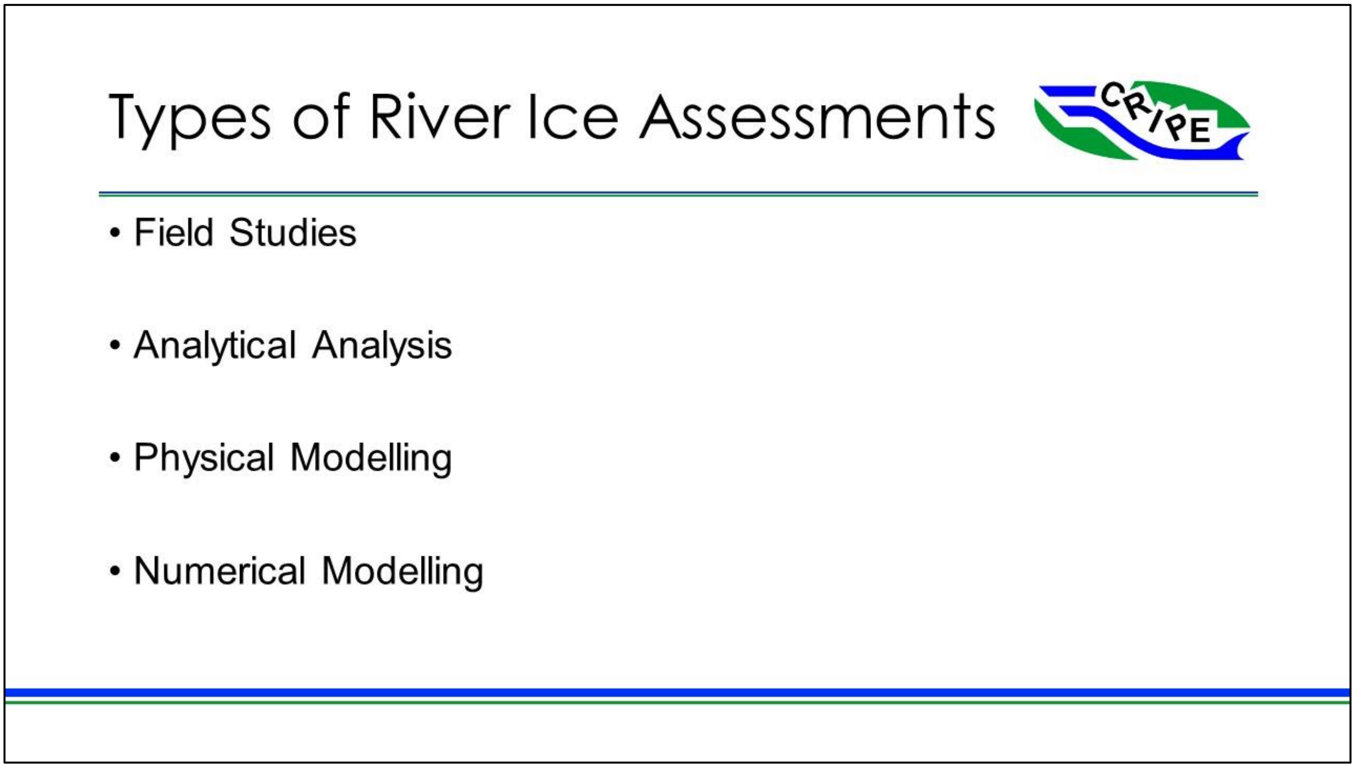


25. It would be worth while to compare the interpolated cross that we have developed to the Final interpolated cross section. Changing the data set that is loaded in the 'Graphical Cross Section' Editor can be a little glitchy when changing the files that are being compared. It is recommended that the window is closed and then reopened.

    Close the window × and then reopen it my left clicking on cross section '*46557.6*' and selecting 'Graphical Cross Section' Editor. Click on '*Compare Geometry Files*' and '*Update Compare XS'*. Click the '*Geometry Files*' button and select "**9 Module 5: Ice Jam Interp_Final**". In the 'RS:' drop down menu, select '*46541.66 INTERP*'. The RS values are slightly different because the interpolated cross section was in a slightly different location.

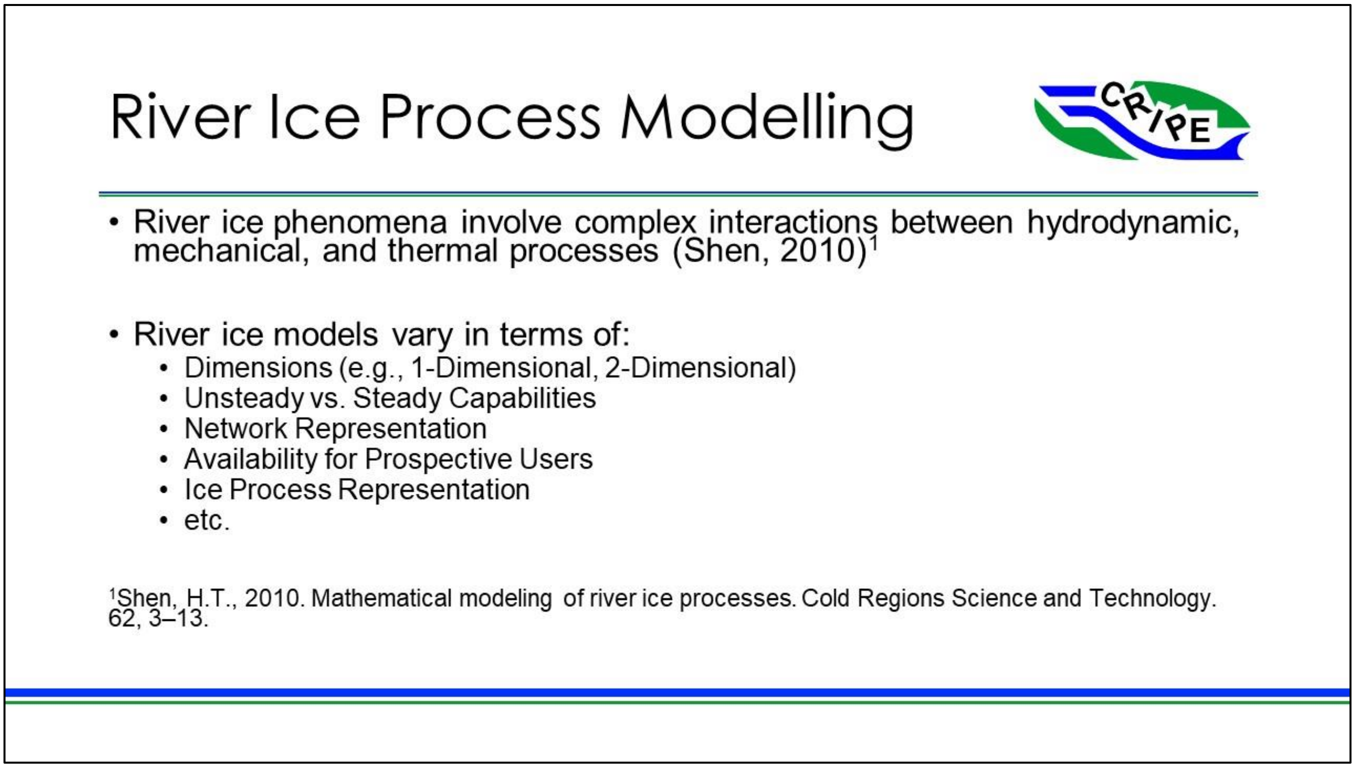


5. Summary of Available River Ice Models



Types of River Ice Assessments

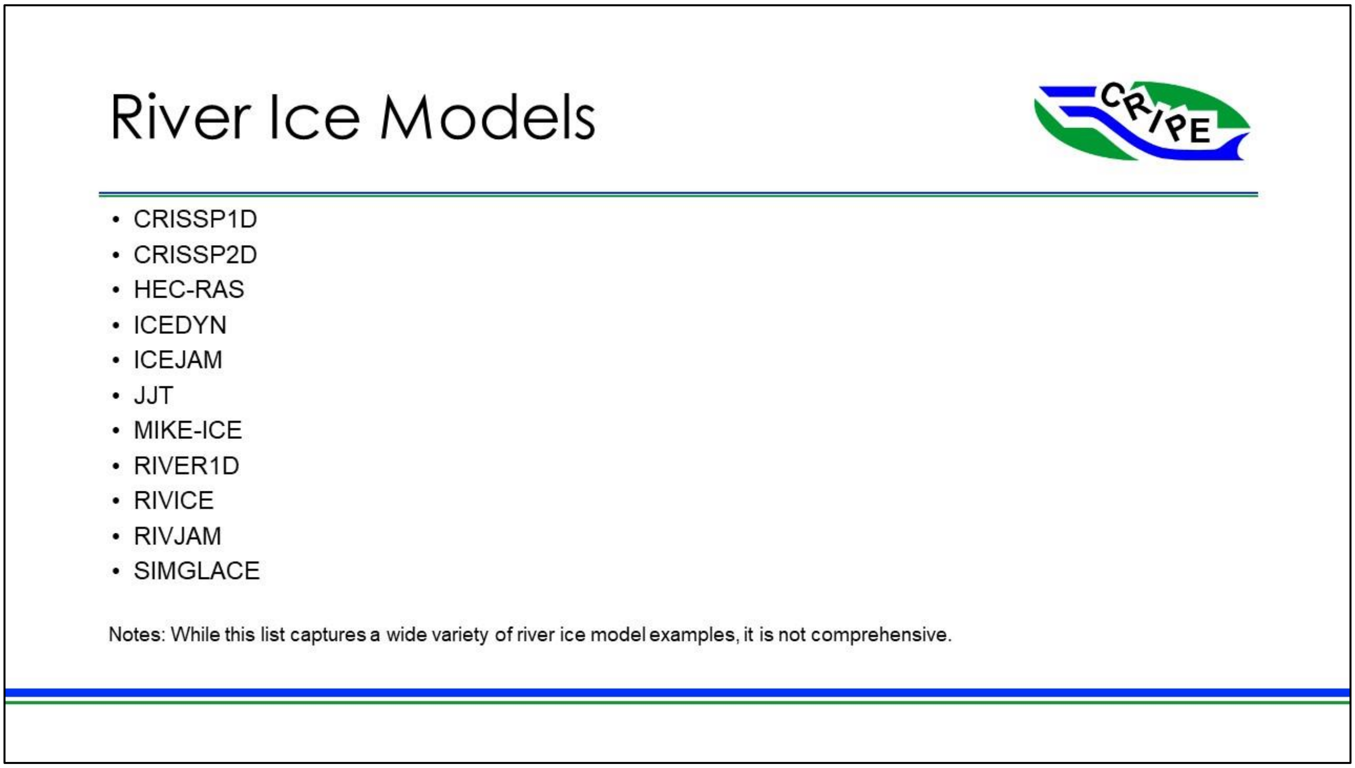
- Field Studies
- Analytical Analysis
- Physical Modelling
- Numerical Modelling



River Ice Process Modelling

- River ice phenomena involve complex interactions between hydrodynamic, mechanical, and thermal processes (Shen, 2010)[1]
- River ice models vary in terms of:
  - Dimensions (e.g., 1-Dimensional, 2-Dimensional)
  - Unsteady vs. Steady Capabilities
  - Network Representation
  - Availability for Prospective Users
  - Ice Process Representation
  - etc.

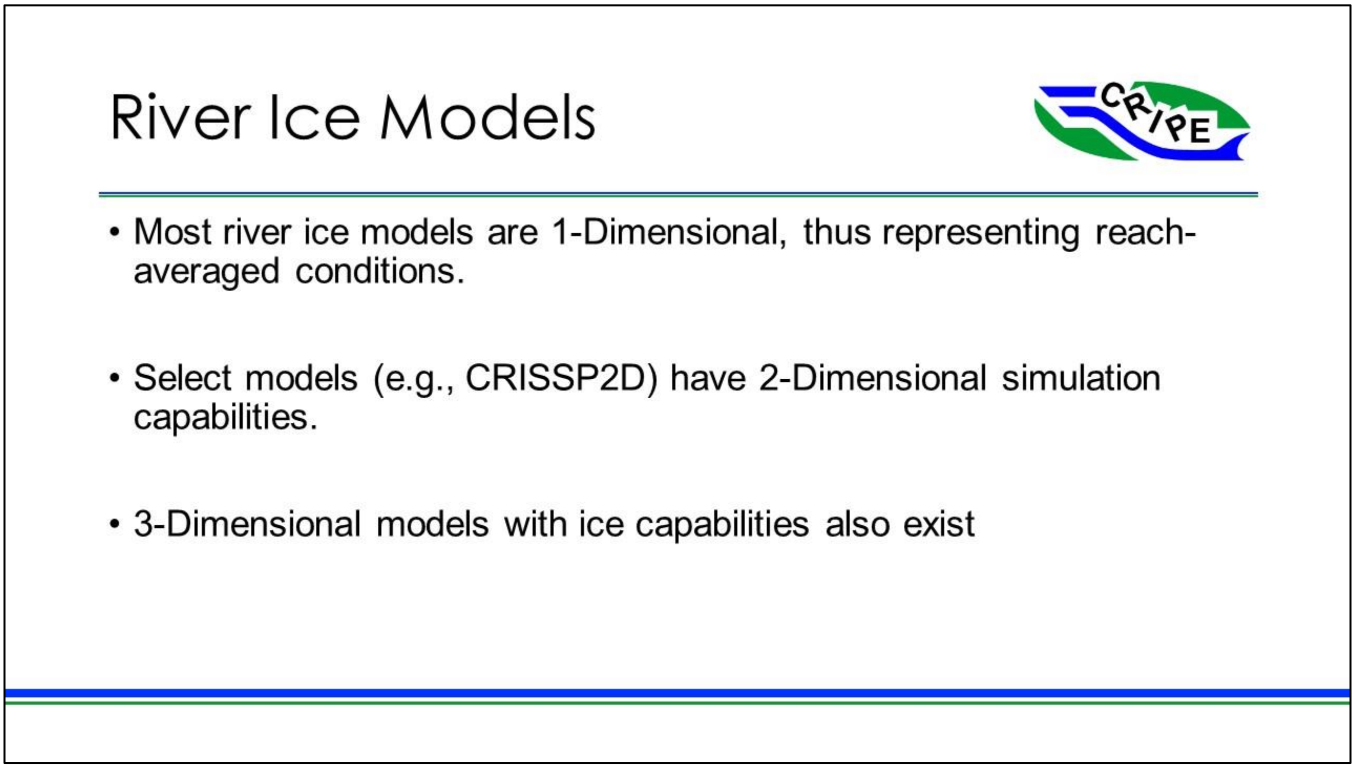
[1] Shen, H.T., 2010. Mathematical modeling of river ice processes. Cold Regions Science and Technology. 62, 3–13.



River Ice Models

- CRISSP1D
- CRISSP2D
- HEC-RAS
- ICEDYN
- ICEJAM
- JJT
- MIKE-ICE
- RIVER1D
- RIVICE
- RIVJAM
- SIMGLACE

Notes: While this list captures a wide variety of river ice model examples, it is not comprehensive.



River Ice Models

- Most river ice models are 1-Dimensional, thus representing reach-averaged conditions.
- Select models (e.g., CRISSP2D) have 2-Dimensional simulation capabilities.
- 3-Dimensional models with ice capabilities also exist

Steady/Unsteady & Network Representation

- **Steady/Unsteady**
  - Hydraulics (e.g., flows, water levels)
  - Ice Processes (e.g., ice volumes, ice accumulations)
  - Models can have steady, unsteady, or quasi-steady capabilities

- **Network Representation**
  - Nodes
  - Multiple channels
  - Other hydraulic features (bridges, etc.)
  - Most models limited to a single channel for ice process simulations

Numerical Scheme

- Algorithmic descriptions that yield a solution to one or more mathematical equation

- Vary between models (with some commonalities), some models implement more than one

- Examples:
  - Weighted Four-Point Implicit Scheme (common for 1D models)
  - Characteristic Dissipative Galerkin
  - Streamline Upwind Petrov-Galerkin
  - Lagrangian Discrete Parcel Method with Smooth Particle Hydrodynamics

Simulation Capabilities

- **Water Cooling:**
  - process of lowering the temperature of water to near/at/below its freezing point.
- **Frazil and Ice Floe Generation:**
  - formation of ice (frazil ice, frazil pans, skim ice, etc.) as a result of effectively supercooled conditions.
- **Border Ice and Static Ice Cover:**
  - ice that originates at the channel banks and grows laterally into the channel (either thermally or mechanically due to deposition/buttering) … static ice cover refers to a thermally grown ice cover that spans the entire water body.
- **Dynamic Surface Ice Cover Formation:**
  - formation of either a surface jam, wide channel jam, or narrow channel jam.

Simulation Capabilities

- **Thermal Ice Growth/Decay:**
  - thickening/thinning of an ice cover, and can include surface ice covers, border ice, static ice, or even ice floes.
- **Undercover Deposition and Transport of Ice:**
  - submergence, depositing, and movement of ice floes under a static ice cover or dynamic surface ice cover. This can lead to the formation of a hanging dam.
- **Anchor Ice:**
  - ice that is attached to the bed of a channel or other submerged surface.
- **Ice Jam Seepage and Ice Cover Seepage Flow:**
  - water conveyance through the ice units that comprise an ice cover.

Model-Specific Capabilities

Ice Process	*CRISSP1D*	*CRISSP2D*	*HEC-RAS*	*ICEDYN*	*MIKE-ICE*	*ICEJAM*	*JJT*	*RIVER1D*	*RIVICE*	*RIVJAM*	*SIMGLACE*
Water Cooling	X	X	X	X	X		X	X	X		X
Ice Generation	X	X		X	X		X	X	X		X
Border/Static Ice	X	X	X	X	X		X	X	X		X
Dynamic Ice	X	X	X	X	X	X	X	X	X	X	X
Thermal Growth/Decay	X	X		X	X		X	X	X		X
Undercover Ice	X	X		X	X		X	X	X		X
Anchor Ice	X	X		X	X				X		
Seepage Flow		X			X					X	

For More Information

- See **Appendix B** for detailed descriptions of ice process models.
- Information provided to describe current state of development, and availability of the model.
- Accompanying reference list highlights works that discuss these, and other, ice process models.

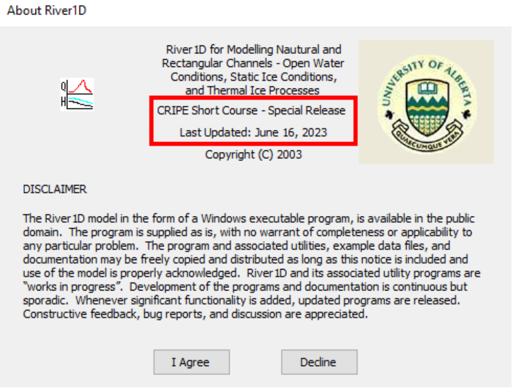
6. Introduction to Ice Process Modelling

University of Alberta's River1D

- Originally developed as a 1D open channel model based on the Characteristic Dissipative Galerkin (CDG) finite element method (FEM) for rectangular channels only (Hicks & Steffler, 1992)
- Ice process capabilities first introduced included water cooling, frazil formation and rise, and ice cover formation and retreat (Andrishak & Hicks, 2008)
- Model later enhanced to include natural channel capabilities, water supercooling, anchor ice evolution, border ice formation, under-cover frazil transport, and ice cover formation based leading edge stability criteria (Blackburn & She, 2019)

University of Alberta's River1D

- Current version available for download – July 21, 2021
- Current version also includes:
  - ice jam profile modelling module for single channels and channel networks
  - options for multiple bridging locations
- Special short course release with new features (released to public soon!)



About River1D

River1D for Modelling Nautural and
Rectangular Channels - Open Water
Conditions, Static Ice Conditions,
and Thermal Ice Processes

CRIPE Short Course - Special Release

Last Updated: June 16, 2023

Copyright (C) 2003

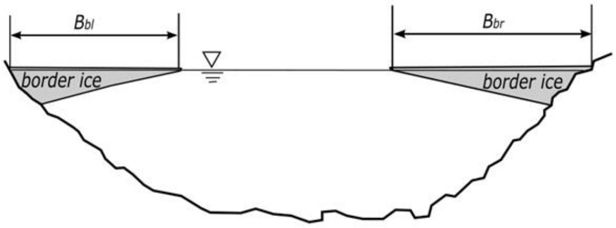
DISCLAIMER

The River1D model in the form of a Windows executable program, is available in the public domain. The program is supplied as is, with no warrant of completeness or applicability to any particular problem. The program and associated utilities, example data files, and documentation may be freely copied and distributed as long as this notice is included and use of the model is properly acknowledged. River1D and its associated utility programs are "works in progress". Development of the programs and documentation is continuous but sporadic. Whenever significant functionality is added, updated programs are released. Constructive feedback, bug reports, and discussion are appreciated.

Ice Processes with River1D

Overview of modelling ice regime with River1D

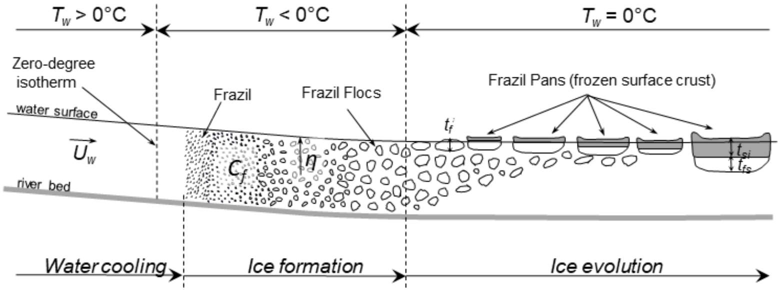
- Water cools (T_w)
- Border ice grows out from banks (B_b) and thickens (t_b)



Ice Processes with River1D

Overview of modelling ice regime with River1D

- Once water is super cooled, frazil production begins (C_f)
- Frazil rises (η) to surface with initial pan thickness(t_f')
- Surface ice pans grow and move with flow (C_i, t_{fs}, t_{si})

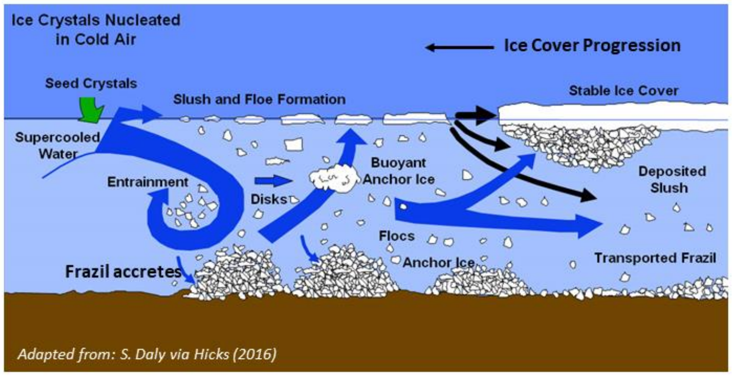


Adapted from: She et al. (2012) and Michel (1971)

Ice Processes with River1D

Overview of modelling ice regime with River1D

- Frazil accretes (γ) to bed to form anchor ice (t_{an})
- Anchor ice releases to join surface ice
- Ice bridging occurs at user specified time and location
- Ice cover progresses in upstream direction, controlled by flow (F_r)
- Frazil transported undercover (t_{ui})
- Water warms, ice retreats



Adapted from: S. Daly via Hicks (2016)

Ice Processes with River1D

Water temperature and moving ice modelled with 1D advection partial differential equation (T_w, C_f, C_i, t_{fs}, t_{si}, t_{ui}):

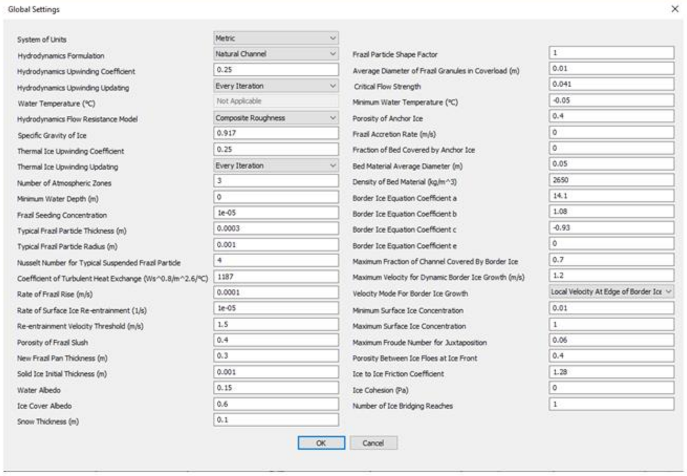
$$\underbrace{\frac{\partial}{\partial t}(\Phi)}_{\text{change in time}} + \underbrace{\frac{\partial}{\partial x}(U\Phi)}_{\text{change in space}} = \underbrace{S}_{\text{source terms}}$$

Solved using Streamlined Upwinded Petrov Galerkin (SUPG) finite element method (FEM)

Ice Processes with River1D

Lots of parameters!

We will focus on some of the key processes and parameters



System of Units	Metric
Hydrodynamics Formulation	Natural Channel
Hydrodynamics Upwinding Coefficient	0.25
Hydrodynamics Upwinding Updating	Every Iteration
Water Temperature (°C)	Not Applicable
Hydrodynamics Flow Resistance Model	Composite Roughness
Specific Gravity of Ice	0.917
Thermal Ice Upwinding Coefficient	0.25
Thermal Ice Upwinding Updating	Every Iteration
Number of Atmospheric Zones	3
Minimum Water Depth (m)	0
Frazil Seeding Concentration	1e-05
Typical Frazil Particle Thickness (m)	0.0003
Typical Frazil Particle Radius (m)	0.001
Nusselt Number for Typical Suspended Frazil Particle	4
Coefficient of Turbulent Heat Exchange (Ws^0.8/m^2.6/°C)	1187
Rate of Frazil Rise (m/s)	0.0001
Rate of Surface Ice Re-entrainment (1/s)	1e-05
Re-entrainment Velocity Threshold (m/s)	1.5
Porosity of Frazil Slush	0.4
New Frazil Pan Thickness (m)	0.3
Solid Ice Initial Thickness (m)	0.001
Water Albedo	0.15
Ice Cover Albedo	0.6
Snow Thickness (m)	0.1
Frazil Particle Shape Factor	1
Average Diameter of Frazil Granules in Coverload (m)	0.01
Critical Flow Strength	0.041
Minimum Water Temperature (°C)	-0.05
Porosity of Anchor Ice	0.4
Frazil Accretion Rate (m/s)	0
Fraction of Bed Covered by Anchor Ice	0
Bed Material Average Diameter (m)	0.05
Density of Bed Material (kg/m^3)	2650
Border Ice Equation Coefficient a	14.1
Border Ice Equation Coefficient b	1.08
Border Ice Equation Coefficient c	-0.93
Border Ice Equation Coefficient e	0
Maximum Fraction of Channel Covered By Border Ice	0.7
Maximum Velocity for Dynamic Border Ice Growth (m/s)	1.2
Velocity Mode For Border Ice Growth	Local Velocity At Edge of Border Ice
Minimum Surface Ice Concentration	0.01
Maximum Surface Ice Concentration	1
Maximum Froude Number for Juxtaposition	0.06
Porosity Between Ice Floes at Ice Front	0.4
Ice to Ice Friction Coefficient	1.28
Ice Cohesion (Pa)	0
Number of Ice Bridging Reaches	1

Ice Processes with River1D

Water cooling and supercooling

$$\underbrace{\phi_{wa}}_{\substack{\text{net heat exchange}\\ \text{between water and air}}} = \underbrace{h_{wa}(T_w - T_a) - j_{wa}T_a + k_{wa}}_{\substack{\text{linear approximation to temperature}\\ \text{dependent terms in the full energy budget equation}}} - \underbrace{(1-\alpha_w)\phi_s}_{\substack{\text{net incoming solar}\\ \text{radiation}}}$$

$T_w =$ water temperature (calculated)

$$\left.\begin{array}{l} T_a = \text{air temperature (input as time series)} \\ \phi_s = \text{incoming solar radiation (input as time series)} \end{array}\right\} \text{atmospheric data}$$

$h_{wa}, j_{wa}, k_{wa} =$ linear heat transfer model parameters (nodal calibration parameters)

$\alpha_w =$ albedo of water (global calibration parameter)

Ice Processes with River1D

Once water temperature reaches zero…

- Border ice starts to grow, $f(h_{wa}, h_{ia})$

Once water temperature drops below zero (supercooling)…

- Frazil forms, $f(d_e, r_o, C_{fo}, N_u^f)$
- Frazil rises to surface to form frazil pans, $f(\eta, t_f')$
- Frazil accretes to bed to form anchor ice, $f(\gamma, C_{an})$
- Anchor ice growth thermally on the bed $f(\alpha_{wi}, C_{an})$

Ice Processes with River1D

At some point ice bridging occurs…

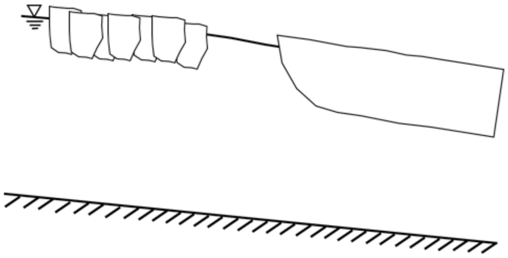
- Ice bridging is specified by the user in terms of time and location (based on observations)
- Once bridging occurs, the ice front will start to progress upstream
- Multiple bridging locations can be simulated

photo by: J. Blackburn

Ice Processes with River1D

Ice cover progression is controlled by incoming ice and Froude number

- When $F_r < F_{rjux}$, ice cover progress with a juxtaposed cover (edge-to-edge)
- When $F_{rjux} < F_r < F_{rmax}$, ice cover progress with thickness based on static jam theory
- When $F_r > F_{rmax}$, incoming ice swept downstream and is transported undercover



Ice Processes with River1D

Solid (thermal) ice growth from frazil slush or water

$$\underbrace{\phi_{ia}}_{\substack{\text{net heat exchange} \\ \text{between water and air through} \\ \text{floating ice (and snow) layer} \\ \phi_{ia}>0 \text{ and } T_w \le 0}} = \frac{h_{ia}(T_m - T_a) - (1-\alpha_i)\phi_s}{h_{ia}\left(\dfrac{1}{h_{ia}} + \dfrac{t_{si}}{K_i} + \dfrac{t_{sn}}{K_{sn}}\right)}$$

$h_{ia} =$ heat transfer coefficient (nodal calibration parameter)

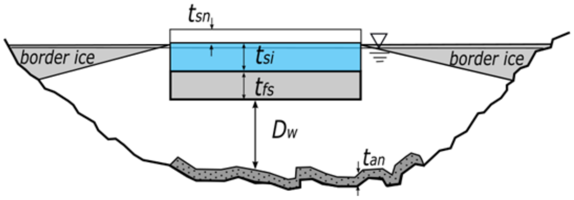
$T_m =$ freezing temperature of water (0°C)

$\alpha_i =$ albedo of ice (global calibration parameter)

$t_{si} =$ solid (thermal) ice thickness (calculated)

$t_{sn} =$ snow thickness (global parameter)

$K_i, K_{sn} =$ thermal conductivity ice, snow



Ice Processes with River1D

Solid (thermal) ice decay at surface

$$\underbrace{\phi_{ia(surface)}}_{\substack{\text{net heat exchange}\\\text{between ice and air}\\\phi_{ia(surface)}<0\text{ and }T_w>0}} = h_{ia}(T_s - T_a) - (1-\alpha_i)\phi_s$$

Ice decay at water-ice interface

$$\underbrace{\phi_{wi}}_{\substack{\text{net heat exchange}\\\text{at water-ice interface}\\\text{when }T_w>0}} = \alpha_{wi}\left(\frac{|U_w|^{0.8}}{D_w^{\ 0.2}}\right)T_w$$

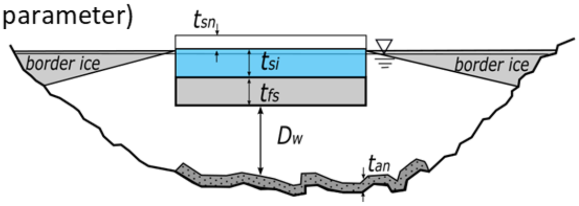
h_{ia} = heat transfer coefficient (nodal calibration parameter)

α_{wi} = coefficient of turbulent heat exchange (global parameter)

T_s = surface ice temperature (0°C)

U_w = water velocity

D_w = water depth



Ice Processes with River1D

For model calibration and validation you need…

- At least two seasons of data – 1 for calibration, 1 for validation
- For each season you will need inflow boundary conditions (Q_w, T_w) atmospheric data (T_a, ϕ_s), and observations (water and ice)
- More observations will improve the model calibration and validation
- Observations can include: water temperature, stage, ice front progression, surface ice concentration, ice thicknesses (t_{an}, t_{fs}, t_{si}), border ice widths

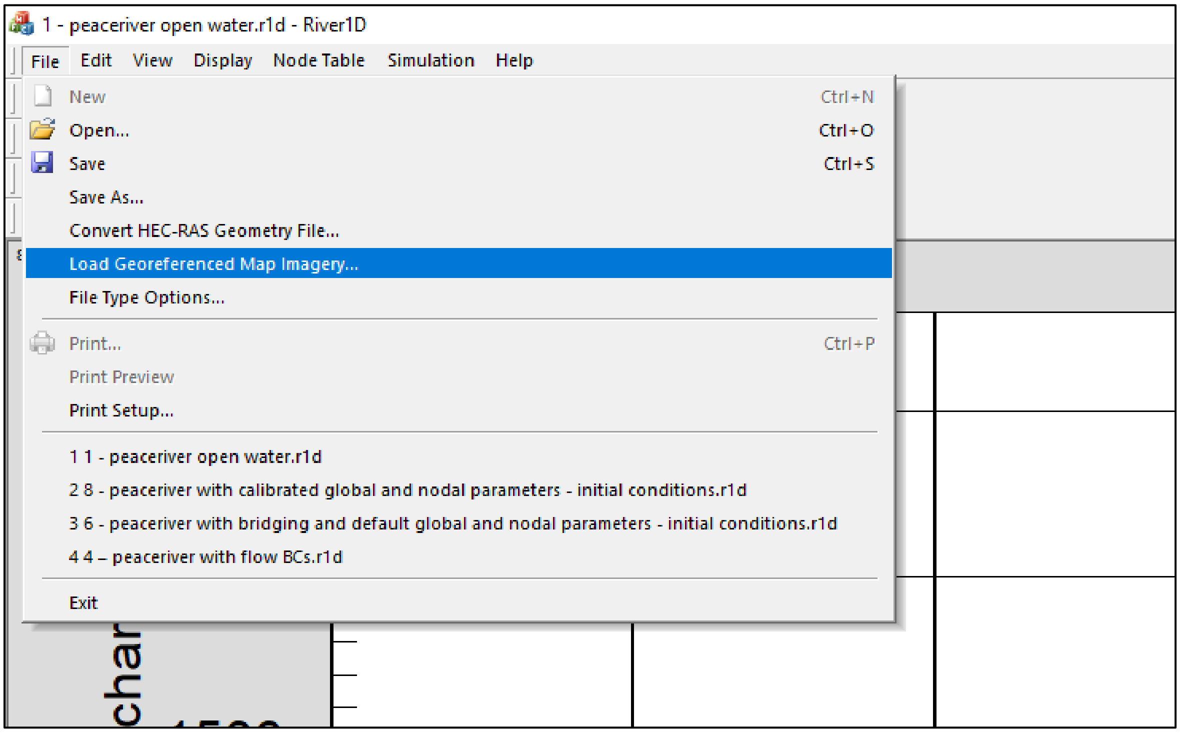
7. Ice Process Modelling with River1D

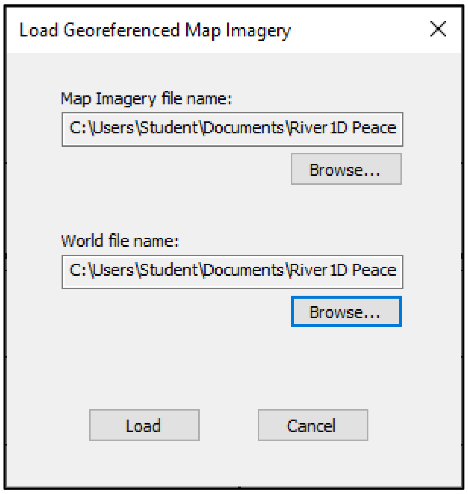
In this tutorial, we will demonstrate how to use River1D for thermal ice process modeling. The model will simulate the freeze-up and breakup of a river, which will include water temperature, ice production, ice accumulation, ice growth, and ice melt. This tutorial will use the Peace River in Alberta as an example. We will walkthrough steps to set up the model, compare its results with real world data, and how to calibrate the model based on this data.

Module 1: Setting up the Model

Task 1A: Setting up Thermal Ice Processes Modelling in River1D

1. Launch River1D.exe River1D.exe from the desktop, or from "Documents\River1D Peace River Model\River1D".
2. Click on 📂 to open an existing file. Navigate to the "Documents\River1D Peace River Model\Working Files" folder and open "**1 – peaceriver open water.r1d**".
3. Go to File, and select '*Load Georeferenced Map Imagery'* from the drop-down menu. From the pop up window, click on Browse... under 'Map Imagery file name'. Find and open "**PR.jpg**" in the "Working files" folder. Likewise, browse and select "**PR.jgw**" for the 'world file name' field. Then, click Load. (This step is not required, but allows you to visualize the river relative to the surroundings).
    - ○ **NOTE**: If you re-open a file, the imagery will need to be loaded again.



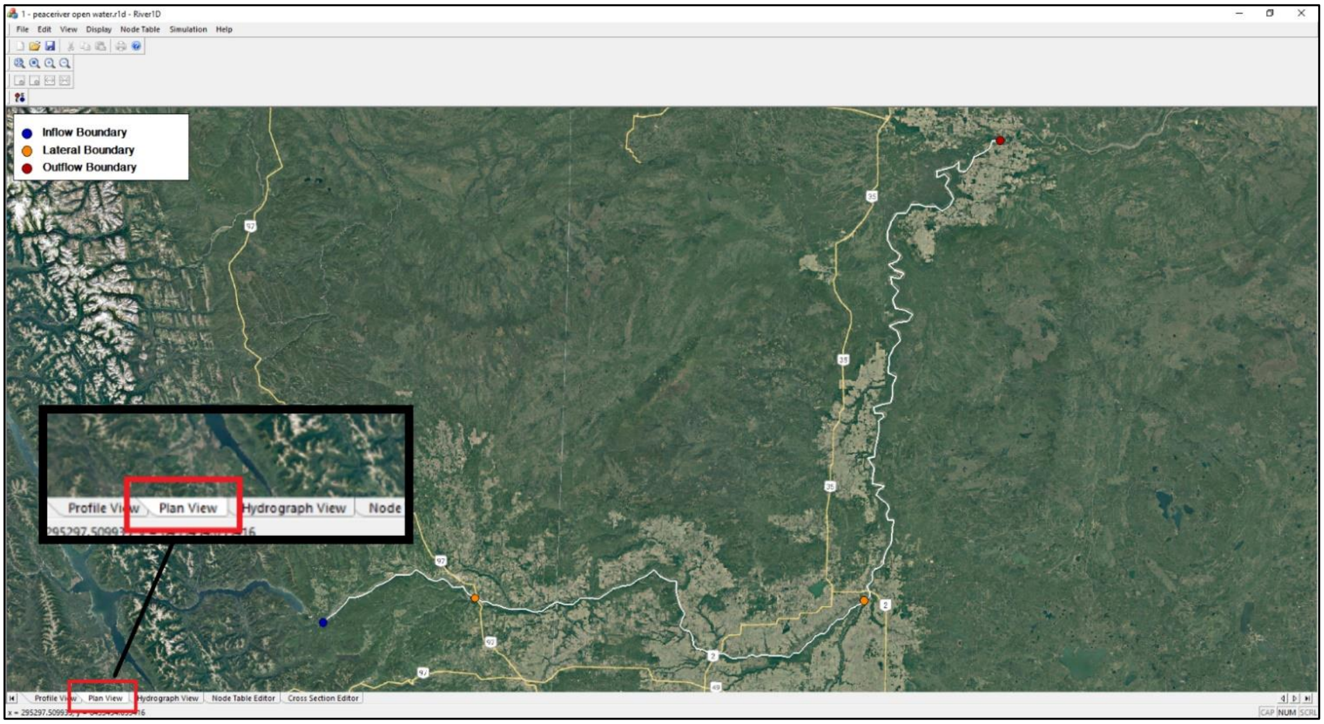


Load Georeferenced Map Imagery

Map Imagery file name: C:\Users\Student\Documents\River1D Peace

World file name: C:\Users\Student\Documents\River1D Peace

4. Click on the Plan View tab (bottom of the program screen) to see the domain with the background map.



5. Go to File and click ‘*File Type Options…*’. Select *‘Thermal Ice Processes’* from the ‘River 1D File Type’ drop-down menu. Click OK.

6. Go to File again and click ‘*Save As…*’. You will get a prompt which asks, ‘Do you want to save the file using the current file type?’. Click Yes and save the file as “**2 – peaceriver converted to thermal.r1d**” into the “Working Files” folder.

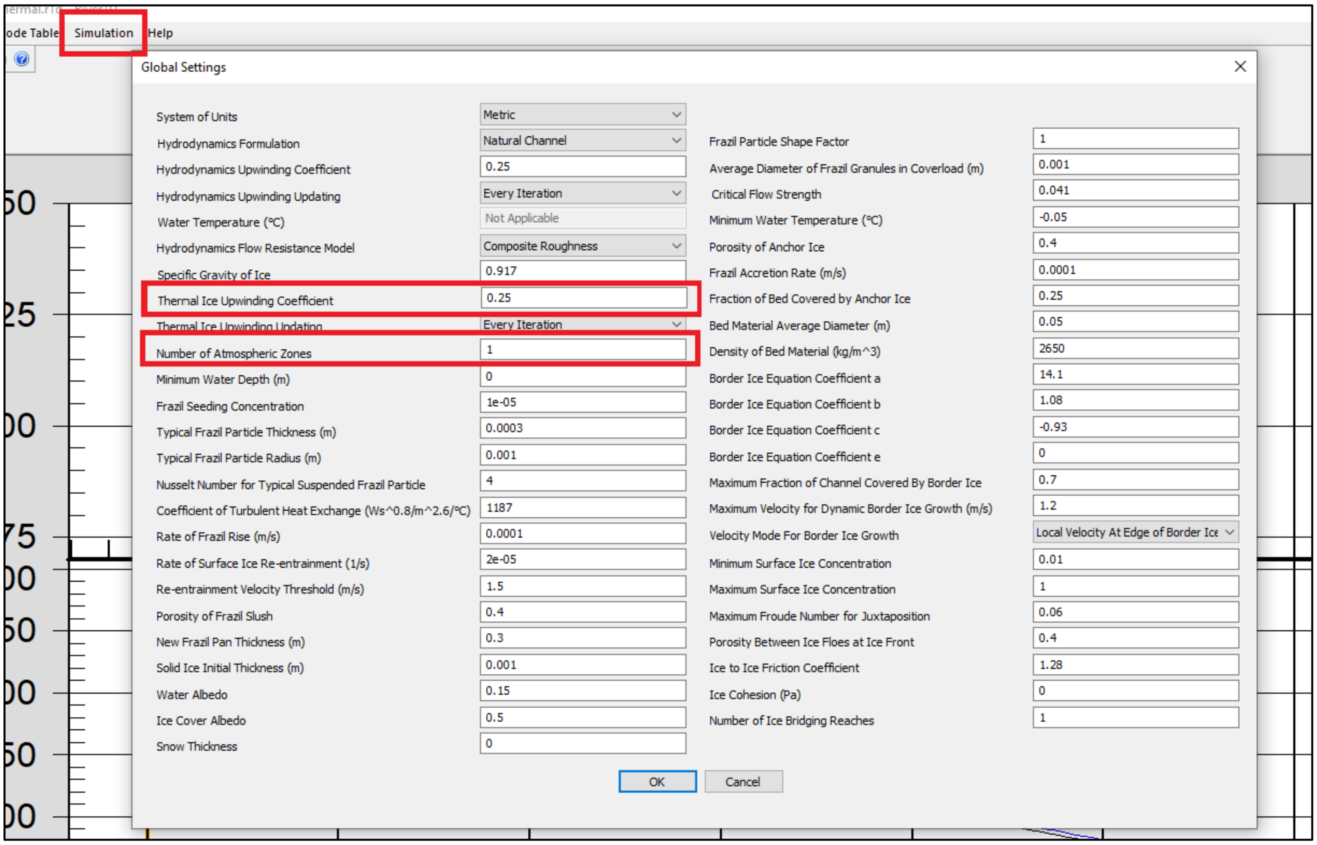
Now that the thermal processes file has been set up, we need to populate the model with the following information:

- Atmospheric zones
- Boundary conditions
- Ice bridging location

All of the required information is available in the "**Model Inputs Calibration.xlsx**" spreadsheet, which is saved in the "Working Files" folder. The following three tasks will guide you through the process of inputting this information.

Task 1B: Setting up Atmospheric Zones

1. We will first need to change the number of atmospheric zones in the model. Our model uses three zones. Click on Simulation at the top of the main River1D window and select '*Global Settings…*' from the drop-down menu. In the pop up, locate 'Number of Atmospheric Zones' (the default setting is 1).



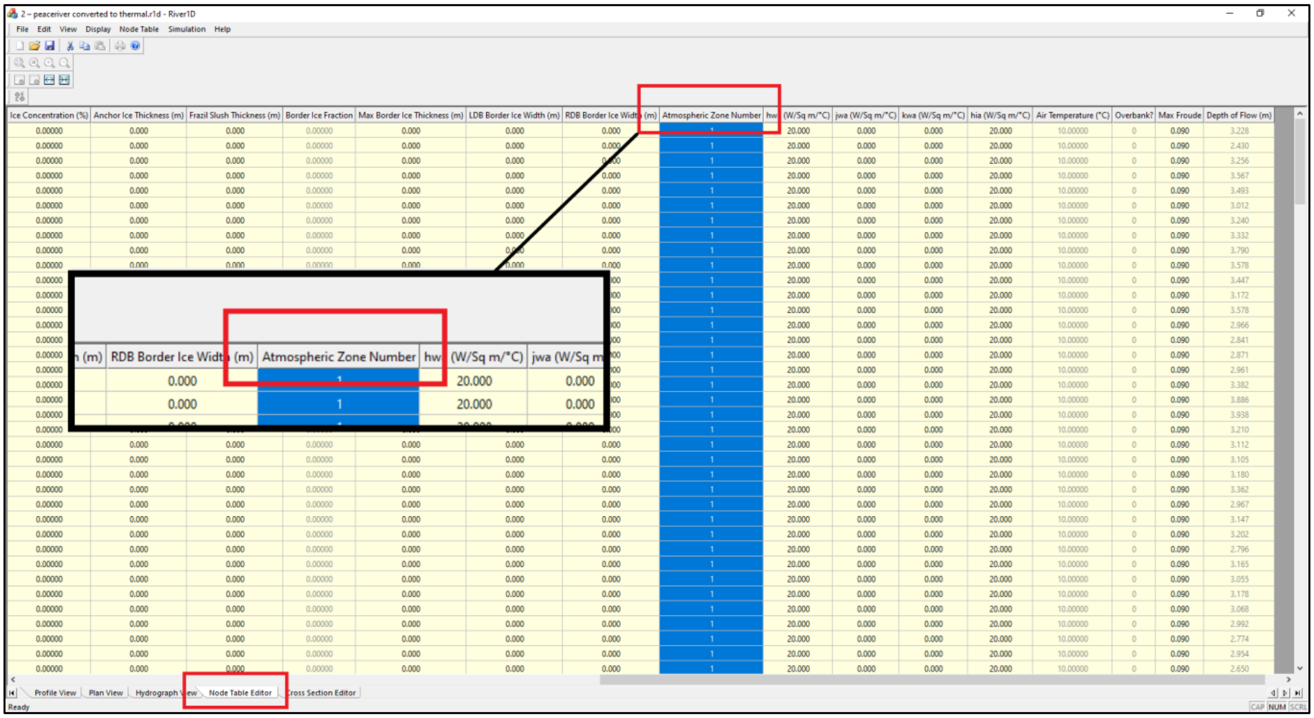
System of Units	Metric
Hydrodynamics Formulation	Natural Channel
Hydrodynamics Upwinding Coefficient	0.25
Hydrodynamics Upwinding Updating	Every Iteration
Water Temperature (°C)	Not Applicable
Hydrodynamics Flow Resistance Model	Composite Roughness
Specific Gravity of Ice	0.917
Thermal Ice Upwinding Coefficient	0.25
Thermal Ice Upwinding Updating	Every Iteration
Number of Atmospheric Zones	1
Minimum Water Depth (m)	0
Frazil Seeding Concentration	1e-05
Typical Frazil Particle Thickness (m)	0.0003
Typical Frazil Particle Radius (m)	0.001
Nusselt Number for Typical Suspended Frazil Particle	4
Coefficient of Turbulent Heat Exchange (Ws^0.8/m^2.6/°C)	1187
Rate of Frazil Rise (m/s)	0.0001
Rate of Surface Ice Re-entrainment (1/s)	2e-05
Re-entrainment Velocity Threshold (m/s)	1.5
Porosity of Frazil Slush	0.4
New Frazil Pan Thickness (m)	0.3
Solid Ice Initial Thickness (m)	0.001
Water Albedo	0.15
Ice Cover Albedo	0.5
Snow Thickness	0

Frazil Particle Shape Factor	1
Average Diameter of Frazil Granules in Coverload (m)	0.001
Critical Flow Strength	0.041
Minimum Water Temperature (°C)	-0.05
Porosity of Anchor Ice	0.4
Frazil Accretion Rate (m/s)	0.0001
Fraction of Bed Covered by Anchor Ice	0.25
Bed Material Average Diameter (m)	0.05
Density of Bed Material (kg/m^3)	2650
Border Ice Equation Coefficient a	14.1
Border Ice Equation Coefficient b	1.08
Border Ice Equation Coefficient c	-0.93
Border Ice Equation Coefficient e	0
Maximum Fraction of Channel Covered By Border Ice	0.7
Maximum Velocity for Dynamic Border Ice Growth (m/s)	1.2
Velocity Mode For Border Ice Growth	Local Velocity At Edge of Border Ice
Minimum Surface Ice Concentration	0.01
Maximum Surface Ice Concentration	1
Maximum Froude Number for Juxtaposition	0.06
Porosity Between Ice Floes at Ice Front	0.4
Ice to Ice Friction Coefficient	1.28
Ice Cohesion (Pa)	0
Number of Ice Bridging Reaches	1

Change the setting from *1* to *3*.

- ○ **NOTE:** You need to change the number of zones before you can set the nodal zone values to anything other than 1.

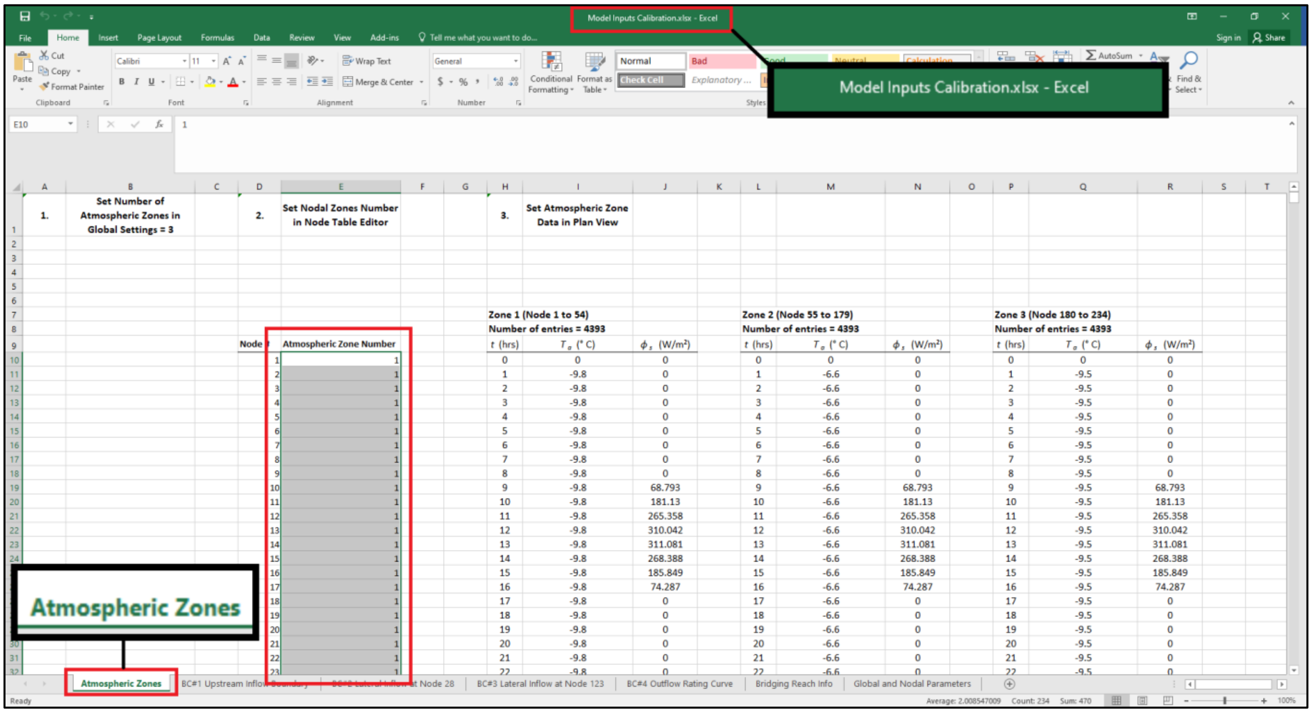
2. The thermal ice upwinding coefficient should also be changed from the default *0.25* to *1.0* for this tutorial. Then click OK.
3. Next click on the Node Table Editor tab (bottom of the screen). In order to see the table better, click either ⟺ or ⋈ in the toolbar to adjust the column widths to your preference.
   - The first one (outward arrows) expands all column widths to fit on one screen, which works well with big screens with small text size. (Expand to fit)
   - The second button adjusts the columns so that all of the headings can be read. (Auto size) We recommend this setting as it prevents columns from being hidden due to size constraints.
4. Locate the 'Atmospheric Zone Number' column (it should be on the far end of the table).



Ice Concentration (%)	Anchor Ice Thickness (m)	Frazil Slush Thickness (m)	Border Ice Fraction	Max Border Ice Thickness (m)	LDB Border Ice Width (m)	RDB Border Ice Width (m)	Atmospheric Zone Number	hw	(W/Sq m/°C)	jwa (W/Sq m/°C)	kwa (W/Sq m/°C)	hia (W/Sq m/°C)	Air Temperature (°C)	Overbank?	Max Froude	Depth of Flow (m)
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.228
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.430
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.256
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.567
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.493
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.012
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.240
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.332
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.790
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.578
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.447
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.172
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.578
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.966
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.841
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.871
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.961
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.382
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.886
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.938
0.00000							1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.210
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.112
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.105
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.180
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.362
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.967
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.147
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.202
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.796
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.165
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.055
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.178
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	3.068
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.992
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.774
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.954
0.00000	0.000	0.000	0.00000	0.000	0.000	0.000	1		20.000	0.000	0.000	20.000	10.00000	0	0.090	2.650

5. Open the "**Model Inputs Calibration.xlsx**" spreadsheet. Inside the Atmospheric Zones tab, copy the column of data under the heading 'Atmospheric Zone Number**'**. Go back to the River1D program. Paste the information into the *'*Atmospheric Zone Number*'* column in the Node Table Editor tab.

Tip: You can select a cell and use CRTL + Shift + Down to quickly select all data in a column in excel.



1. Set Number of Atmospheric Zones in Global Settings = 3

2. Set Nodal Zones Number in Node Table Editor

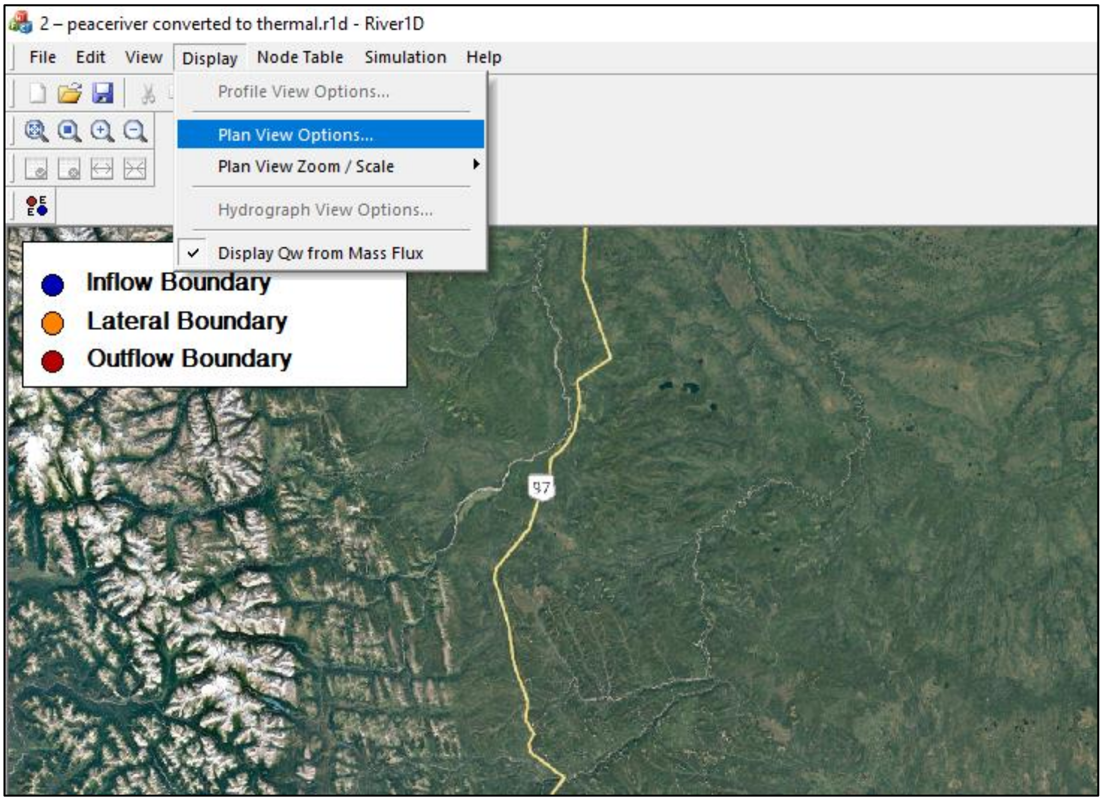
3. Set Atmospheric Zone Data in Plan View

Zone 1 (Node 1 to 54)
Number of entries = 4393 — Zone 2 (Node 55 to 179)
Number of entries = 4393 — Zone 3 (Node 180 to 234)
Number of entries = 4393

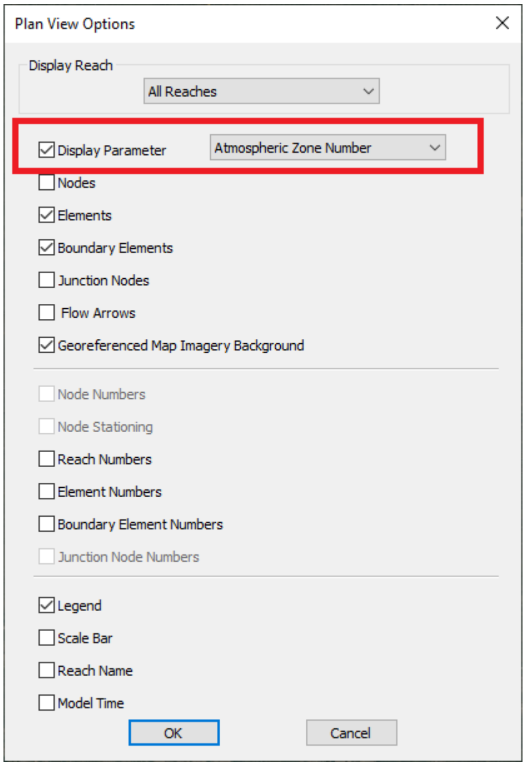
Node #	Atmospheric Zone Number	Zone 1 (Node 1 to 54) Number of entries = 4393 t (hrs)	T_a (° C)	ϕ_s (W/m²)	Zone 2 (Node 55 to 179) Number of entries = 4393 t (hrs)	T_a (° C)	ϕ_s (W/m²)	Zone 3 (Node 180 to 234) Number of entries = 4393 t (hrs)	T_a (° C)	ϕ_s (W/m²)
1	1	0	0	0	0	0	0	0	0	0
2	1	1	-9.8	0	1	-6.6	0	1	-9.5	0
3	1	2	-9.8	0	2	-6.6	0	2	-9.5	0
4	1	3	-9.8	0	3	-6.6	0	3	-9.5	0
5	1	4	-9.8	0	4	-6.6	0	4	-9.5	0
6	1	5	-9.8	0	5	-6.6	0	5	-9.5	0
7	1	6	-9.8	0	6	-6.6	0	6	-9.5	0
8	1	7	-9.8	0	7	-6.6	0	7	-9.5	0
9	1	8	-9.8	0	8	-6.6	0	8	-9.5	0
10	1	9	-9.8	68.793	9	-6.6	68.793	9	-9.5	68.793
11	1	10	-9.8	181.13	10	-6.6	181.13	10	-9.5	181.13
12	1	11	-9.8	265.358	11	-6.6	265.358	11	-9.5	265.358
13	1	12	-9.8	310.042	12	-6.6	310.042	12	-9.5	310.042
14	1	13	-9.8	311.081	13	-6.6	311.081	13	-9.5	311.081
15	1	14	-9.8	268.388	14	-6.6	268.388	14	-9.5	268.388
16	1	15	-9.8	185.849	15	-6.6	185.849	15	-9.5	185.849
17	1	16	-9.8	74.287	16	-6.6	74.287	16	-9.5	74.287
18	1	17	-9.8	0	17	-6.6	0	17	-9.5	0
19	1	18	-9.8	0	18	-6.6	0	18	-9.5	0
20	1	19	-9.8	0	19	-6.6	0	19	-9.5	0
21	1	20	-9.8	0	20	-6.6	0	20	-9.5	0
22	1	21	-9.8	0	21	-6.6	0	21	-9.5	0
23	1	22	-9.8	0	22	-6.6	0	22	-9.5	0

6. At this point, the ‘Accept Changes’ and ‘Reject Changes’ toolbar buttons will become active (at the top of the River1D window). Click on *‘Accept Changes’* .

7. Click on the <u>Plan View</u> tab, and then go to Display. Select ‘*Plan View Options…*’ to open a new window.



8. In the ‘Plan View Options’ pop-up, check the ‘*Display Parameter*’ box and then use the dropdown menu to select ‘*Atmospheric Zone Number*’. Then click OK. The three different atmospheric zones in the reach should now be highlighted by different colours.



Plan View Options

Display Reach: All Reaches

☑ Display Parameter: Atmospheric Zone Number

☐ Nodes

☑ Elements

☑ Boundary Elements

☐ Junction Nodes

☐ Flow Arrows

☑ Georeferenced Map Imagery Background

☐ Node Numbers

☐ Node Stationing

☐ Reach Numbers

☐ Element Numbers

☐ Boundary Element Numbers

☐ Junction Node Numbers

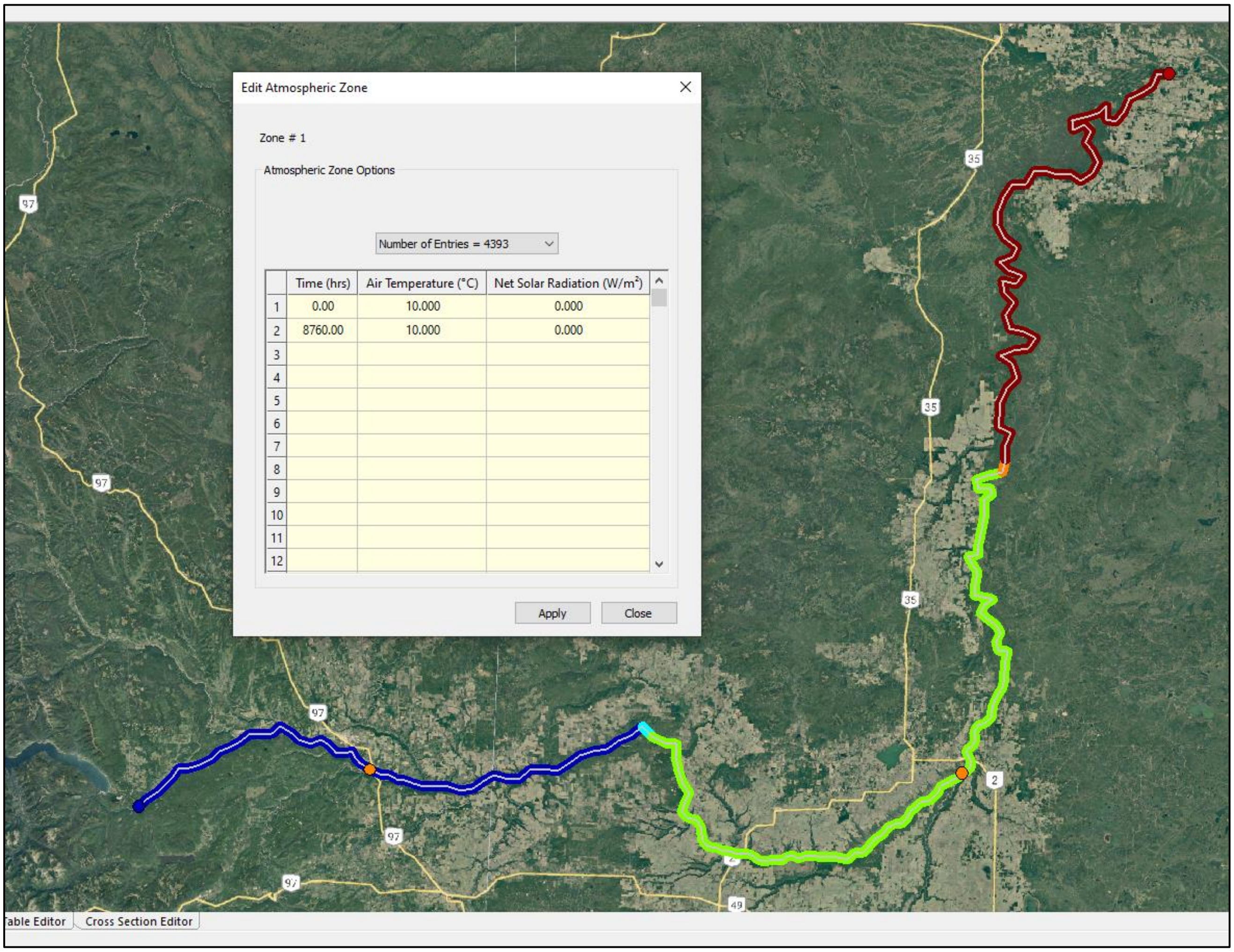
☑ Legend

☐ Scale Bar

☐ Reach Name

☐ Model Time

9. Go to Simulation and click on ‘*Edit Atmospheric Zone…*’. The mouse pointer should turn into a cross. Click anywhere on the blue line to edit Zone 1. This will open the ‘Edit Atmospheric Zone’ Dialogue.
10. Change the ‘number of entries’ to *4393*. Then, go to the Atmospheric Zones tab of the “**Model Input Calibration.xlsx**” spreadsheet. Copy and paste the data for Zone 1 into the ‘Edit Atmospheric Zone’ window. When finished, click Apply and then Close.



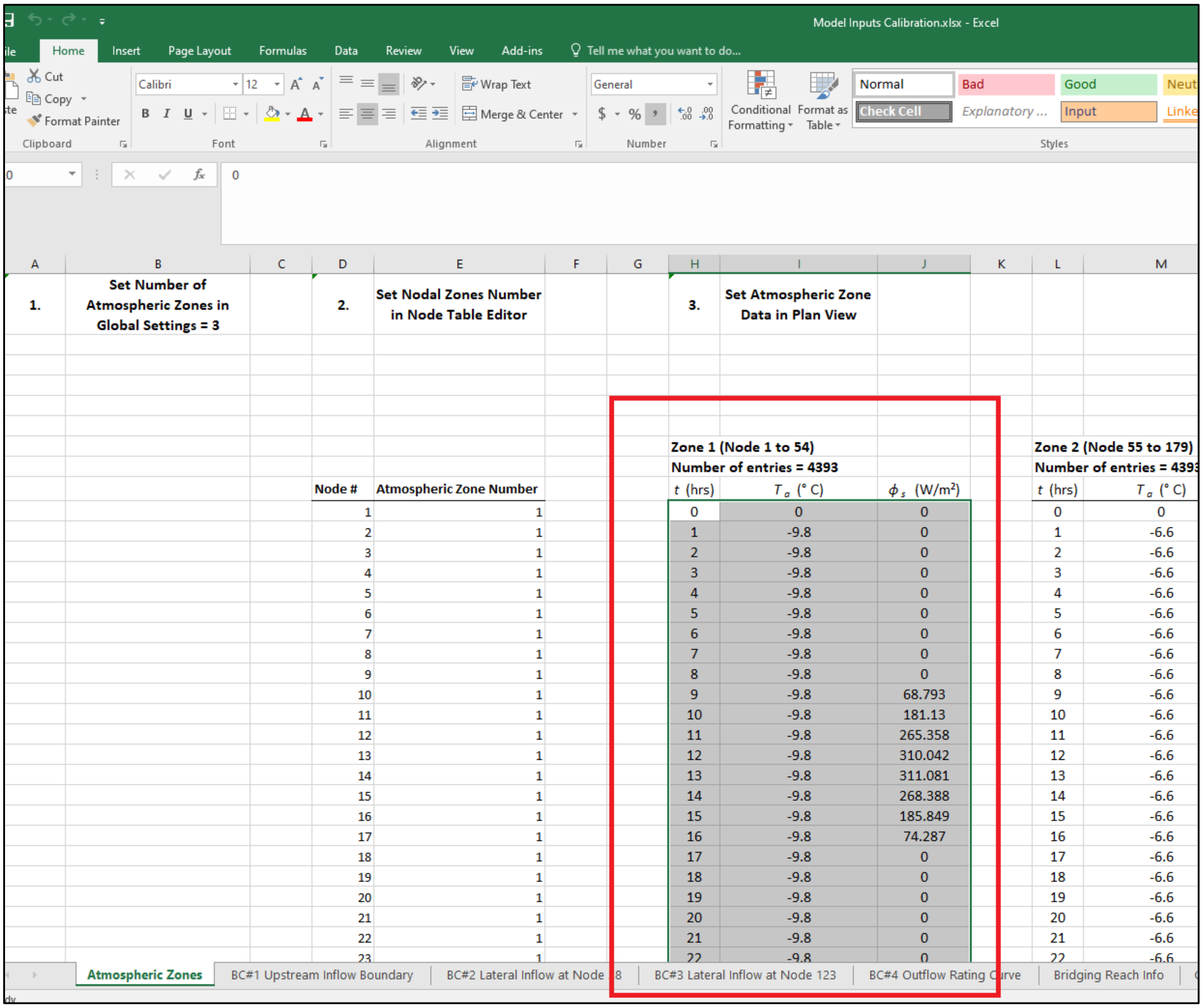
Edit Atmospheric Zone

Zone # 1

Atmospheric Zone Options

Number of Entries = 4393

	Time (hrs)	Air Temperature (°C)	Net Solar Radiation (W/m²)
1	0.00	10.000	0.000
2	8760.00	10.000	0.000
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			



1. Set Number of Atmospheric Zones in Global Settings = 3

2. Set Nodal Zones Number in Node Table Editor

3. Set Atmospheric Zone Data in Plan View

Zone 1 (Node 1 to 54)
Number of entries = 4393

Zone 2 (Node 55 to 179)
Number of entries = 439

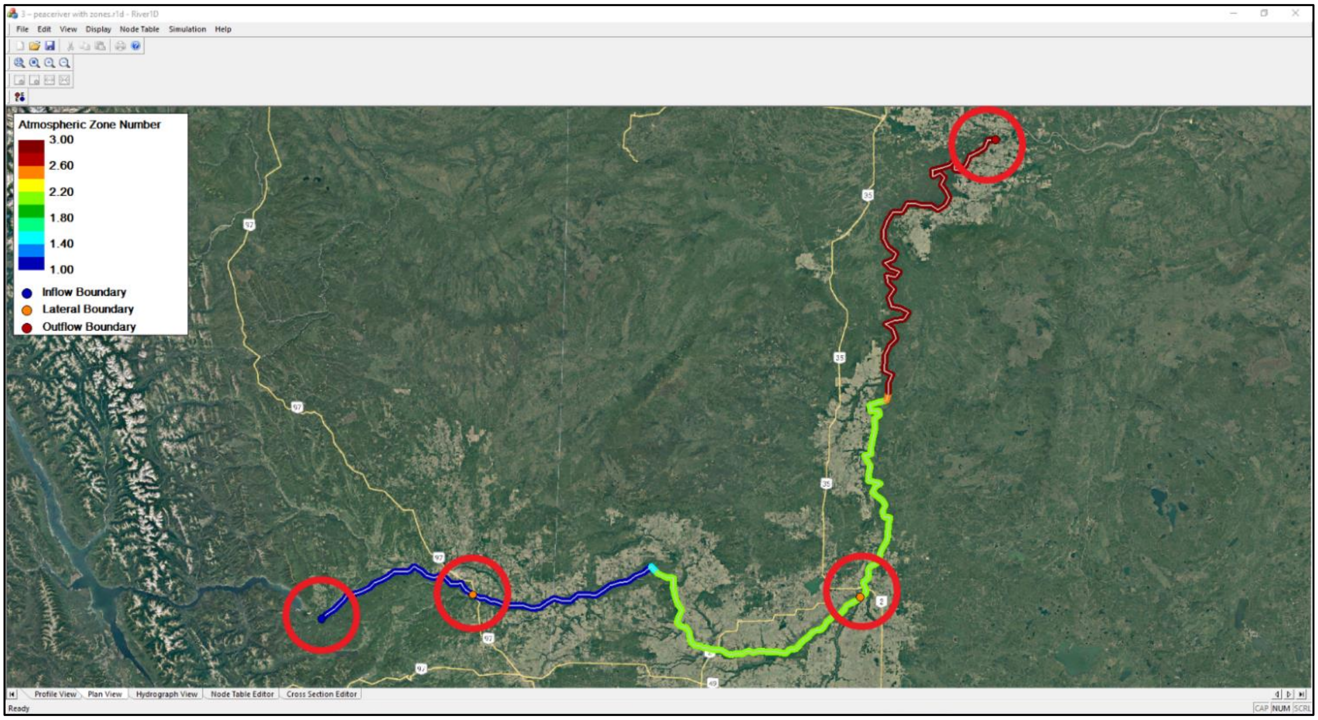
Node #	Atmospheric Zone Number	t (hrs)	T_a (° C)	ϕ_s (W/m^2)	t (hrs)	T_a (° C)
1	1	0	0	0	0	0
2	1	1	-9.8	0	1	-6.6
3	1	2	-9.8	0	2	-6.6
4	1	3	-9.8	0	3	-6.6
5	1	4	-9.8	0	4	-6.6
6	1	5	-9.8	0	5	-6.6
7	1	6	-9.8	0	6	-6.6
8	1	7	-9.8	0	7	-6.6
9	1	8	-9.8	0	8	-6.6
10	1	9	-9.8	68.793	9	-6.6
11	1	10	-9.8	181.13	10	-6.6
12	1	11	-9.8	265.358	11	-6.6
13	1	12	-9.8	310.042	12	-6.6
14	1	13	-9.8	311.081	13	-6.6
15	1	14	-9.8	268.388	14	-6.6
16	1	15	-9.8	185.849	15	-6.6
17	1	16	-9.8	74.287	16	-6.6
18	1	17	-9.8	0	17	-6.6
19	1	18	-9.8	0	18	-6.6
20	1	19	-9.8	0	19	-6.6
21	1	20	-9.8	0	20	-6.6
22	1	21	-9.8	0	21	-6.6
23	1	22	-9.8	0	22	-6.6

11. Repeat steps 9 and 10 for Zone 2 (Green) and Zone 3 (Red).

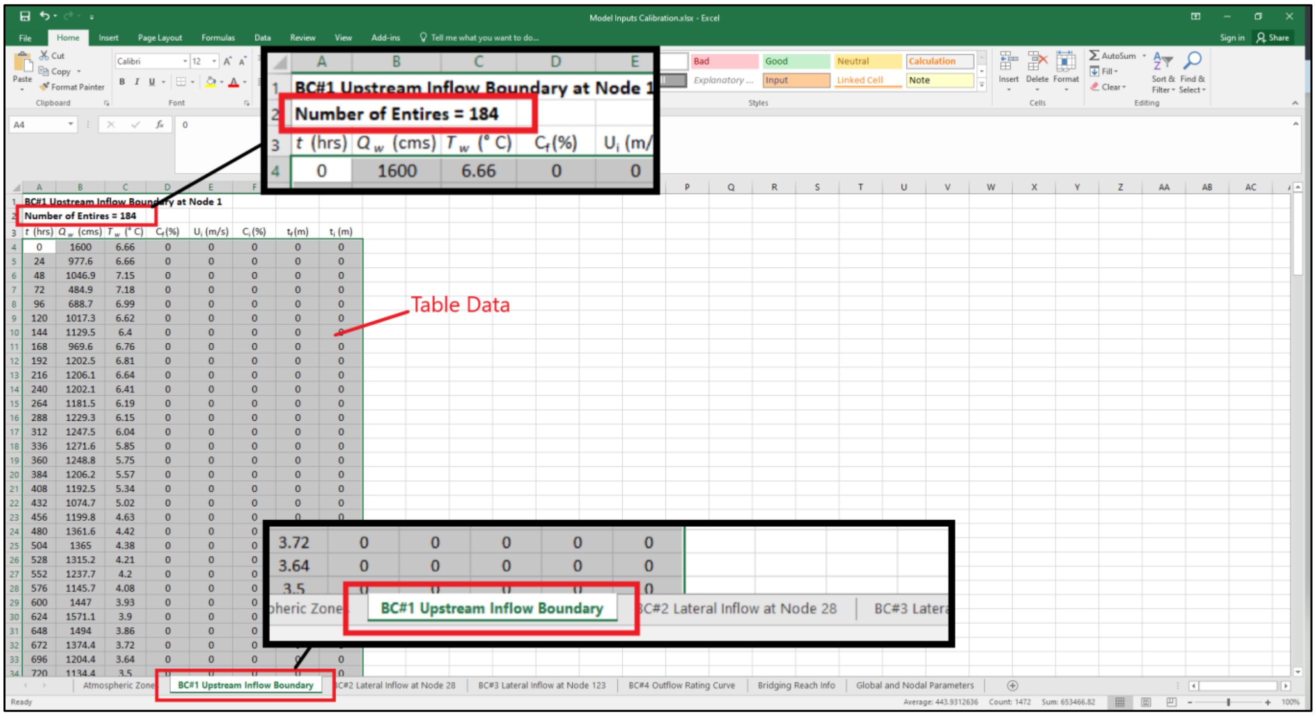
12. Save file as “**3 – peaceriver with zones.r1d**”

Task 1C: Inputting Flow Boundary Conditions

Next we will add in the flow boundary conditions. Our model contains an upstream boundary (blue dot), two lateral inflow boundaries (orange dots), and an outflow boundary at the downstream end (red dot).



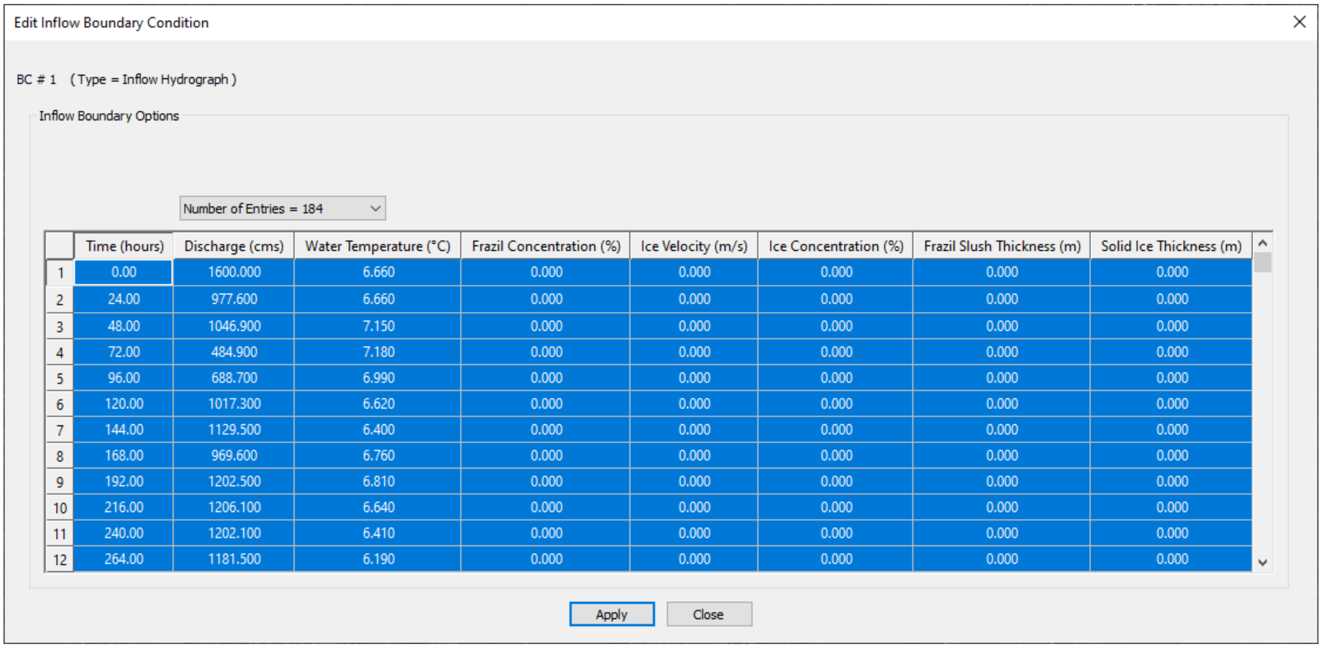
1. Let's start with the inflow. You can either use the toolbar button or you can go to Simulation and select '*Edit Boundary Conditions…*'. This will turn the mouse into a cross and then you can click on the boundary dot that you want to edit. Click on the blue dot. This will open the 'Edit Inflow Boundary Condition' dialogue.
2. Go to the tab <u>BC#1 Upstream Inflow Boundary</u> in "**Model Input Calibration.xlsx**". Set the number of entries in River1D to the number indicated on this tab. Copy and paste the table data from the spreadsheet into the River1D dialogue table. Click Apply, then Close.



BC#1 Upstream Inflow Boundary at Node 1

Number of Entires = 184

t (hrs)	Q_w (cms)	T_w (° C)	C_f(%)	U_i (m/s)	C_i(%)	t_f(m)	t_i (m)
0	1600	6.66	0	0	0	0	0
24	977.6	6.66	0	0	0	0	0
48	1046.9	7.15	0	0	0	0	0
72	484.9	7.18	0	0	0	0	0
96	688.7	6.99	0	0	0	0	0
120	1017.3	6.62	0	0	0	0	0
144	1129.5	6.4	0	0	0	0	0
168	969.6	6.76	0	0	0	0	0
192	1202.5	6.81	0	0	0	0	0
216	1206.1	6.64	0	0	0	0	0
240	1202.1	6.41	0	0	0	0	0
264	1181.5	6.19	0	0	0	0	0
288	1229.3	6.15	0	0	0	0	0
312	1247.5	6.04	0	0	0	0	0
336	1271.6	5.85	0	0	0	0	0
360	1248.8	5.75	0	0	0	0	0
384	1206.2	5.57	0	0	0	0	0
408	1192.5	5.34	0	0	0	0	0
432	1074.7	5.02	0	0	0	0	0
456	1199.8	4.63	0	0	0	0	0
480	1361.6	4.42	0	0	0		
504	1365	4.38	0	0	0		
528	1315.2	4.21	0	0	0		
552	1237.7	4.2	0	0	0		
576	1145.7	4.08	0	0	0		
600	1447	3.93	0	0	0		
624	1571.1	3.9	0	0	0		
648	1494	3.86	0	0	0		
672	1374.4	3.72	0	0	0		
696	1204.4	3.64	0	0	0	0	0
720	1134.4	3.5	0	0	0	0	0



Edit Inflow Boundary Condition

BC # 1 (Type = Inflow Hydrograph)

Inflow Boundary Options

Number of Entries = 184

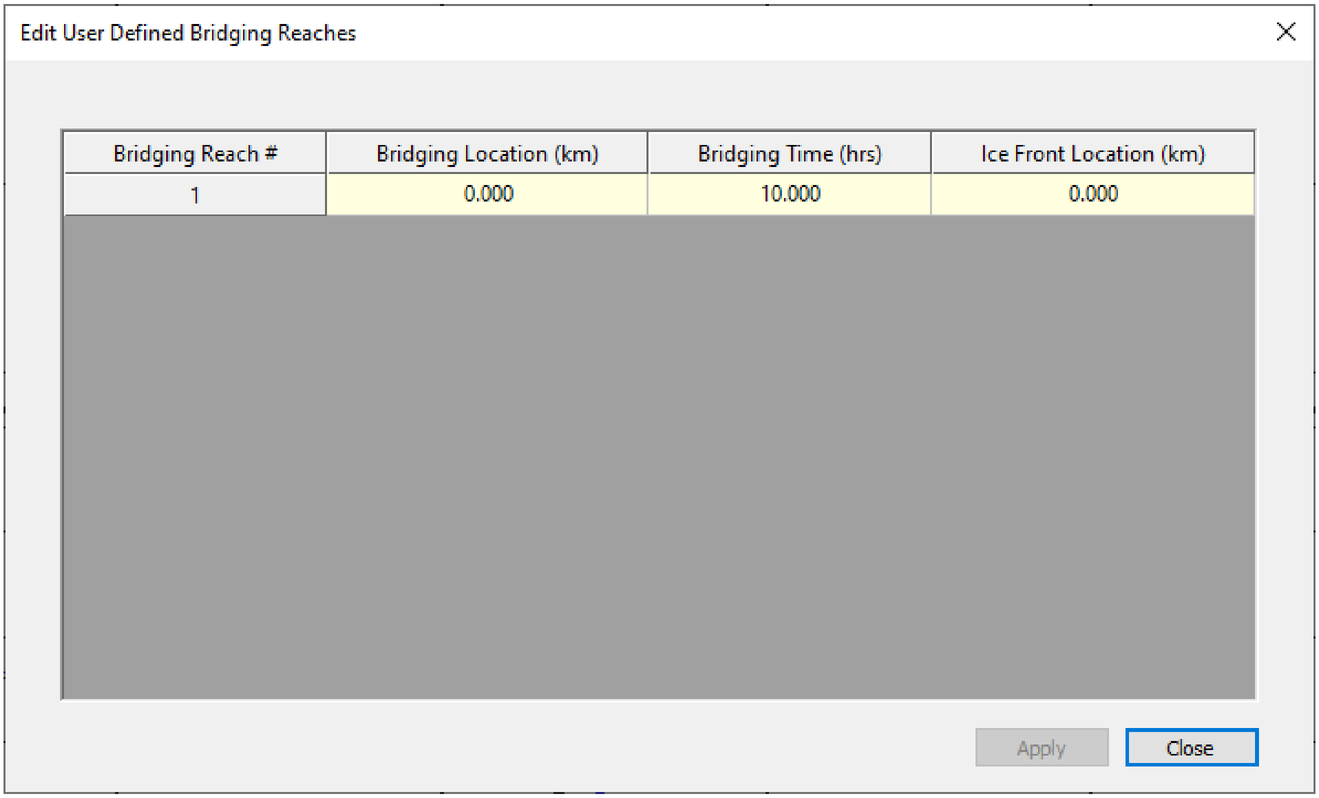
	Time (hours)	Discharge (cms)	Water Temperature (°C)	Frazil Concentration (%)	Ice Velocity (m/s)	Ice Concentration (%)	Frazil Slush Thickness (m)	Solid Ice Thickness (m)
1	0.00	1600.000	6.660	0.000	0.000	0.000	0.000	0.000
2	24.00	977.600	6.660	0.000	0.000	0.000	0.000	0.000
3	48.00	1046.900	7.150	0.000	0.000	0.000	0.000	0.000
4	72.00	484.900	7.180	0.000	0.000	0.000	0.000	0.000
5	96.00	688.700	6.990	0.000	0.000	0.000	0.000	0.000
6	120.00	1017.300	6.620	0.000	0.000	0.000	0.000	0.000
7	144.00	1129.500	6.400	0.000	0.000	0.000	0.000	0.000
8	168.00	969.600	6.760	0.000	0.000	0.000	0.000	0.000
9	192.00	1202.500	6.810	0.000	0.000	0.000	0.000	0.000
10	216.00	1206.100	6.640	0.000	0.000	0.000	0.000	0.000
11	240.00	1202.100	6.410	0.000	0.000	0.000	0.000	0.000
12	264.00	1181.500	6.190	0.000	0.000	0.000	0.000	0.000

3. Repeat steps 1 and 2 for the 3 other flow boundaries. The data for each boundary are under separate tabs in "**Model Inputs Calibration.xlsx**".
4. Save the file as "**4 – peaceriver with flow BCs.r1d**".

Task 1D: Inputting Ice Bridging Information

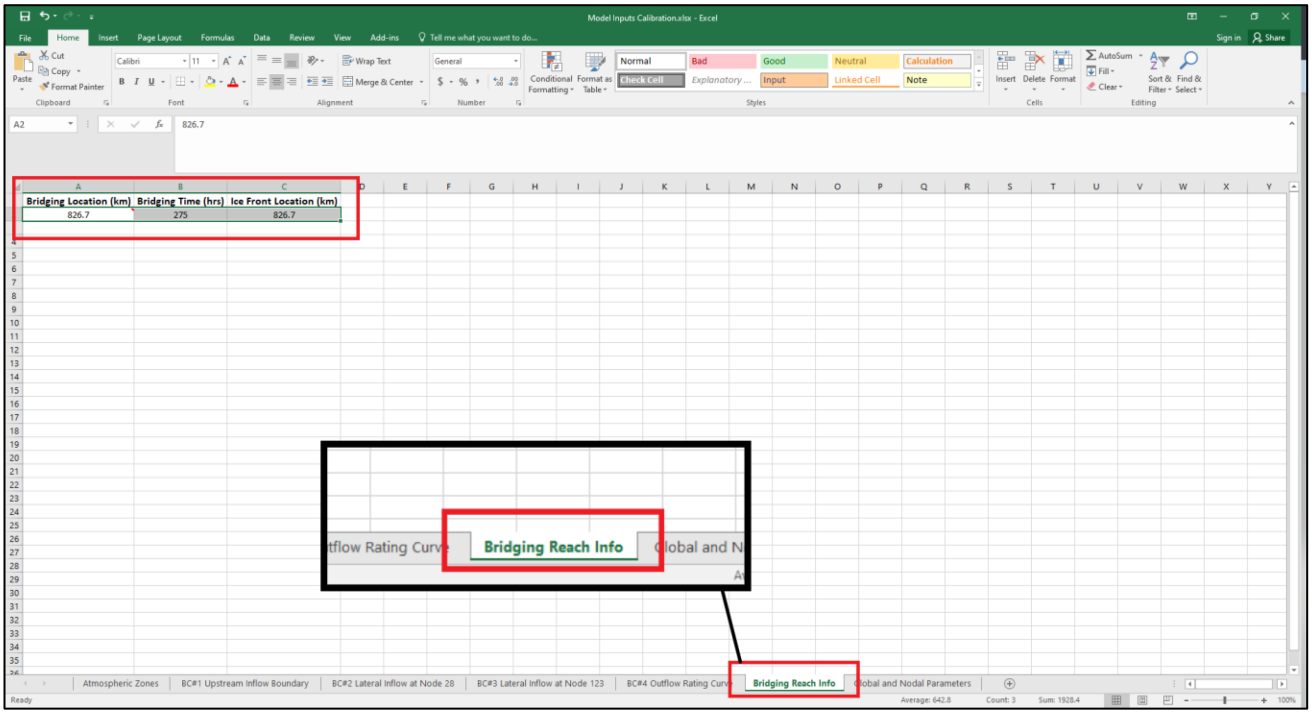
Now we will define the bridging location. For this model we are only considering 1 bridging location. If you wanted to consider additional bridging locations, you would have to change the number of bridging reaches in the '*Global Settings*' dialogue box.

1. To edit the bridging reach information, go to Simulation and select '*Edit User Defined Bridging Reaches…*'. This opens a dialogue box.



Bridging Reach #	Bridging Location (km)	Bridging Time (hrs)	Ice Front Location (km)
1	0.000	10.000	0.000

2. The required information can be found in the Bridging Reach Info tab in the "**Model Input Calibration.xlsx**" file. Copy and paste this data into the dialogue box. Click Apply, then Close.
   - **IMPORTANT**: The bridging location MUST coincide with the exact stationing for a node. It cannot be located between nodes. This is how the program is currently set up, but may change in future releases.



Bridging Location (km)	Bridging Time (hrs)	Ice Front Location (km)
826.7	275	826.7

3. Save the file as "**5 - peaceriver with bridging and default global and nodal parameters.r1d**".

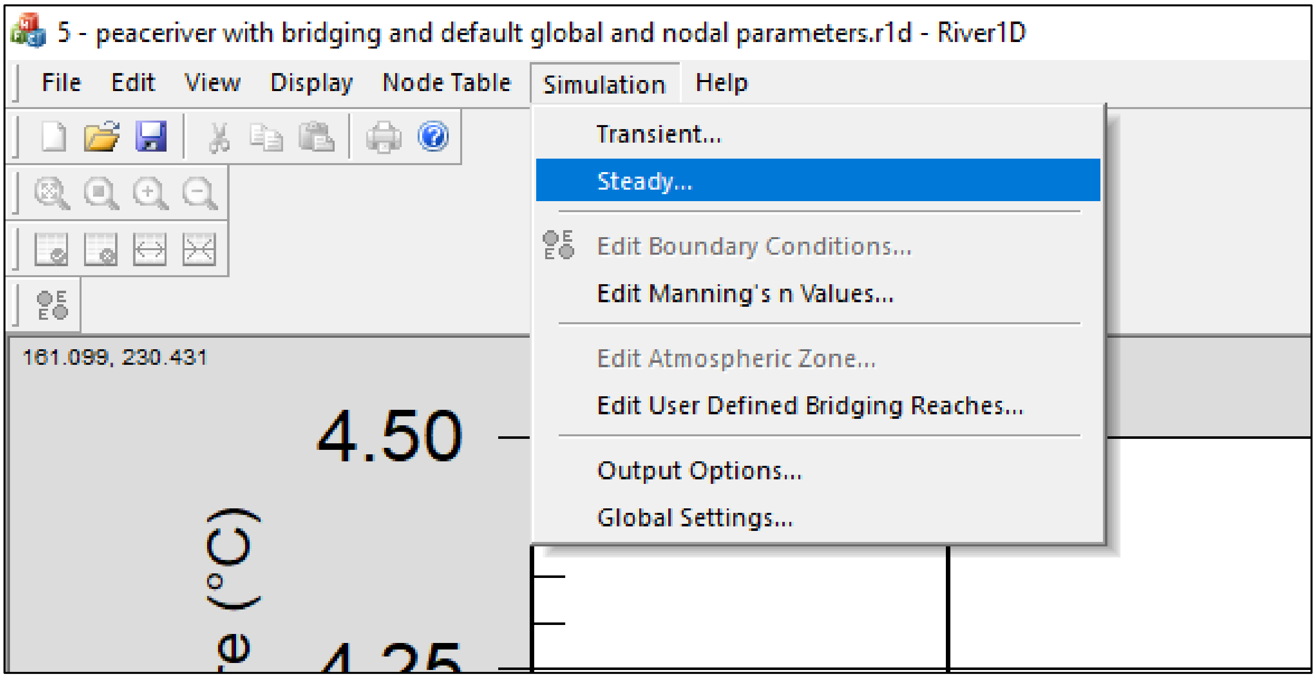
The file is now ready to run. It has all of the necessary boundary conditions and the bridging reach information, but it is using the default settings for all of the global and nodal parameters. Later, in module 3, we will calibrate these settings against real world data.

Module 2: Running the Model with Default Settings (No Calibration)

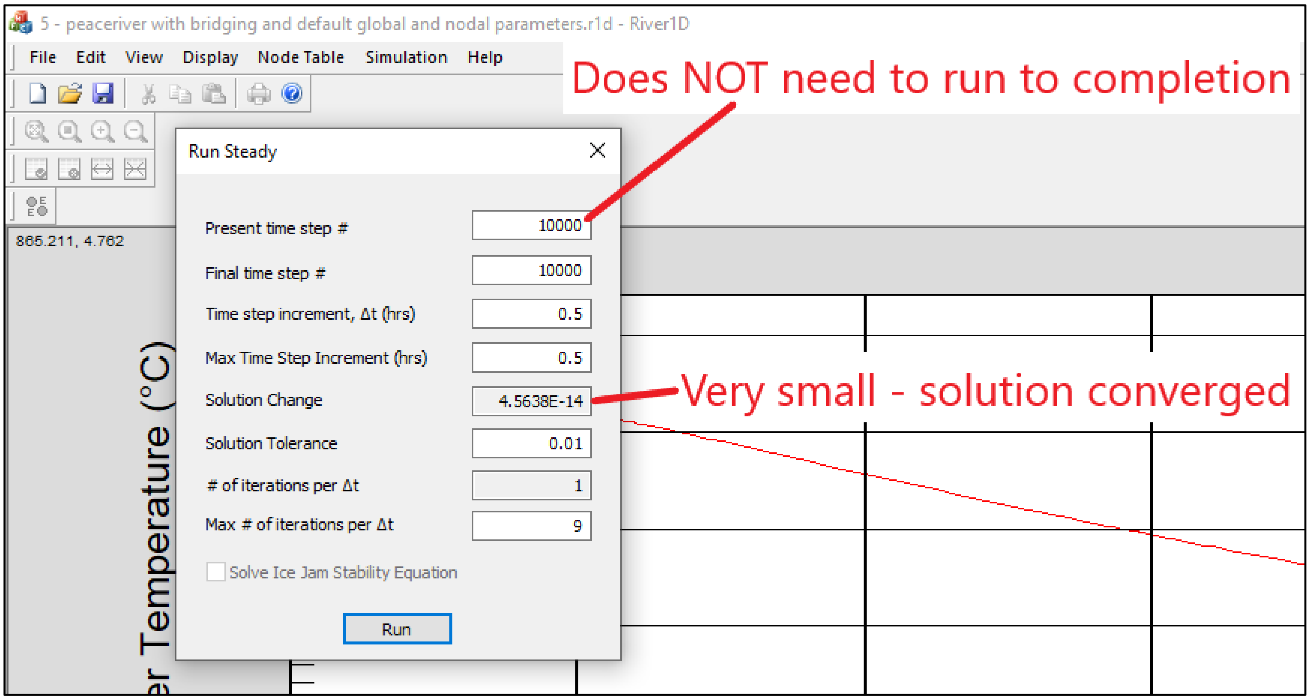
We will run the model in two simulations using its default setting: steady state and transient. The steady state simulation will generate the initial conditions needed for the transient simulation.

Task 2A: Steady State Simulation

1. Go to Simulation and select '*Steady…*'.Then hit Run .
    - **NOTE**: You need to be in the <u>Profile View</u>, <u>Plan View</u>, or <u>Hydrograph View</u> tabs for the 'Steady…' menu item to be active.



2. Let the model run until the solution has converged. (The solution change should get very small and not change. The profile view of the solution should also no longer be changing).



Present time step # 10000
Final time step # 10000
Time step increment, Δt (hrs) 0.5
Max Time Step Increment (hrs) 0.5
Solution Change 4.5638E-14
Solution Tolerance 0.01
# of iterations per Δt 1
Max # of iterations per Δt 9
☐ Solve Ice Jam Stability Equation

Does NOT need to run to completion

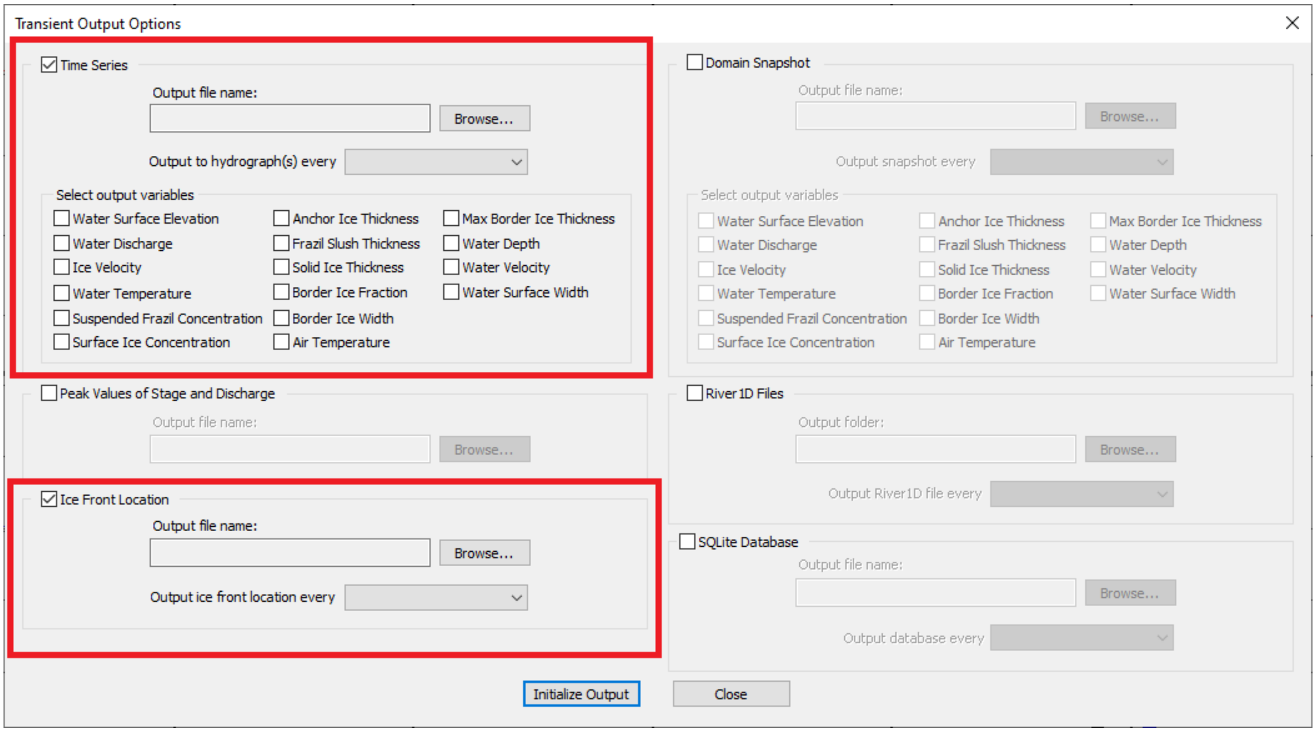
Very small - solution converged

3. Once the steady solution has converged, save the file as “**6 - peaceriver with bridging and default global and nodal parameters - initial conditions.r1d**”.

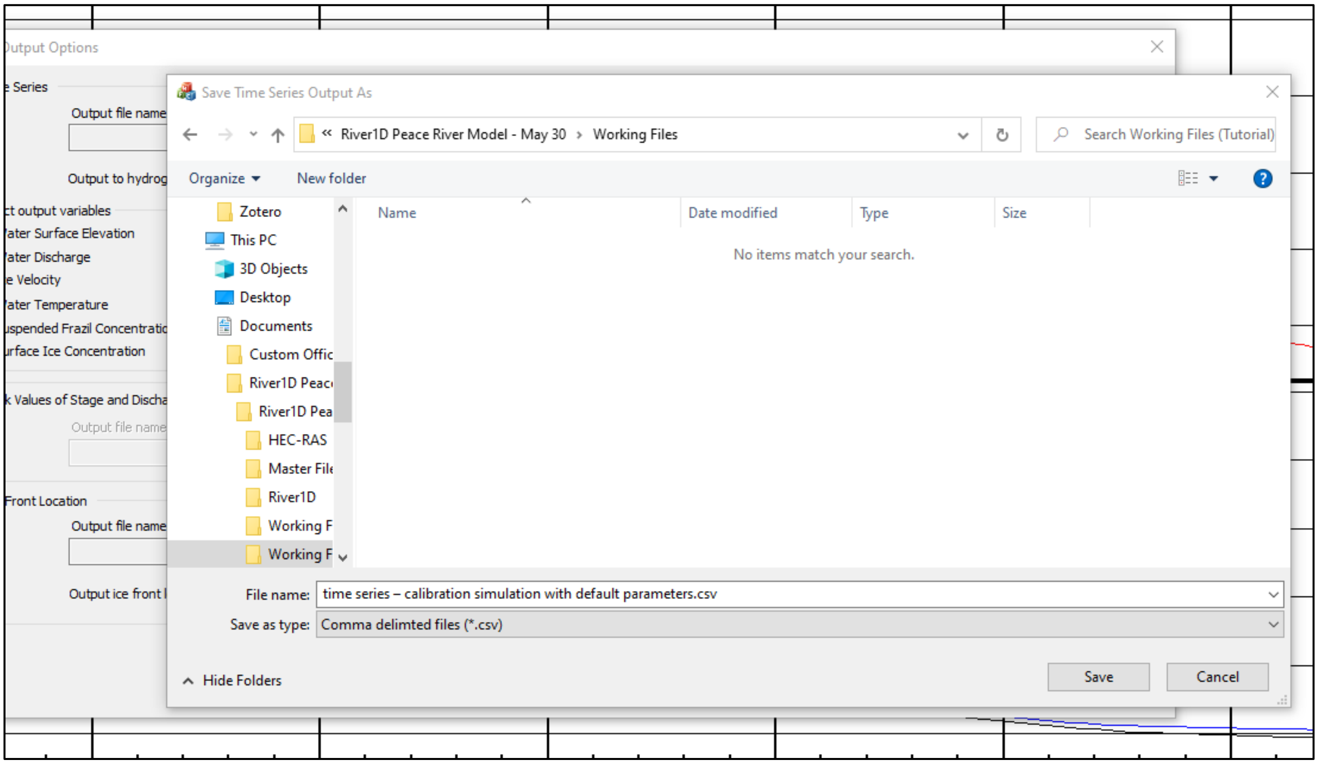
Task 2B: Transient Simulation

Time to run the transient simulation. Before we do this, we will want to set up the model to output some results that we can use to compare to field observations to see how well the model performs with the default settings.

1. Go to Simulation and select ‘*Output Options…*’. This opens the ‘Transient Output Options’ dialogue. For this exercise, we are going to output ‘*Time Series*’ and the ‘*Ice Front Location*’ data. Check these boxes.



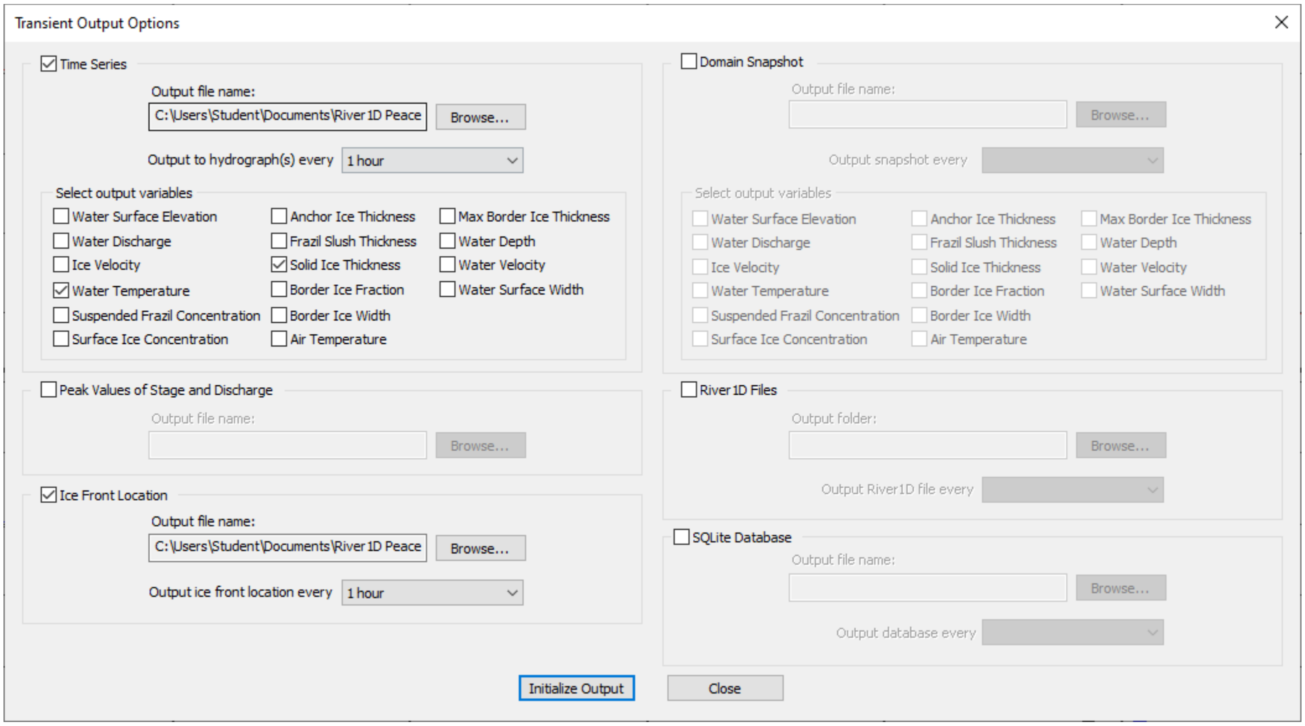
2. For the time series data, click Browse… to determine the output file location. Navigate to the “Working Files” folder and name the output file “**time series – calibration simulation with default parameters.csv**”. Click Save .



File name: time series – calibration simulation with default parameters.csv

Save as type: Comma delimted files (*.csv)

3. Choose ‘*1 hour*’ for the frequency of hydrograph(s) output. Check the boxes for *‘Water Temperature’* and ‘*Solid Ice Thickness*’.
4. For the ice front location data, click Browse... and navigate to the “Working Files” folder. Name the output file “**ice front – calibration simulation with default parameters.csv**”.
5. Choose ‘*1 hour’* for the frequency of ice front location output.
6. The dialogue window should look like this before continuing.



Transient Output Options

☑ Time Series

Output file name: C:\Users\Student\Documents\River1D Peace

Output to hydrograph(s) every: 1 hour

Select output variables

☐ Water Surface Elevation
☐ Water Discharge
☐ Ice Velocity
☑ Water Temperature
☐ Suspended Frazil Concentration
☐ Surface Ice Concentration
☐ Anchor Ice Thickness
☐ Frazil Slush Thickness
☑ Solid Ice Thickness
☐ Border Ice Fraction
☐ Border Ice Width
☐ Air Temperature
☐ Max Border Ice Thickness
☐ Water Depth
☐ Water Velocity
☐ Water Surface Width

☐ Peak Values of Stage and Discharge

☑ Ice Front Location

Output file name: C:\Users\Student\Documents\River1D Peace

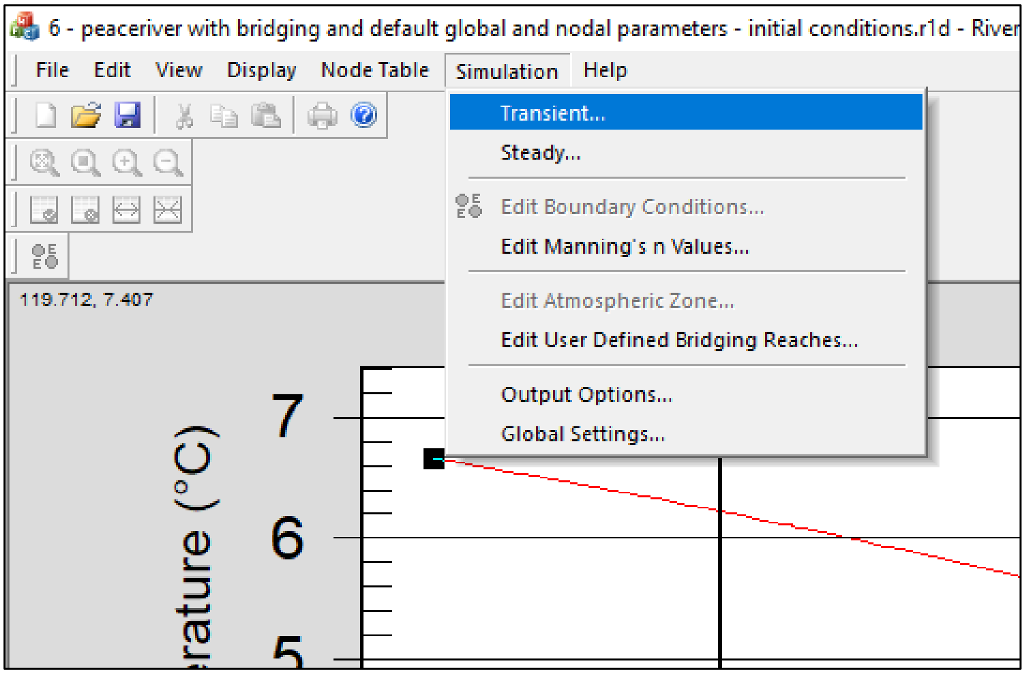
Output ice front location every: 1 hour

☐ Domain Snapshot

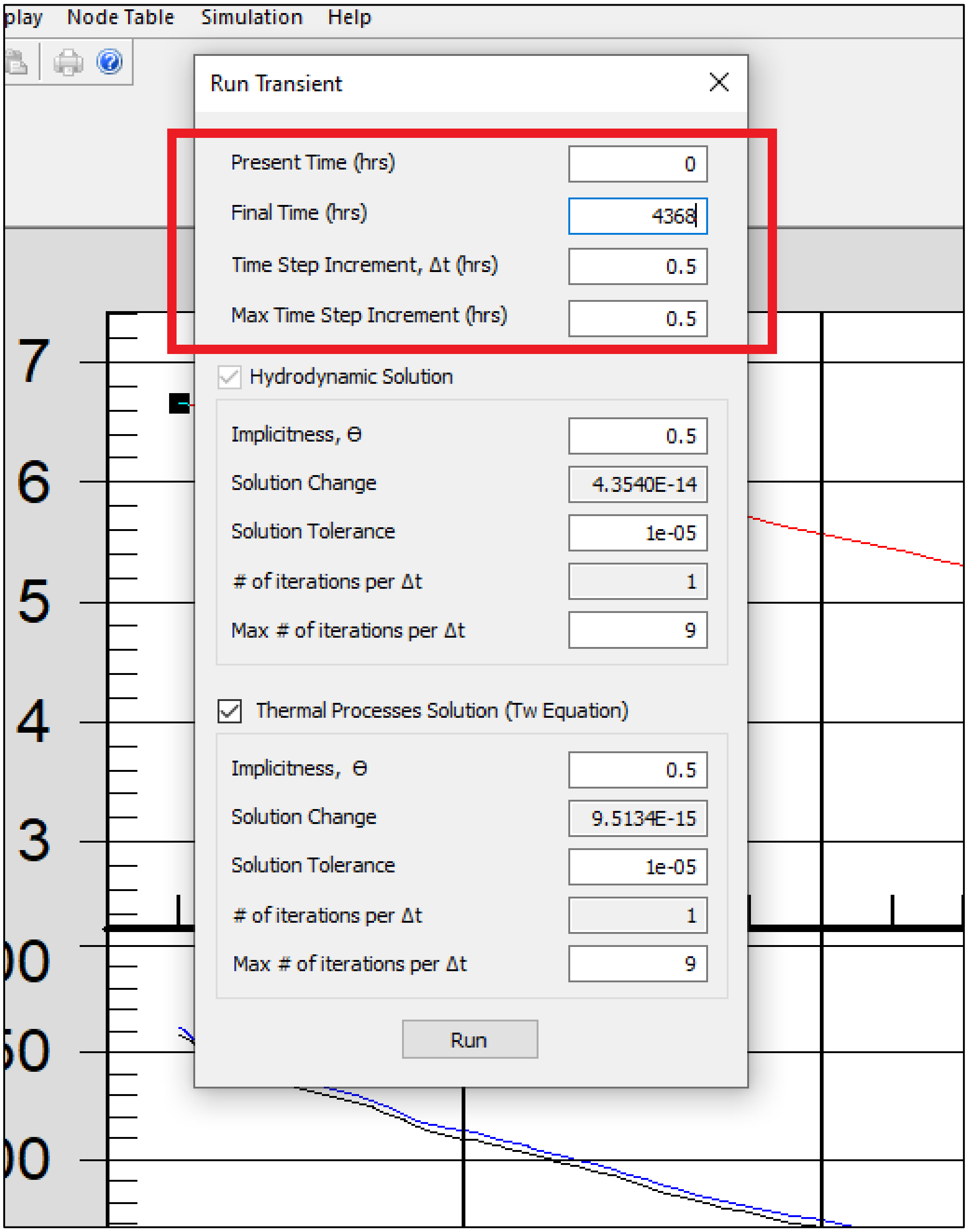
☐ River1D Files

☐ SQLite Database

7. Click Initialize Output, then click Close.
8. Now we are ready to run. Go to Simulation and select the *’Transient…*’ option. This opens the ‘Run Transient’ dialogue box.
   - **NOTE**: You need to be in the Profile View, Plan View, or Hydrograph View tabs for the ‘Transient…’ menu item to be active.



9. Set the 'Final Time' to *4368* hrs (this is 182 days and stops just before the boundary conditions end), and set the 'Time Step Increment' and 'Max Time Step Increment' to *0.5 (if it is not already)*.



Run Transient

Present Time (hrs) 0

Final Time (hrs) 4368

Time Step Increment, Δt (hrs) 0.5

Max Time Step Increment (hrs) 0.5

☑ Hydrodynamic Solution

Implicitness, θ 0.5

Solution Change 4.3540E-14

Solution Tolerance 1e-05

# of iterations per Δt 1

Max # of iterations per Δt 9

☑ Thermal Processes Solution (Tw Equation)

Implicitness, θ 0.5

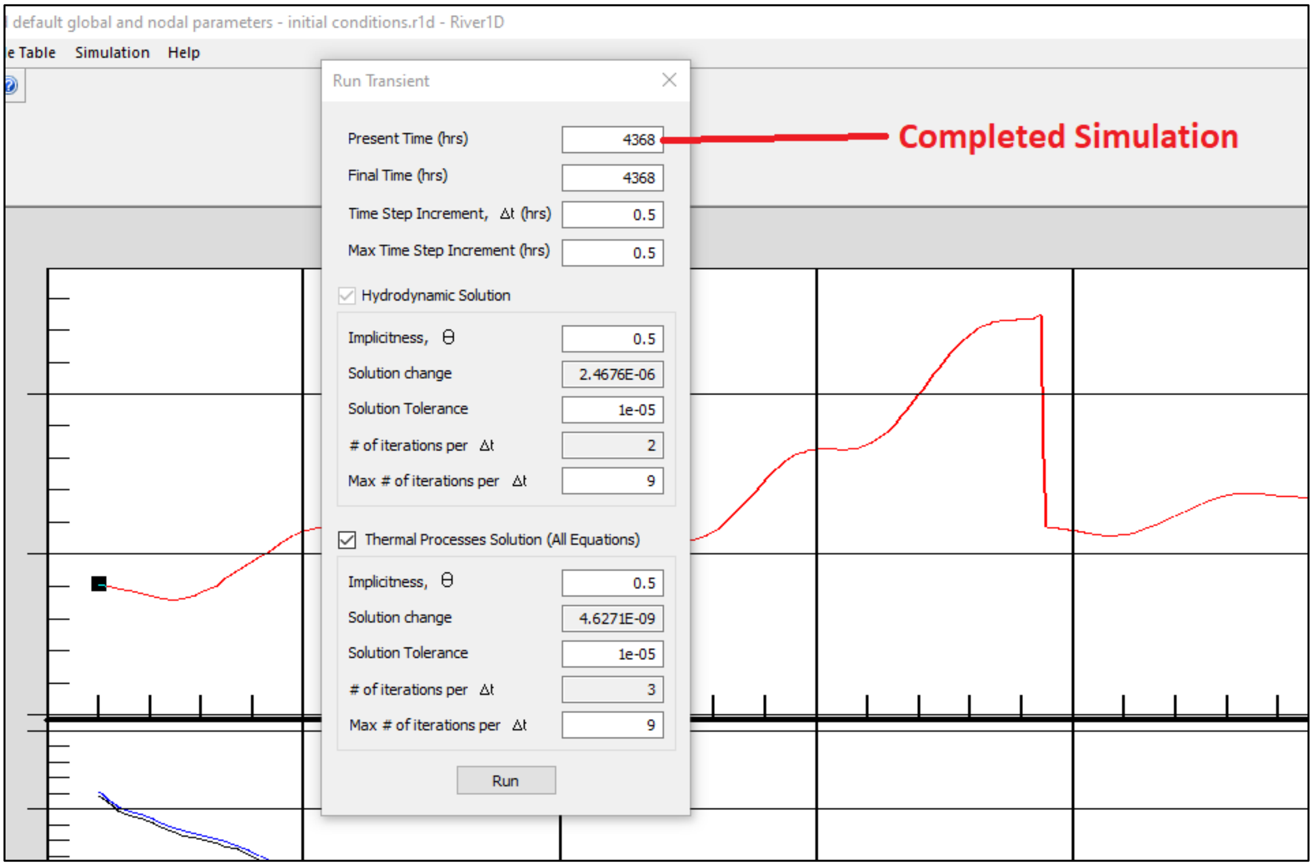
Solution Change 9.5134E-15

Solution Tolerance 1e-05

# of iterations per Δt 1

Max # of iterations per Δt 9

10. Hit Run .



Present Time (hrs) 4368

Final Time (hrs) 4368

Time Step Increment, Δt (hrs) 0.5

Max Time Step Increment (hrs) 0.5

☑ Hydrodynamic Solution

Implicitness, θ 0.5

Solution change 2.4676E-06

Solution Tolerance 1e-05

# of iterations per Δt 2

Max # of iterations per Δt 9

☑ Thermal Processes Solution (All Equations)

Implicitness, θ 0.5

Solution change 4.6271E-09

Solution Tolerance 1e-05

# of iterations per Δt 3

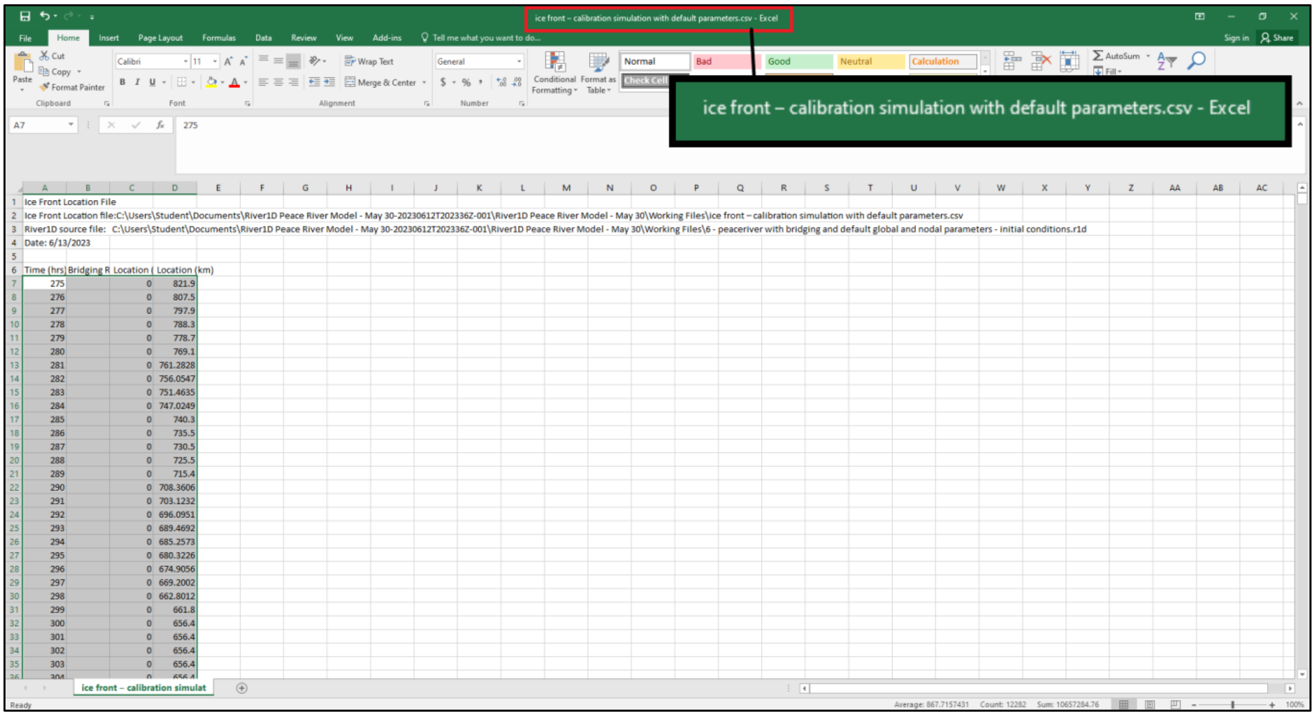
Max # of iterations per Δt 9

Completed Simulation

11. Once the model has stopped running, close the dialogue and save the file as "**7 - peaceriver with bridging and default global and nodal parameters - end.r1d**".

Task 2C: Checking Outputs

1. Open the "**2012-2013 Peace River Calibration Results with default parameters.xlsx**" file in the "Working Files" folder. This excel file will be used to check the outputs of the model against real world data.
2. Open the "**ice front – calibration simulation with default parameters.csv**" file. Copy and paste the output data into the Paste Ice Front tab of the "**2012-2013 Peace River Calibration Results with default parameters.xlsx**" spreadsheet. The simulated ice front will automatically be plotted along with the observed ice front data for the 2012-2013 season in the Ice Front Chart tab.



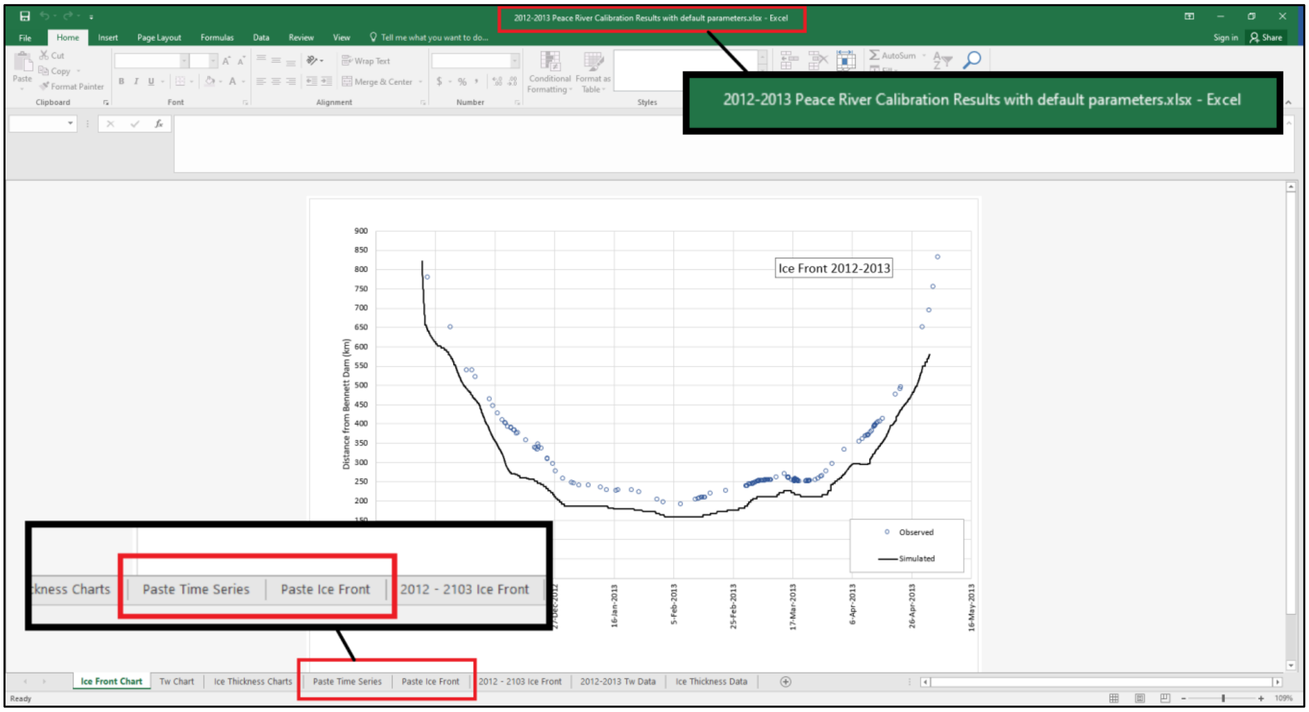
Ice Front Location File

Ice Front Location file:C:\Users\Student\Documents\River1D Peace River Model - May 30-20230612T202336Z-001\River1D Peace River Model - May 30\Working Files\ice front – calibration simulation with default parameters.csv

River1D source file: C:\Users\Student\Documents\River1D Peace River Model - May 30-20230612T202336Z-001\River1D Peace River Model - May 30\Working Files\6 - peaceriver with bridging and default global and nodal parameters - initial conditions.r1d

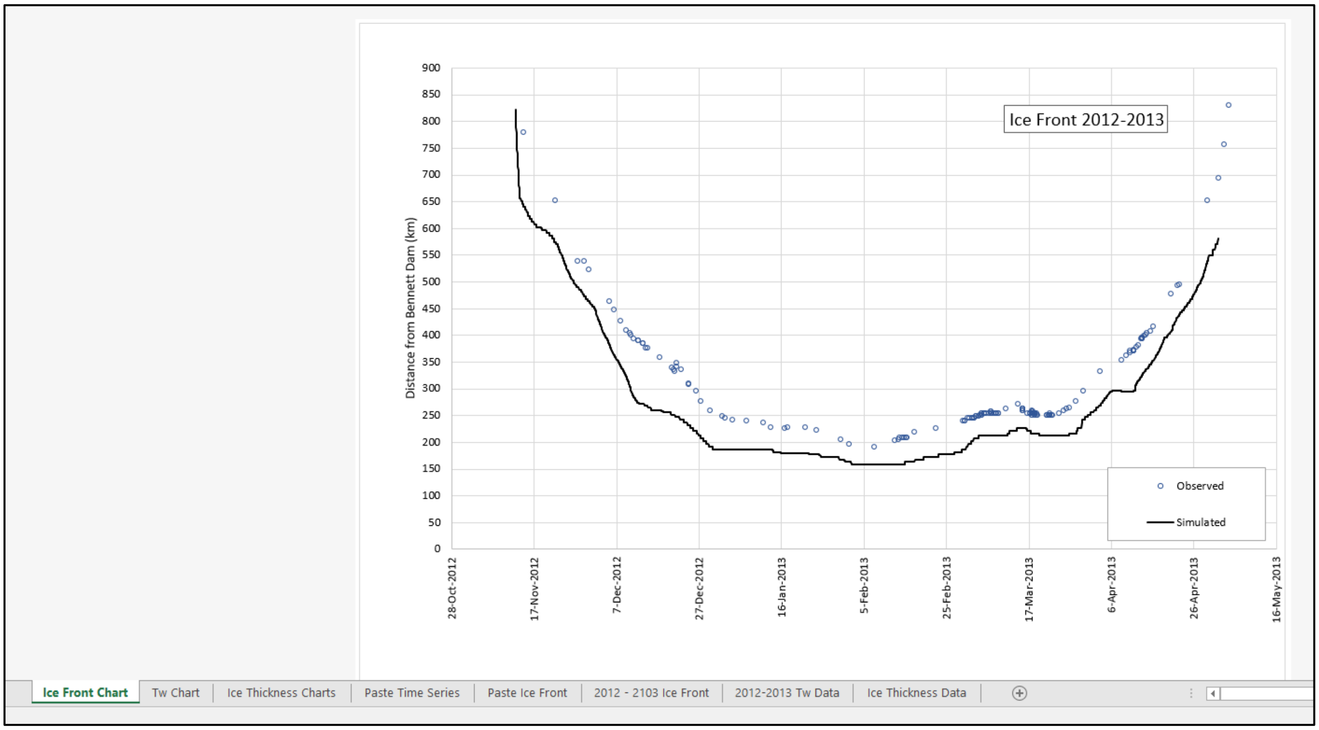
Date: 6/13/2023

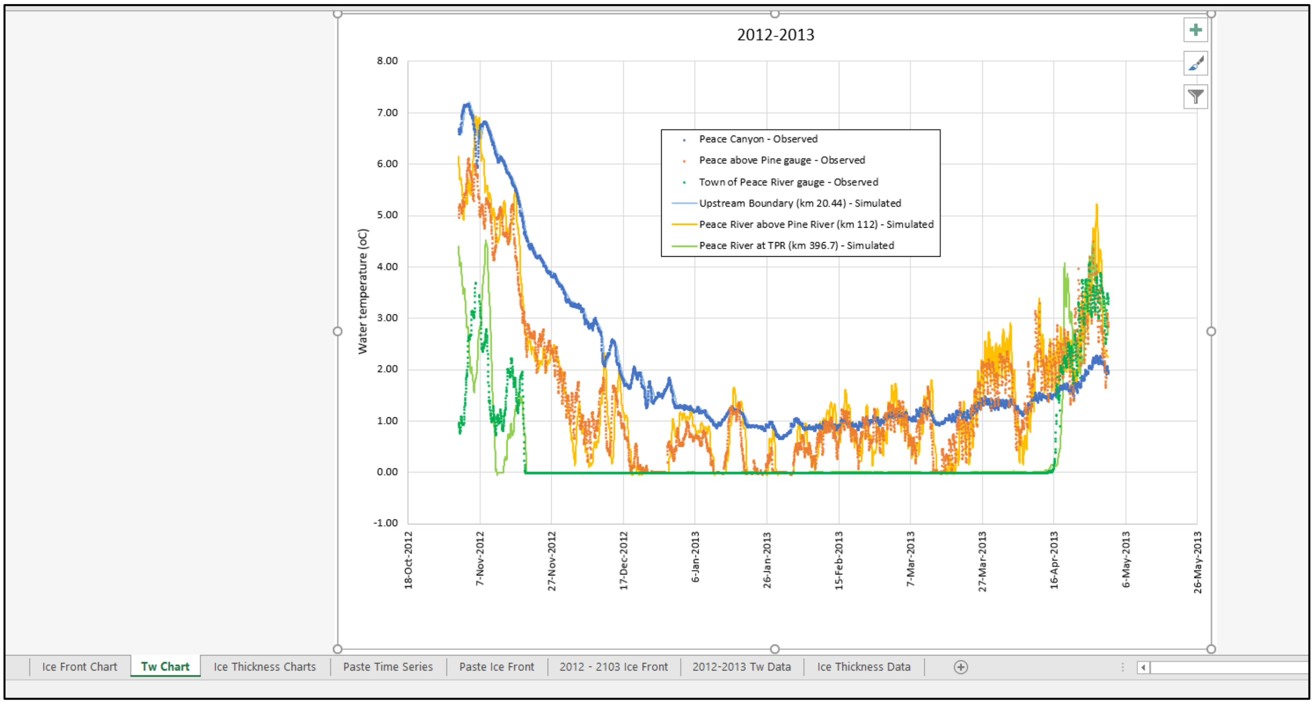
Time (hrs)	Bridging R	Location (	Location (km)
275		0	821.9
276		0	807.5
277		0	797.9
278		0	788.3
279		0	778.7
280		0	769.1
281		0	761.2828
282		0	756.0547
283		0	751.4635
284		0	747.0249
285		0	740.3
286		0	735.5
287		0	730.5
288		0	725.5
289		0	715.4
290		0	708.3606
291		0	703.1232
292		0	696.0951
293		0	689.4692
294		0	685.2573
295		0	680.3226
296		0	674.9056
297		0	669.2002
298		0	662.8012
299		0	661.8
300		0	656.4
301		0	656.4
302		0	656.4
303		0	656.4

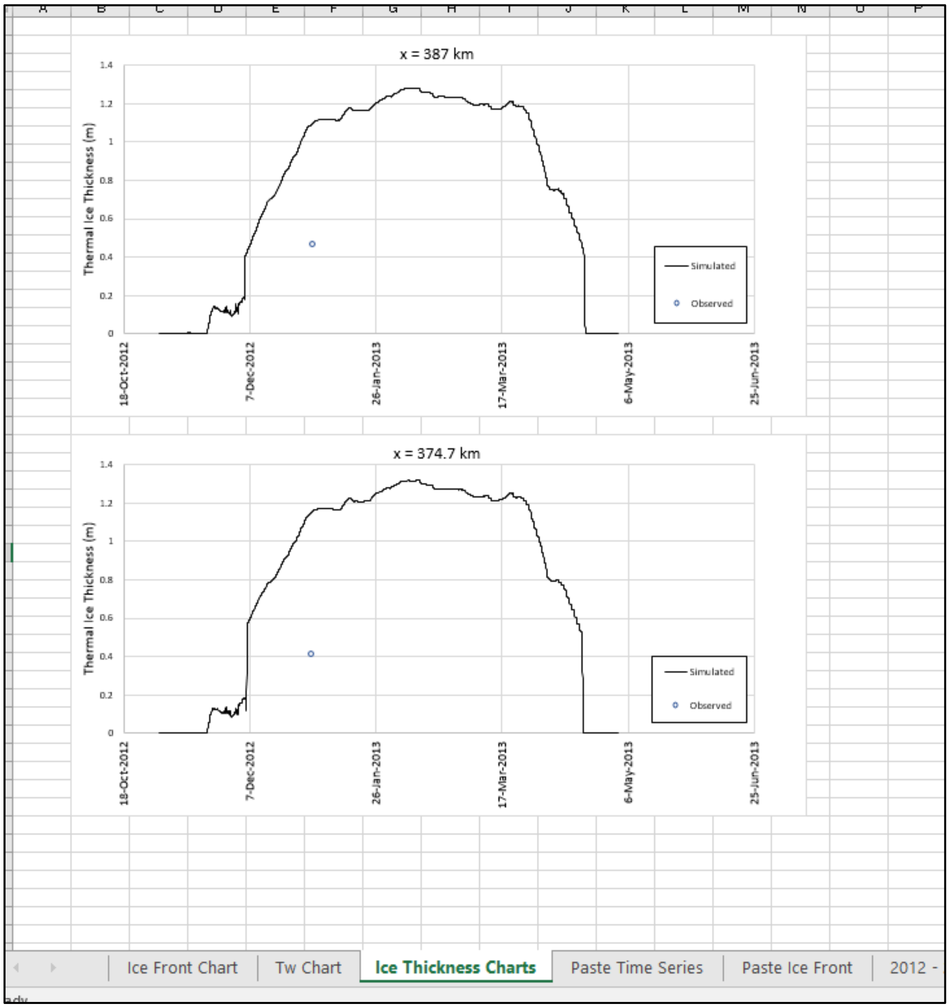


3. Open “**time series - calibration simulation with default parameters.csv**” and paste the data into the Paste Time Series tab in the same excel file.
4. Go to the tabs for Ice Front Chart, Tw Chart, and Ice Thickness Chart to see the results compared to the available data.

5. Notice that the ice front is progressing too quickly. Water temperature results are ok – the results at 112 km are the ones to focus on since this location never freezes over. The model seems to over and under predict the water temperature, suggesting that h_{wa} = 20 is probably too high. h_{wa} also affects the amount of ice being generated, so it will also affect the ice cover advancement. The model is also over predicting the ice thickness, which indicates that h_{ia} is also too high.

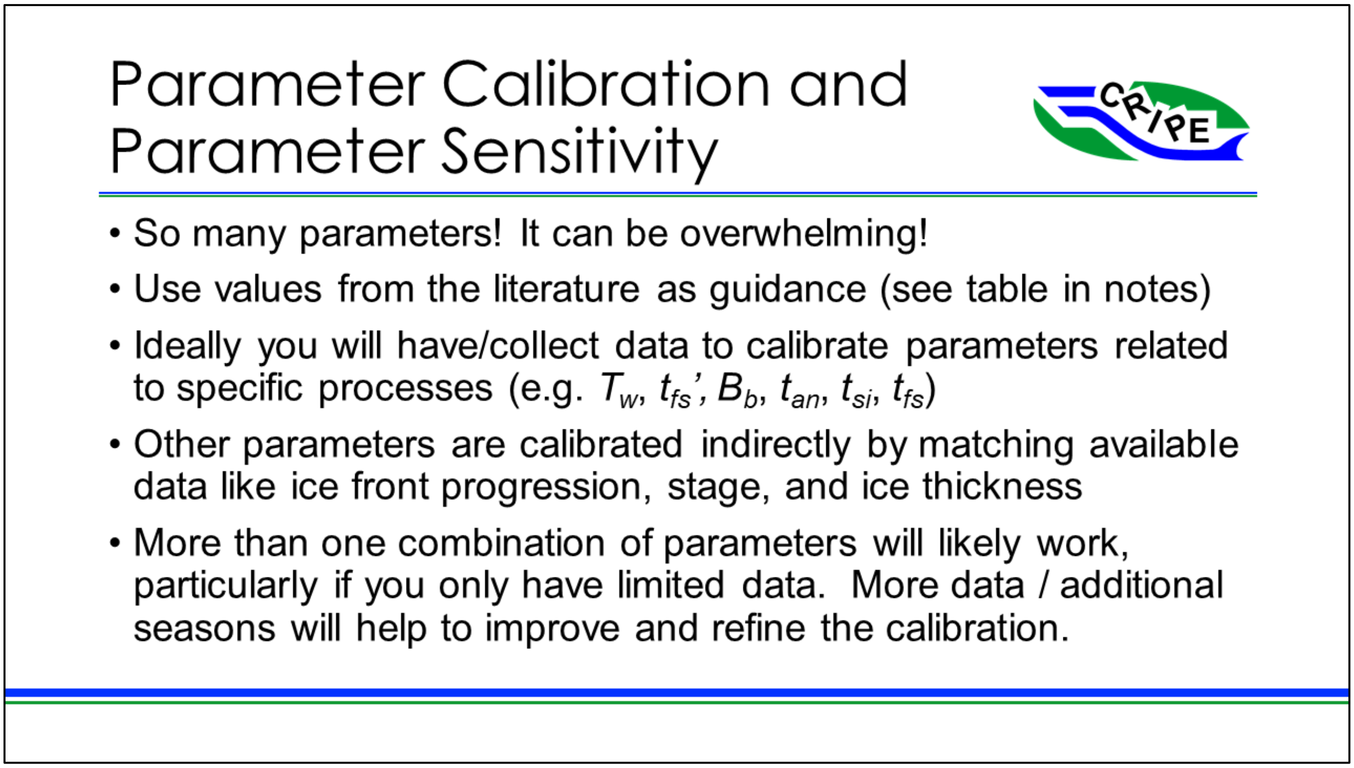





x = 387 km
Thermal Ice Thickness (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
18-Oct-2012
7-Dec-2012
26-Jan-2013
17-Mar-2013
6-May-2013
25-Jun-2013
Simulated
Observed
x = 374.7 km
Thermal Ice Thickness (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
18-Oct-2012
7-Dec-2012
26-Jan-2013
17-Mar-2013
6-May-2013
25-Jun-2013
Simulated
Observed
Ice Front Chart
Tw Chart
Ice Thickness Charts
Paste Time Series
Paste Ice Front
2012 -

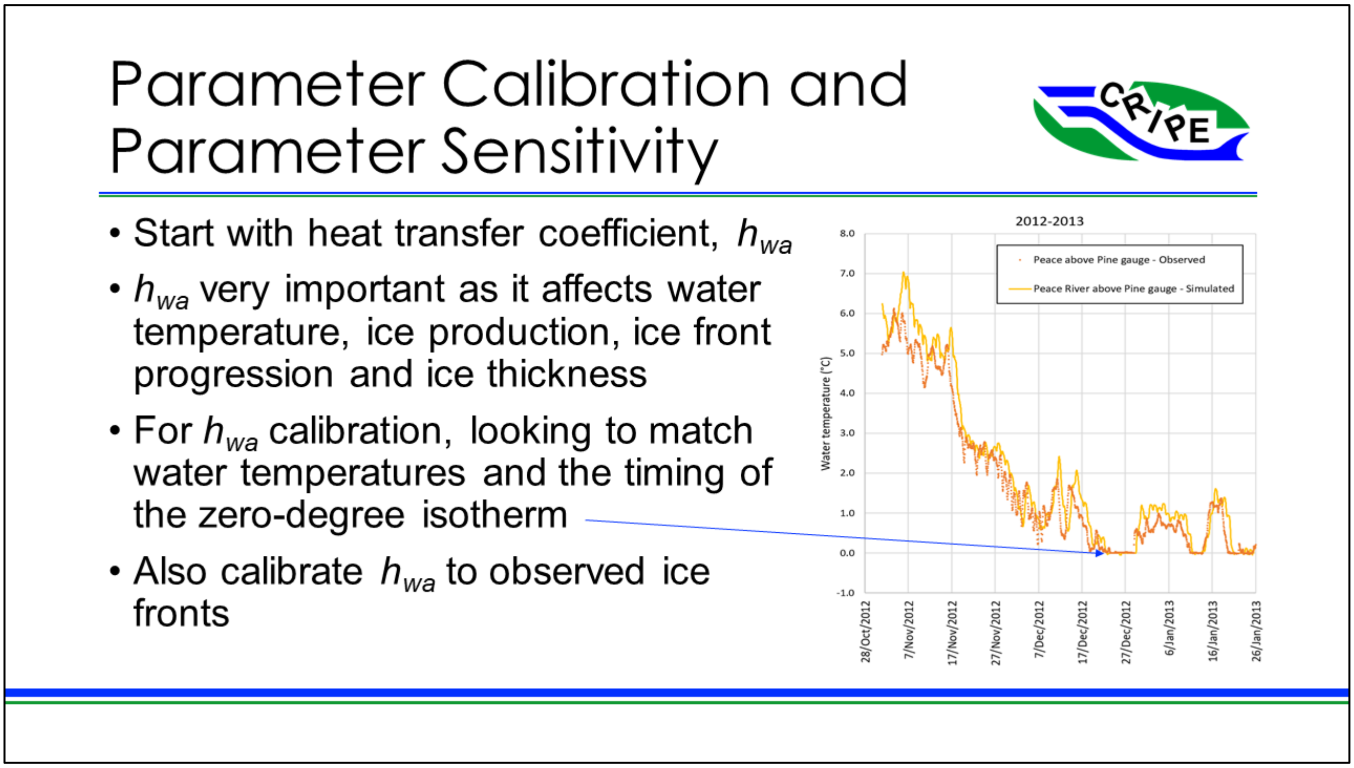
Module 3: Calibrating the Model

Now that we have compared the output using default settings to real life data, we can begin calibrating the model to increase accuracy.



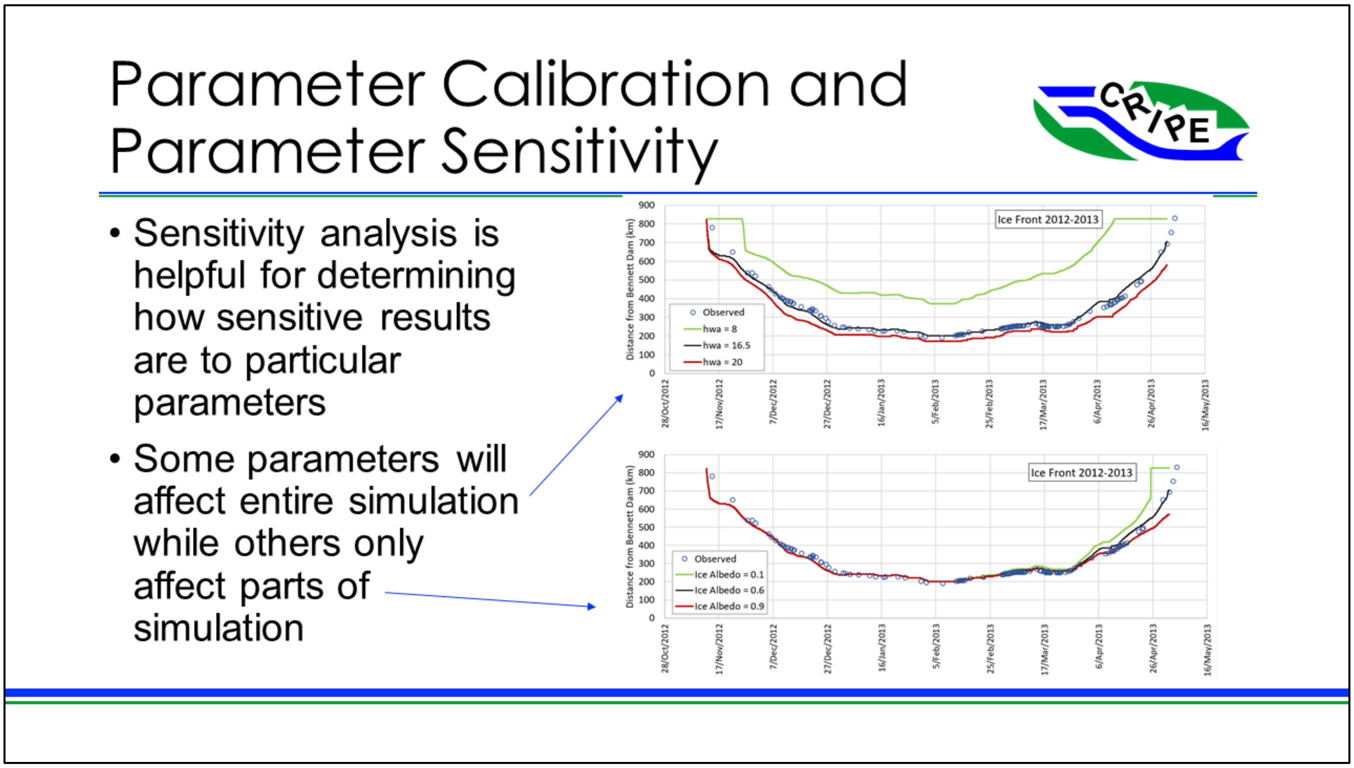
Parameter Calibration and Parameter Sensitivity

- So many parameters! It can be overwhelming!
- Use values from the literature as guidance (see table in notes)
- Ideally you will have/collect data to calibrate parameters related to specific processes (e.g. T_w, t_{fs}', B_b, t_{an}, t_{si}, t_{fs})
- Other parameters are calibrated indirectly by matching available data like ice front progression, stage, and ice thickness
- More than one combination of parameters will likely work, particularly if you only have limited data. More data / additional seasons will help to improve and refine the calibration.



Parameter Calibration and Parameter Sensitivity

- Start with heat transfer coefficient, h_{wa}
- h_{wa} very important as it affects water temperature, ice production, ice front progression and ice thickness
- For h_{wa} calibration, looking to match water temperatures and the timing of the zero-degree isotherm
- Also calibrate h_{wa} to observed ice fronts



Parameter Calibration and Parameter Sensitivity

- Sensitivity analysis is helpful for determining how sensitive results are to particular parameters
- Some parameters will affect entire simulation while others only affect parts of simulation

As stated previously, h_{wa} = 20 is likely too high. We can begin by adjusting this parameter. In the following task, we will experiment with the h_{wa} parameter to improve the water temperature modelling. This task will help you to familiarize yourself with the effects of the model parameters.

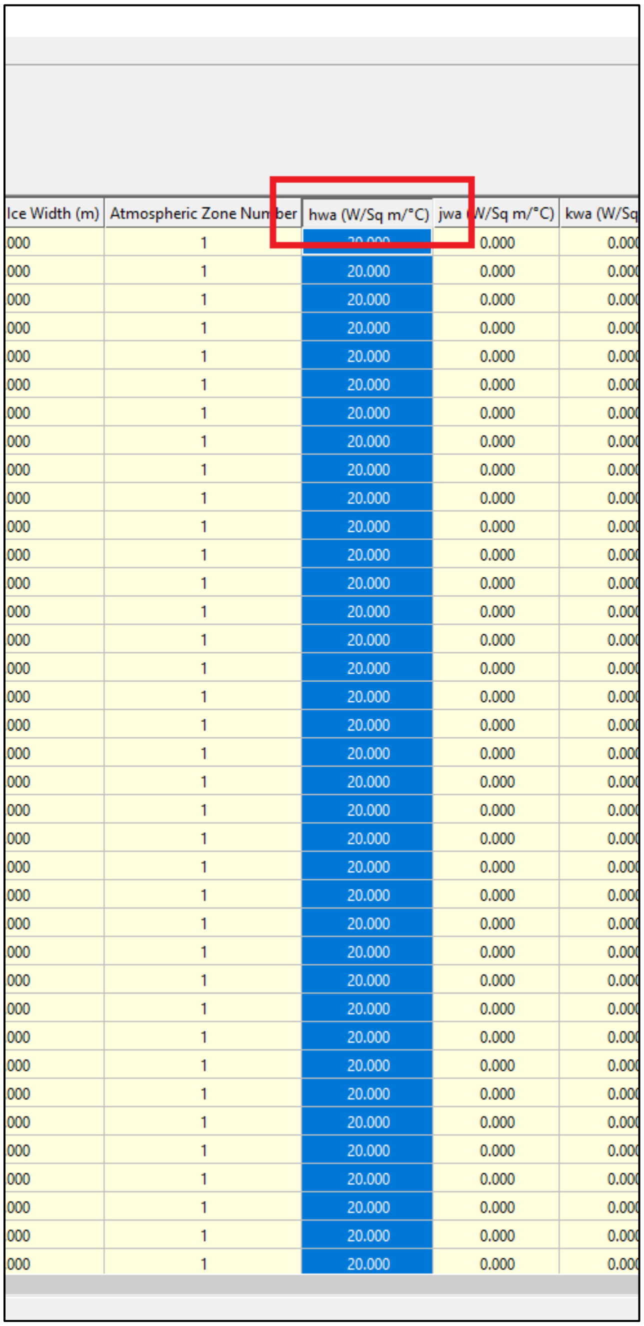
Task 3B will show you the properly calibrated parameters if you want to skip the experimentation.

- **NOTE**: A complete list of the ice process modelling parameters used in River1D along with default values and values reported in literature is available in **Appendix A**.

Task 3A: OPTIONAL – Experimenting with the h_{wa} parameter

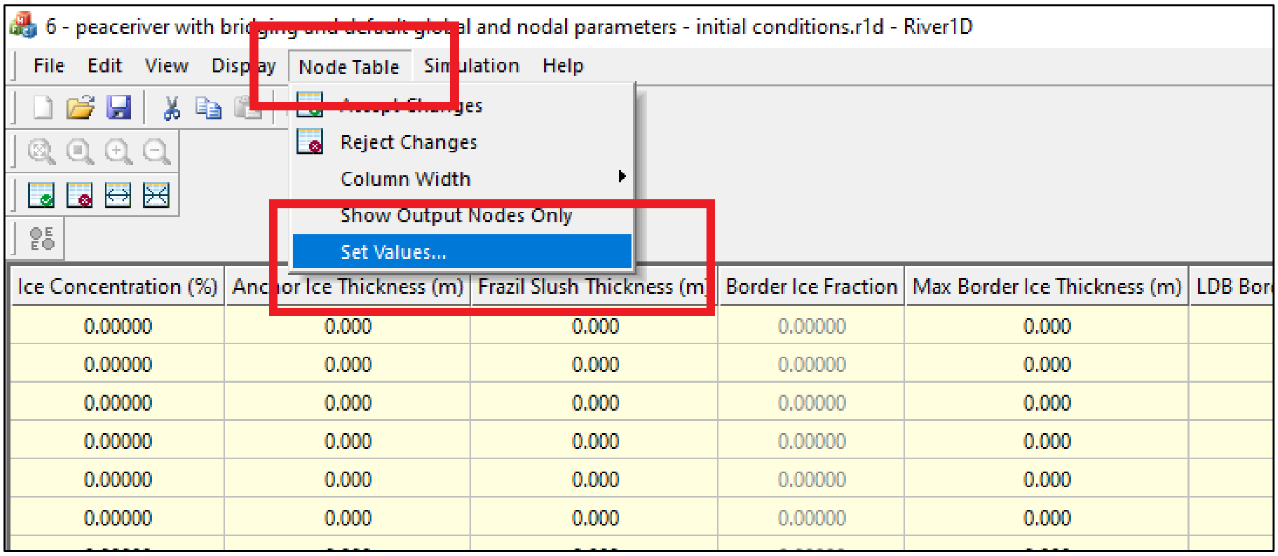
The following task will be similar to the previous tasks in module 2.

1. Re-open the River1D file for ‘**6 - peaceriver with bridging and default global and nodal parameters - initial conditions.r1d**’.
2. Click on the Node Table Editor tab. Find the column for h_{wa}. This is a linear heat transfer coefficient which affects how quickly heat is transferred between the water and the atmosphere.
3. We are going to modify the values in the column to calibrate the temperature model. To do this, select the heading. The entire column should be highlighted.



Ice Width (m)	Atmospheric Zone Number	hwa (W/Sq m/°C)	jwa (W/Sq m/°C)	kwa (W/Sq
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00

4. Next, go to Node Table near the top of the program. Select the ‘*Set Values…*’ option.



Ice Concentration (%)	Anchor Ice Thickness (m)	Frazil Slush Thickness (m)	Border Ice Fraction	Max Border Ice Thickness (m)	LDB Bor
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	

5. Enter a value for the highlighted cells.
   - **HINT**: Since the model is currently over-exaggerating changes in water temperature, you should lower the coefficient. The recommended range for h_{wa} is approximately 8 to 20.
6. Click OK.
7. Click on ✓ to accept the edits. Click on the Profile view tab.
8. Run the model in steady state to generate the initial conditions. Go to Simulation and select '*Steady…*'.Then hit Run.
   - **NOTE**: You need to be in the Profile View, Plan View, or Hydrograph View tabs for the 'Steady…' menu item to be active.
9. Let the model run until the solution has converged.
10. Go to Simulation and select '*Output Options…*'. This opens the 'Transient Output Options' dialogue. Check the boxes for '*Time Series'* and *'Ice Front Location'*.
11. For the *'Time* Series' data, click Browse... to determine the output file location. Navigate to the "Working Files" folder and name the output file "**time series – hwa.csv**". Click Save.
    - **NOTE**: If this is after your first run, select "**time series – hwa.csv**" instead. When you save, you will be asked whether you want to overwrite this file. Click Yes.
12. Choose *'1 hour'* for the frequency of hydrograph(s) output. Check the boxes for *'Water Temperature'* and '*Solid Ice Thickness*'.
13. For the *'Ice Front Location'* data, click Browse... to determine the output file location. Navigate to the "Working Files" folder and name the output file "**ice front – hwa.csv**". Click Save.

- **NOTE**: If this is after your first run, select “**ice front – hwa.csv**” instead. When you save, you will be asked whether you want to overwrite this file. Click Yes .

14. Choose *‘1 hour’* for the frequency of ice front location output.

15. Click Initialize Output , then click Close .

16. Now we are ready to run. Go to Simulation and select the *‘Transient…’* option. This opens the ‘Run Transient’ dialogue box.

    - **NOTE**: You need to be in the <u>Profile View</u>, <u>Plan View</u>, or <u>Hydrograph View</u> tabs for the ‘Transient…’ menu item to be active.

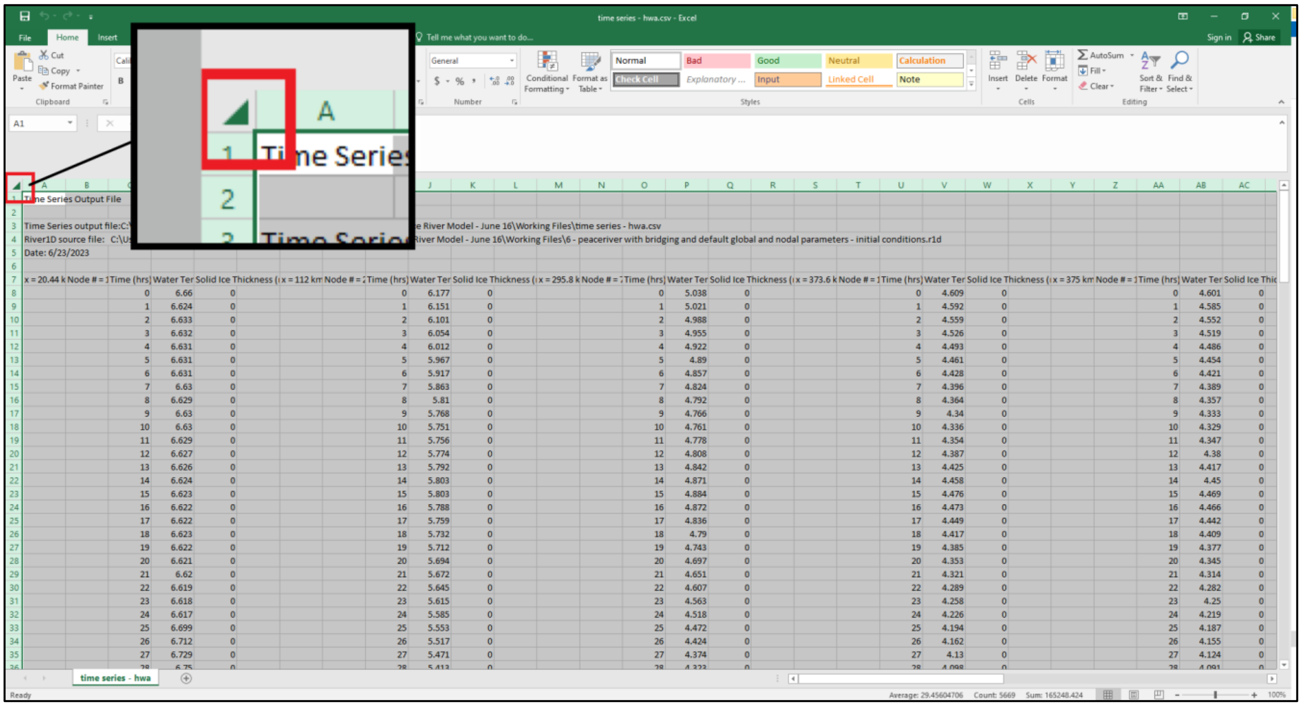
17. Set the ‘Final Time*’* to *800* hrs, and set the ‘Time Step Increment’ and ‘Max Time Step Increment’ to *0.5 (if it is not already)*.

18. Hit Run .

19. Once the model has stopped running, open the “**hwa calibration checker.xlsx**” file in the “Working Files” folder.

20. Open the “**time series – hwa.csv**” and paste the data into the <u>Paste Time Series</u> tab of the **hwa calibration checker.xlsx**.

    - **NOTE**: You can select the entire sheet to copy and paste the data into the checker tab by clicking on the corner of the sheet.



Time Series Output File

Time Series output file:C:\ e River Model - June 16\Working Files\time series - hwa.csv

River1D source file: C:\U River Model - June 16\Working Files\6 - peaceriver with bridging and default global and nodal parameters - initial conditions.r1d

Date: 6/23/2023

x = 20.44 k	Node # = 1	Time (hrs)	Water Ter	Solid Ice Thickness (	x = 112 km	Node # = 2	Time (hrs)	Water Ter	Solid Ice Thickness (	x = 295.8 k	Node # = 7	Time (hrs)	Water Ter	Solid Ice Thickness (	x = 373.6 k	Node # = 1	Time (hrs)	Water Ter	Solid Ice Thickness (	x = 375 km	Node # = 1	Time (hrs)	Water Ter	Solid Ice Thic
		0	6.66	0			0	6.177	0			0	5.038	0			0	4.609	0			0	4.601	0
		1	6.624	0			1	6.151	0			1	5.021	0			1	4.592	0			1	4.585	0
		2	6.633	0			2	6.101	0			2	4.988	0			2	4.559	0			2	4.552	0
		3	6.632	0			3	6.054	0			3	4.955	0			3	4.526	0			3	4.519	0
		4	6.631	0			4	6.012	0			4	4.922	0			4	4.493	0			4	4.486	0
		5	6.631	0			5	5.967	0			5	4.89	0			5	4.461	0			5	4.454	0
		6	6.631	0			6	5.917	0			6	4.857	0			6	4.428	0			6	4.421	0
		7	6.63	0			7	5.863	0			7	4.824	0			7	4.396	0			7	4.389	0
		8	6.629	0			8	5.81	0			8	4.792	0			8	4.364	0			8	4.357	0
		9	6.63	0			9	5.768	0			9	4.766	0			9	4.34	0			9	4.333	0
		10	6.63	0			10	5.751	0			10	4.761	0			10	4.336	0			10	4.329	0
		11	6.629	0			11	5.756	0			11	4.778	0			11	4.354	0			11	4.347	0
		12	6.627	0			12	5.774	0			12	4.808	0			12	4.387	0			12	4.38	0
		13	6.626	0			13	5.792	0			13	4.842	0			13	4.425	0			13	4.417	0
		14	6.624	0			14	5.803	0			14	4.871	0			14	4.458	0			14	4.45	0
		15	6.623	0			15	5.803	0			15	4.884	0			15	4.476	0			15	4.469	0
		16	6.622	0			16	5.788	0			16	4.872	0			16	4.473	0			16	4.466	0
		17	6.622	0			17	5.759	0			17	4.836	0			17	4.449	0			17	4.442	0
		18	6.623	0			18	5.732	0			18	4.79	0			18	4.417	0			18	4.409	0
		19	6.622	0			19	5.712	0			19	4.743	0			19	4.385	0			19	4.377	0
		20	6.621	0			20	5.694	0			20	4.697	0			20	4.353	0			20	4.345	0
		21	6.62	0			21	5.672	0			21	4.651	0			21	4.321	0			21	4.314	0
		22	6.619	0			22	5.645	0			22	4.607	0			22	4.289	0			22	4.282	0
		23	6.618	0			23	5.615	0			23	4.563	0			23	4.258	0			23	4.25	0
		24	6.617	0			24	5.585	0			24	4.518	0			24	4.226	0			24	4.219	0
		25	6.699	0			25	5.553	0			25	4.472	0			25	4.194	0			25	4.187	0
		26	6.712	0			26	5.517	0			26	4.424	0			26	4.162	0			26	4.155	0
		27	6.729	0			27	5.471	0			27	4.374	0			27	4.13	0			27	4.124	0

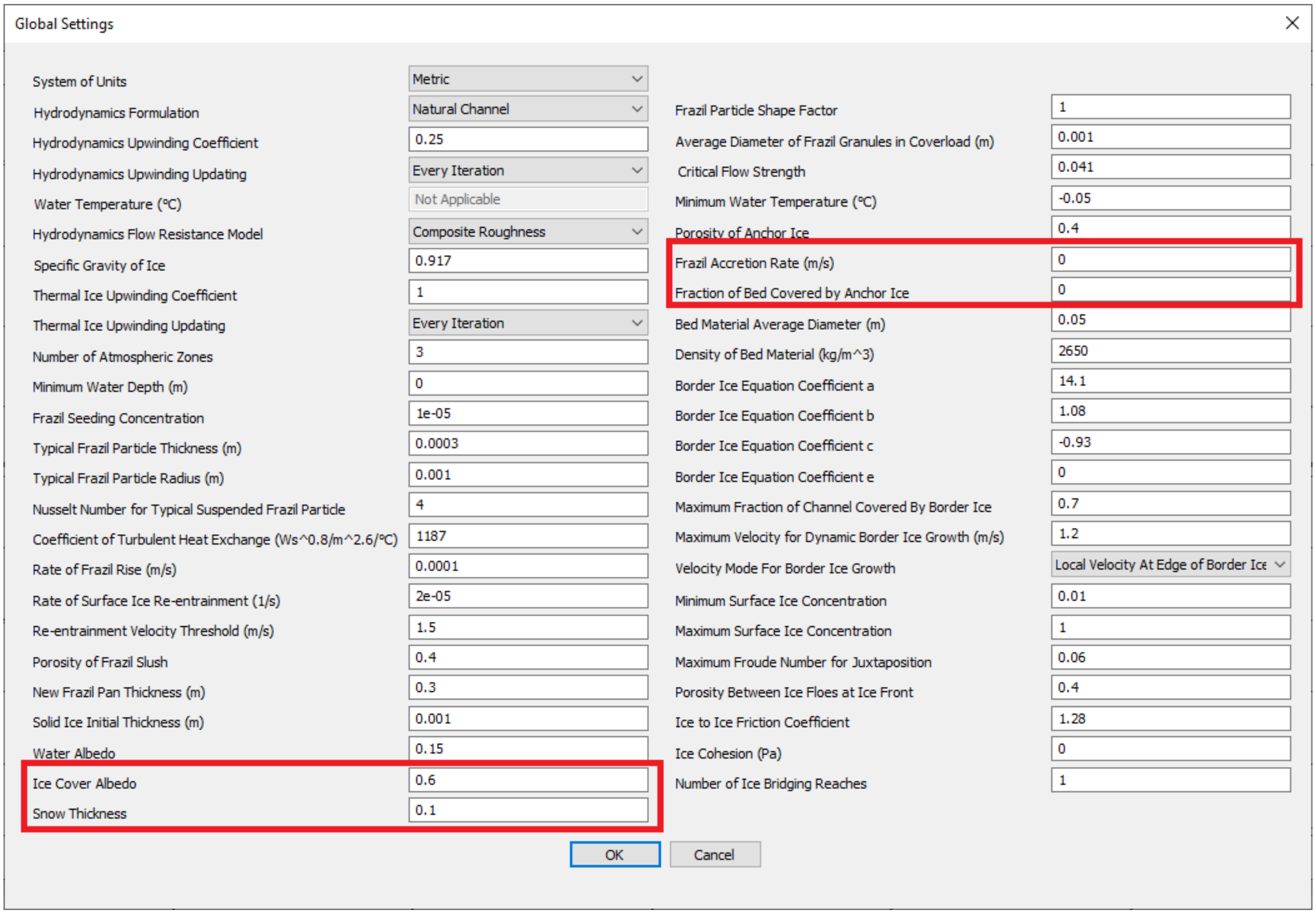
Average: 29.45604706 Count: 5669 Sum: 165248.424

21. Open the “**ice front – hwa.csv**” file and paste the data into the <u>Paste Ice Front</u> tab of **hwa calibration checker.xlsx**.

22. Go to the tabs for <u>Ice Front Chart</u> and <u>Tw Chart</u>. Compare the model results to the previous default model. Does the predicted temperature and ice front location better match the real world data? What further adjustments should be made?
23. Close the River1D model and re-open it. Run the model again with a different hwa coefficient. Repeat the entire task again until you find a suitable fit.

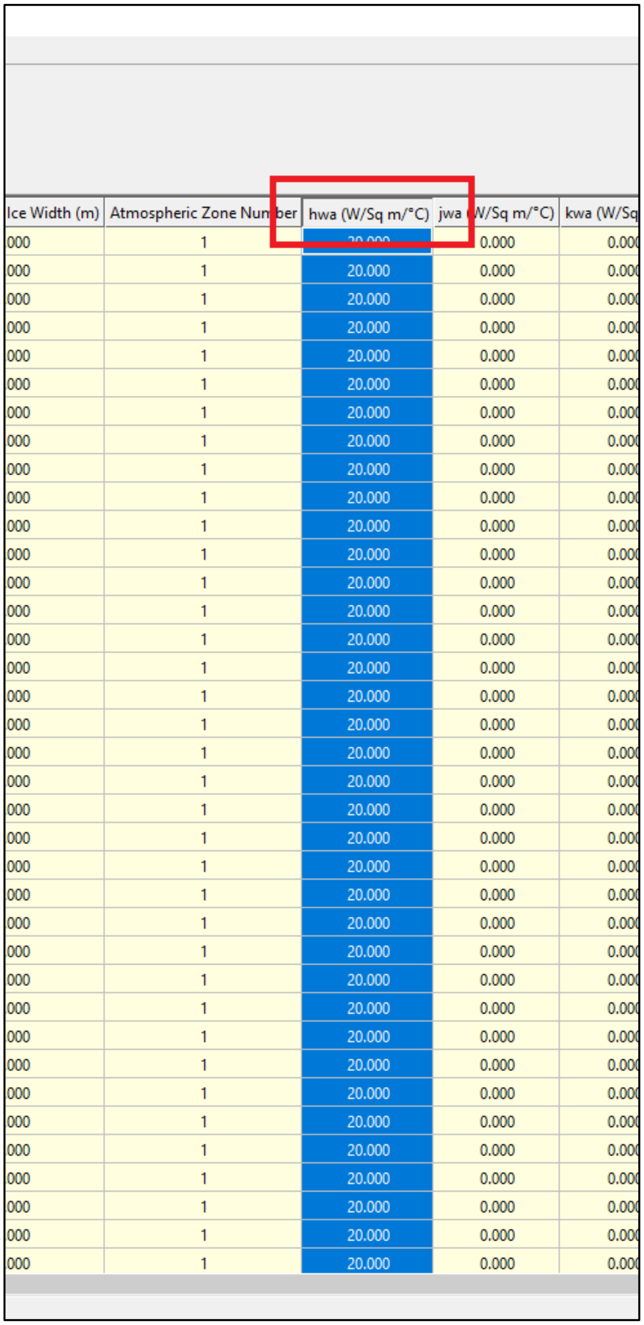
Task 3B: Adjusting Parameters

1. Re-open the River1D file for '**6 - peaceriver with bridging and default global and nodal parameters - initial conditions.r1d**'.
2. Go to Simulation and select '*Global Settings…*' to open the 'Global Settings' dialogue.
3. Change the global parameters that are listed on the <u>Global and Nodal Parameters</u> tab in "**Model Inputs Calibration.xlsx**". These parameters and their calibrated values are:
    - *Ice cover albedo* (set to *0.6*)
    - *Snow thickness* (set to *0.1* m)
    - *Frazil accretion rate* (set to *0* m/s)
    - *Fraction of bed covered by anchor ice* (set to *0*)



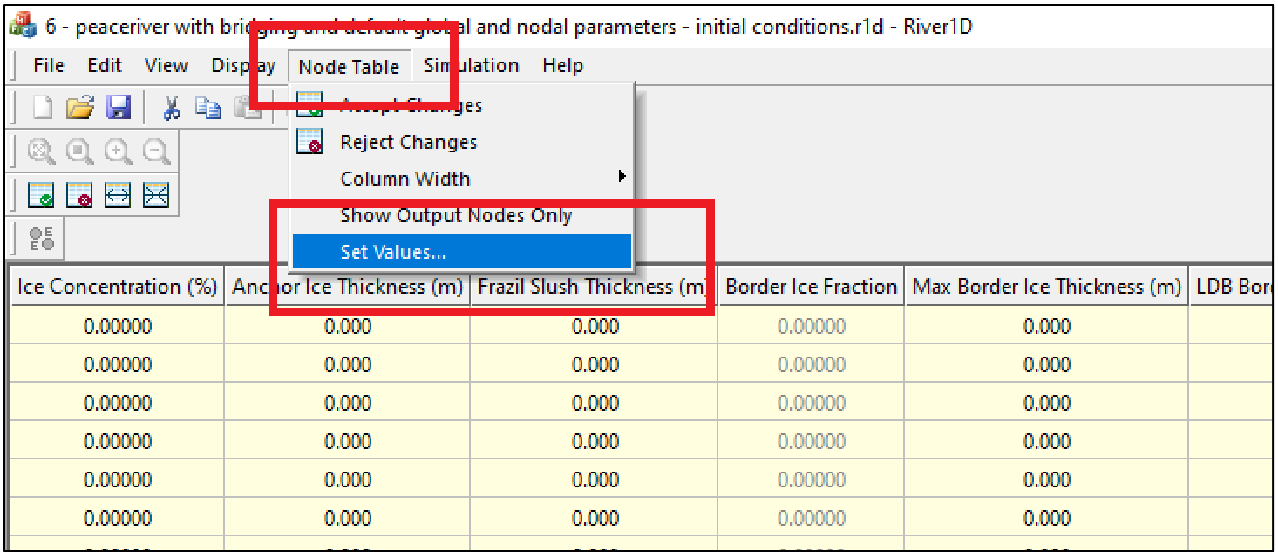
System of Units	Metric
Hydrodynamics Formulation	Natural Channel
Hydrodynamics Upwinding Coefficient	0.25
Hydrodynamics Upwinding Updating	Every Iteration
Water Temperature (°C)	Not Applicable
Hydrodynamics Flow Resistance Model	Composite Roughness
Specific Gravity of Ice	0.917
Thermal Ice Upwinding Coefficient	1
Thermal Ice Upwinding Updating	Every Iteration
Number of Atmospheric Zones	3
Minimum Water Depth (m)	0
Frazil Seeding Concentration	1e-05
Typical Frazil Particle Thickness (m)	0.0003
Typical Frazil Particle Radius (m)	0.001
Nusselt Number for Typical Suspended Frazil Particle	4
Coefficient of Turbulent Heat Exchange (Ws^0.8/m^2.6/°C)	1187
Rate of Frazil Rise (m/s)	0.0001
Rate of Surface Ice Re-entrainment (1/s)	2e-05
Re-entrainment Velocity Threshold (m/s)	1.5
Porosity of Frazil Slush	0.4
New Frazil Pan Thickness (m)	0.3
Solid Ice Initial Thickness (m)	0.001
Water Albedo	0.15
Ice Cover Albedo	0.6
Snow Thickness	0.1
Frazil Particle Shape Factor	1
Average Diameter of Frazil Granules in Coverload (m)	0.001
Critical Flow Strength	0.041
Minimum Water Temperature (°C)	-0.05
Porosity of Anchor Ice	0.4
Frazil Accretion Rate (m/s)	0
Fraction of Bed Covered by Anchor Ice	0
Bed Material Average Diameter (m)	0.05
Density of Bed Material (kg/m^3)	2650
Border Ice Equation Coefficient a	14.1
Border Ice Equation Coefficient b	1.08
Border Ice Equation Coefficient c	-0.93
Border Ice Equation Coefficient e	0
Maximum Fraction of Channel Covered By Border Ice	0.7
Maximum Velocity for Dynamic Border Ice Growth (m/s)	1.2
Velocity Mode For Border Ice Growth	Local Velocity At Edge of Border Ice
Minimum Surface Ice Concentration	0.01
Maximum Surface Ice Concentration	1
Maximum Froude Number for Juxtaposition	0.06
Porosity Between Ice Floes at Ice Front	0.4
Ice to Ice Friction Coefficient	1.28
Ice Cohesion (Pa)	0
Number of Ice Bridging Reaches	1

4. Once you are finished, click OK.
5. Click on the Node Table Editor tab. Change the nodal parameters that are also listed under the Global and Nodal Parameters tab in the spreadsheet. To do this, select the heading of the column of the parameter you are trying to change. The whole column should become highlighted.



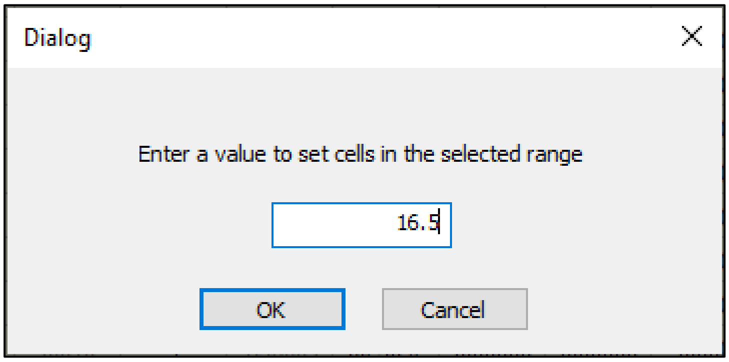
Ice Width (m)	Atmospheric Zone Number	hwa (W/Sq m/°C)	jwa (W/Sq m/°C)	kwa (W/Sq
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00
000	1	20.000	0.000	0.00

6. Then go to Node Table near the top of the program. Select the '*Set Values…*' option.



Ice Concentration (%)	Anchor Ice Thickness (m)	Frazil Slush Thickness (m)	Border Ice Fraction	Max Border Ice Thickness (m)	LDB Bor
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	
0.00000	0.000	0.000	0.00000	0.000	

7. Enter the value for the highlighted cells (e.g. for the h_{wa} column enter *16.5*). Click OK.



Enter a value to set cells in the selected range

16.5

8. Repeat for the h_{ia} field (enter *13*).
9. Once you have made all edits, click on ☑ to accept the edits.

Task 3C: Steady State Initial Conditions

With the calibrated parameters, run the model to steady state again to obtain the initial conditions for the calibration simulation. The steps are the same as Task 2A.

1. Go to Simulation and select '*Steady…*'.Then hit Run .
   - **NOTE**: You need to be in the <u>Profile View</u>, <u>Plan View</u>, or <u>Hydrograph View</u> tabs for the 'Steady…' menu item to be active.
2. Let the model run until the solution has converged.

3. Once the model has converged to a steady state, save the file as “**8 - peaceriver with calibrated global and nodal parameters - initial conditions.r1d**”.

Task 3D: Calibrated Transient Simulation

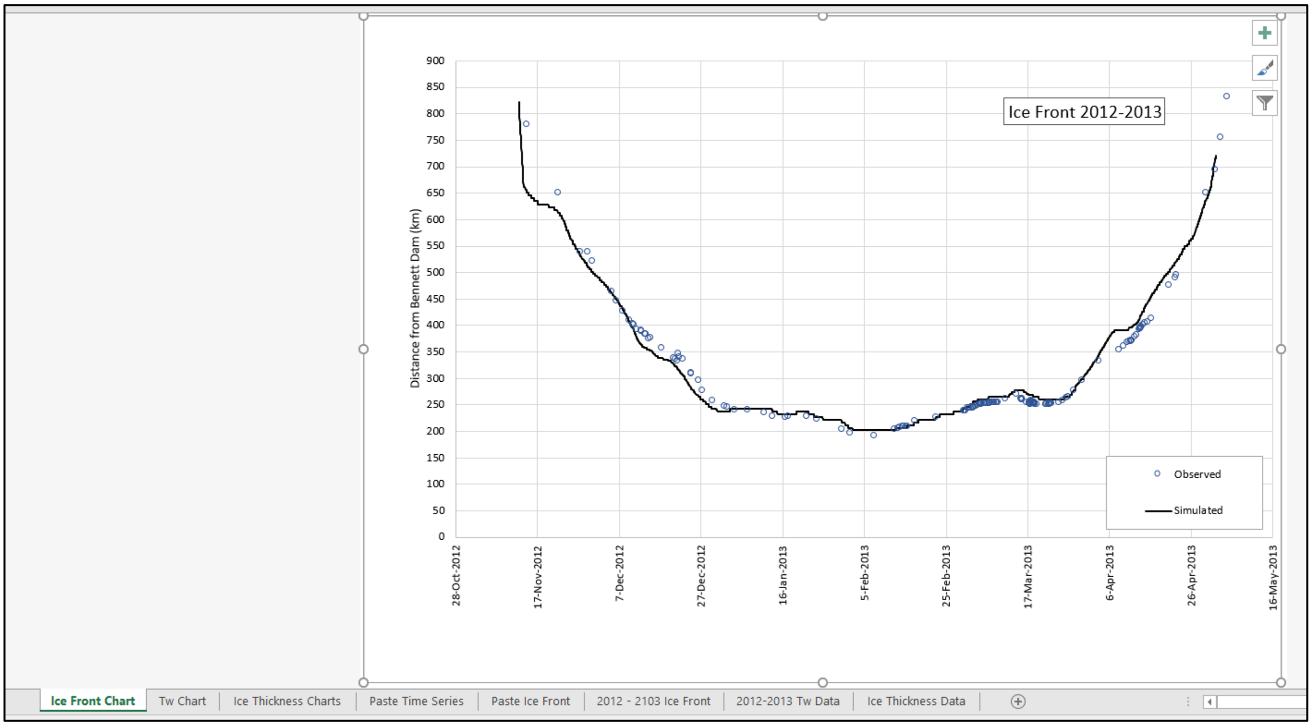
The following steps are similar to Task 2B. The main difference is file names to which outputs are saved.

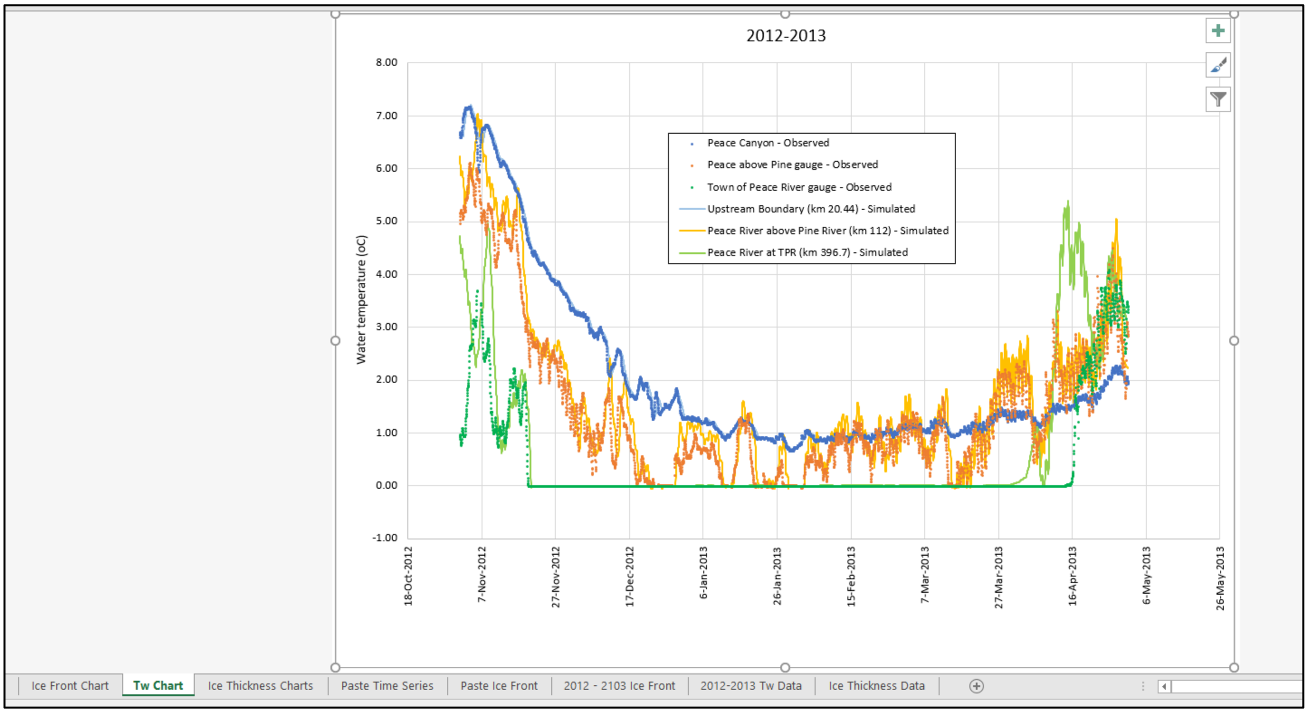
1. Go to Simulation and select ‘*Output Options…*’. This opens the ‘Transient Output Options’ dialogue. Check the boxes for ‘*Time Series’* and the ‘*Ice Front Location’*.
2. For the time series data, click Browse… to determine the output file location. Navigate to the “Working Files” folder and name the output file “**time series – calibration simulation with calibrated parameters.csv**”. Click Save.
3. Choose *‘1 hour’* for the frequency of hydrograph(s) output. Check the boxes for *‘Water Temperature’* and ‘*Solid Ice Thickness*’.
4. For the ice front location data, click Browse… and navigate to the “Working Files” folder. Name the output file “**ice front – calibration simulation with calibrated parameters.csv**”.
5. Choose ‘*1 hour’* for the frequency of ice front location output.
6. Click Initialize Output, then click Close.
7. Now we are ready to run. Go to Simulation and select the *‘Transient…*’ option. This opens the ‘Run Transient’ dialogue box.
    - **NOTE**: You need to be in the Profile View, Plan View, or Hydrograph View tabs for the ‘Transient…’ menu item to be active.
8. Set the ‘Final Time*’* to *4368* hrs (this is 182 days and stops just before the boundary conditions end), and set the ‘Time Step Increment’ and ‘Max Time Step Increment’ to *0.5 (if it is not already)*.
9. Hit Run.
10. Once the model has stopped running, save the file as “**9 - peaceriver with bridging and calibrated global and nodal parameters - end.r1d**”.

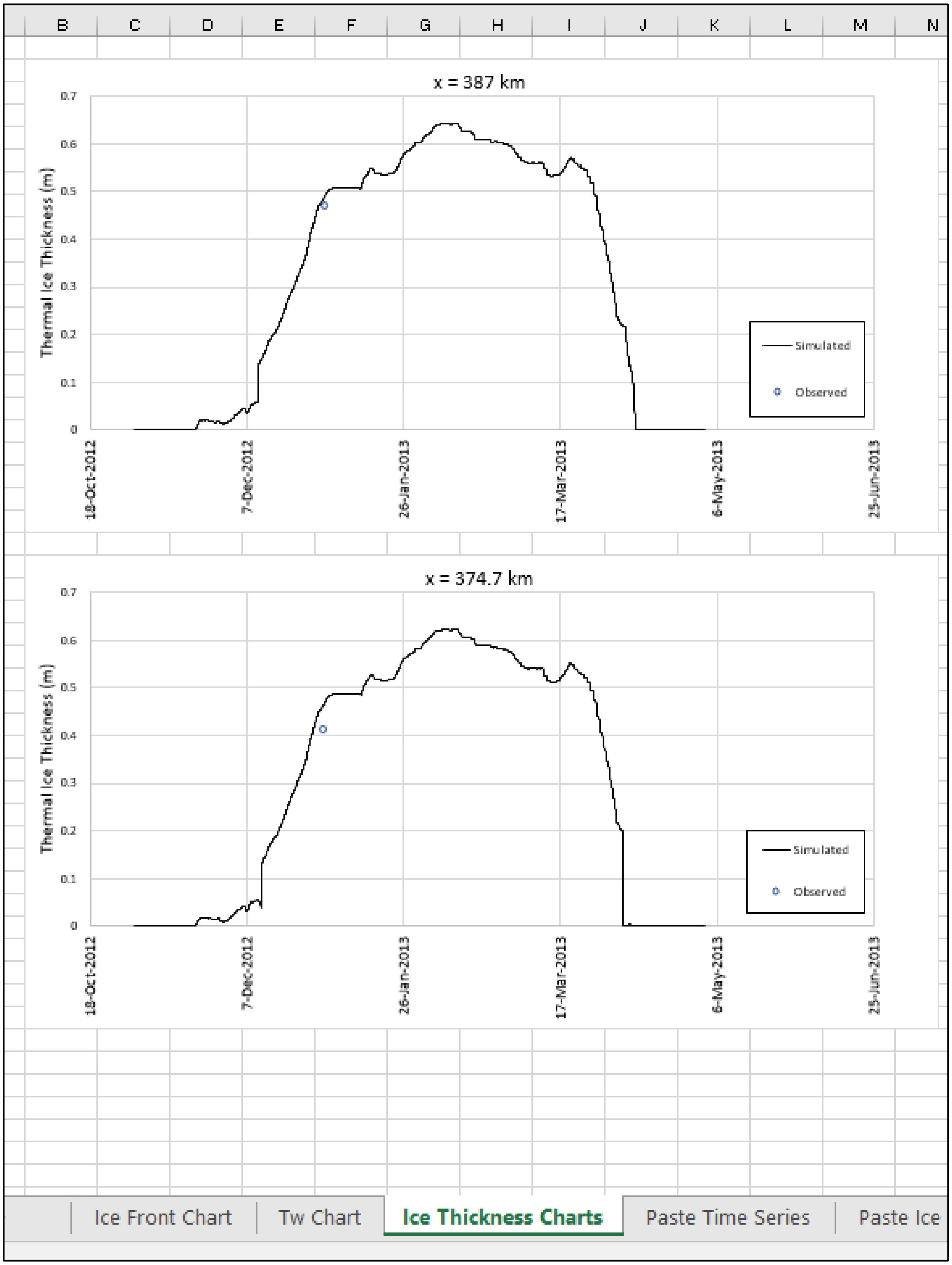
Task 3E: Checking Calibrated Outputs

The steps are also very similar to Task 2C.

1. Open the “**2012-2013 Peace River Calibration Results with calibrated parameters.xlsx**” file in the “Working Files” folder. This excel file will be used to check the outputs of the calibrated model with real world data.
2. Open the “**ice front – calibration simulation with calibrated parameters.csv**” file. Copy and paste the output data into the <u>Paste Ice Front</u> tab of the “**2012-2013 Peace River Calibration Results with calibrated parameters.xlsx**”. The simulated ice front will automatically be plotted with observed ice front data in the <u>Ice Front Chart</u> tab.
3. Open “**time series – calibration simulation with calibrated parameters.csv**” and paste the data into the <u>Paste Time Series</u> tab in the same excel file.
4. Go to the tabs for <u>Ice Front Chart</u>, <u>Tw Chart</u>, and <u>Ice Thickness Chart</u> to see the new results compared to the available data.
5. The simulated ice front location and ice thickness now match the observed data quite well. The model is still over predicting the water temperature, but not under predicting it like before. As well, since h_{wa} will affect both water temperature and ice front progression (because it affects the amount of ice), h_{wa} = 16.5 seems reasonable.

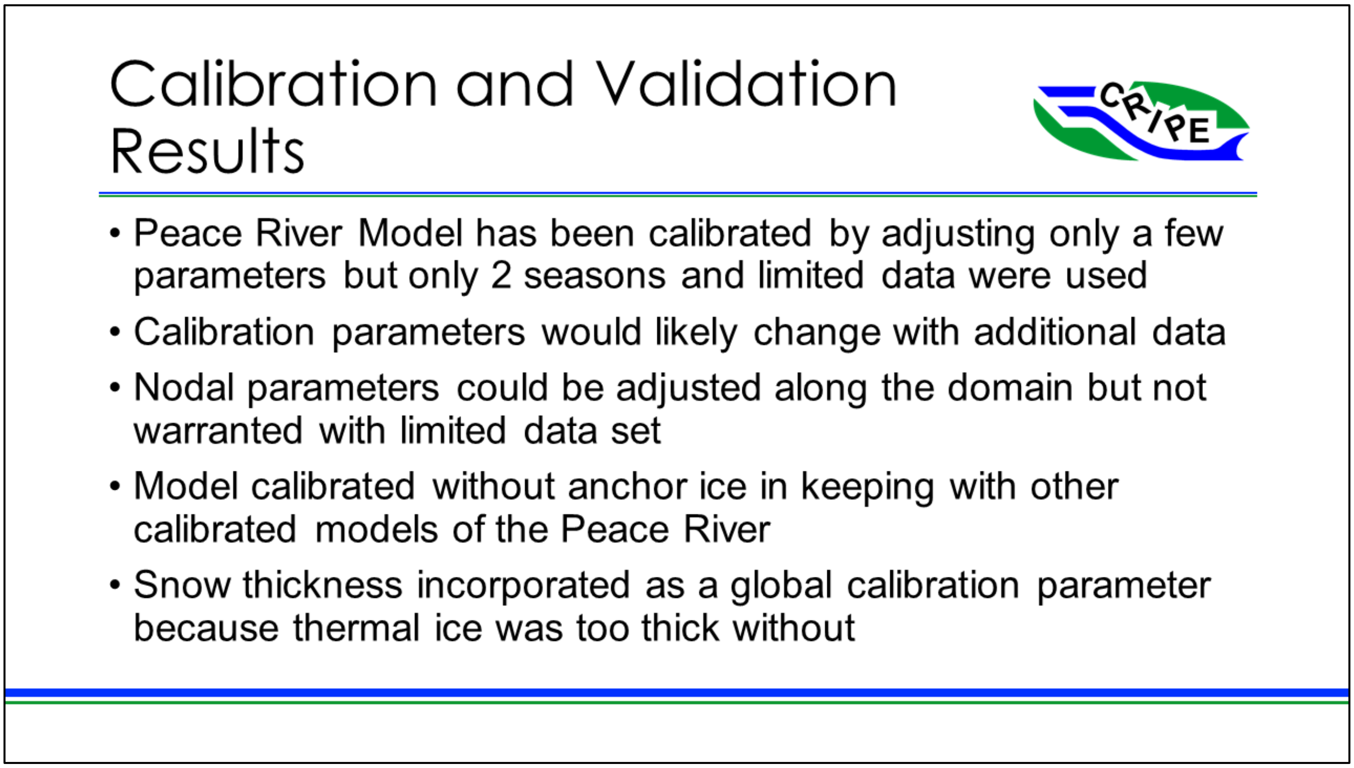



2012-2013
Water temperature (oC)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
18-Oct-2012
7-Nov-2012
27-Nov-2012
17-Dec-2012
6-Jan-2013
26-Jan-2013
15-Feb-2013
7-Mar-2013
27-Mar-2013
16-Apr-2013
6-May-2013
26-May-2013
Peace Canyon - Observed
Peace above Pine gauge - Observed
Town of Peace River gauge - Observed
Upstream Boundary (km 20.44) - Simulated
Peace River above Pine River (km 112) - Simulated
Peace River at TPR (km 396.7) - Simulated
Ice Front Chart
Tw Chart
Ice Thickness Charts
Paste Time Series
Paste Ice Front
2012 - 2103 Ice Front
2012-2013 Tw Data
Ice Thickness Data


B
C
D
E
F
G
H
I
J
K
L
M
N
x = 387 km
Thermal Ice Thickness (m)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
18-Oct-2012
7-Dec-2012
26-Jan-2013
17-Mar-2013
6-May-2013
25-Jun-2013
Simulated
Observed
x = 374.7 km
Thermal Ice Thickness (m)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
18-Oct-2012
7-Dec-2012
26-Jan-2013
17-Mar-2013
6-May-2013
25-Jun-2013
Simulated
Observed
Ice Front Chart
Tw Chart
Ice Thickness Charts
Paste Time Series
Paste Ice

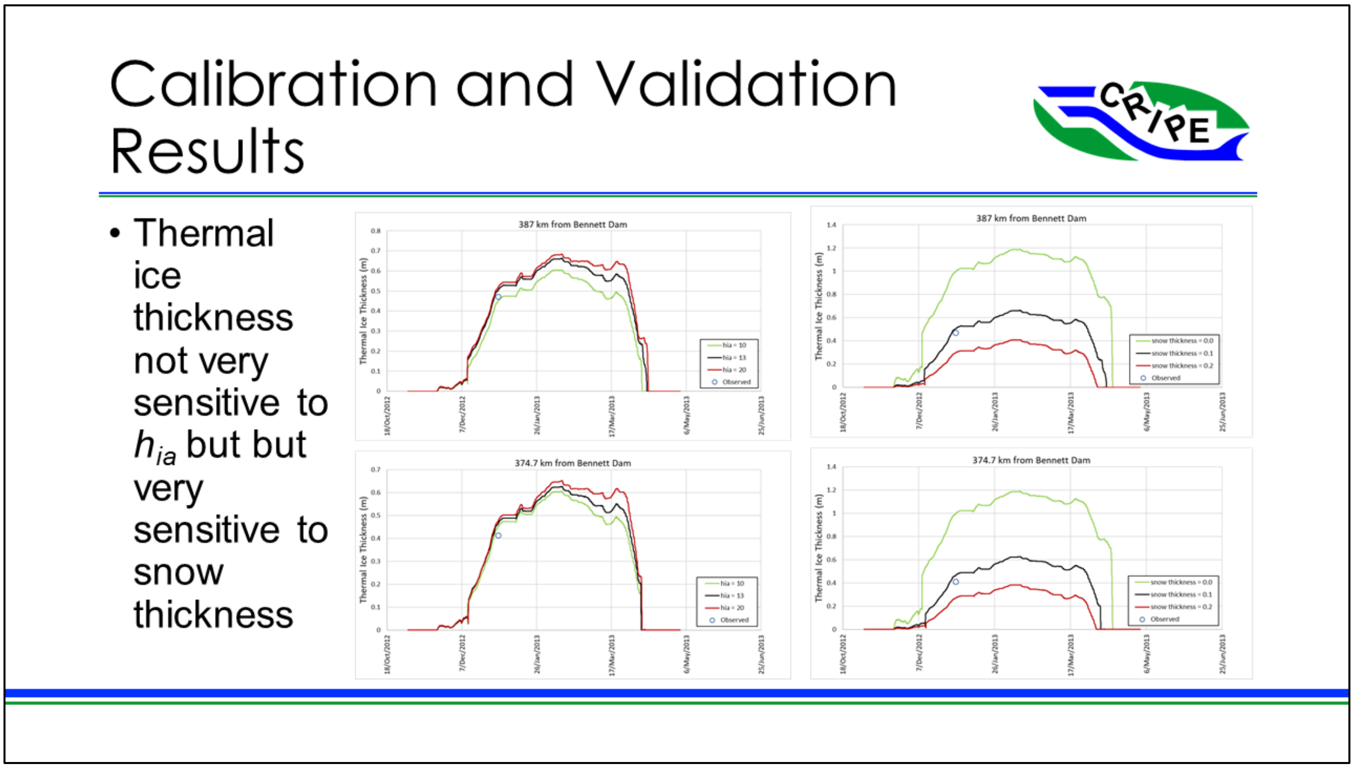
Task 3F: OPTIONAL – Model Validation

1. Open up “**2010-2011 Peace River Validation Results.xlsx**” in the “Working Files” folder to see the results of the validation run with the calibrated parameters.



Calibration and Validation Results

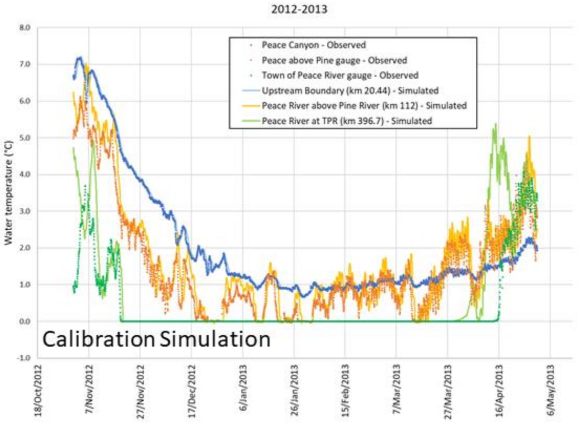
- Peace River Model has been calibrated by adjusting only a few parameters but only 2 seasons and limited data were used
- Calibration parameters would likely change with additional data
- Nodal parameters could be adjusted along the domain but not warranted with limited data set
- Model calibrated without anchor ice in keeping with other calibrated models of the Peace River
- Snow thickness incorporated as a global calibration parameter because thermal ice was too thick without

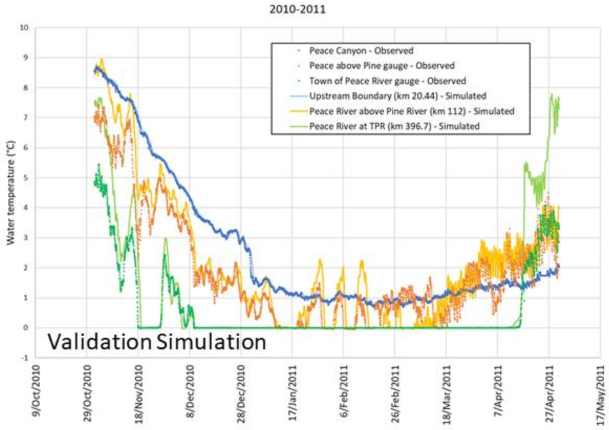


Calibration and Validation Results

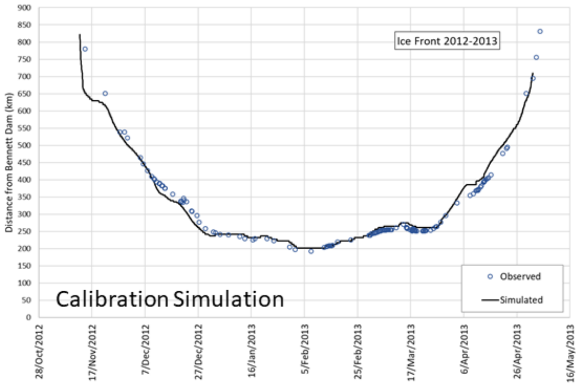
- Thermal ice thickness not very sensitive to h_{ia} but but very sensitive to snow thickness

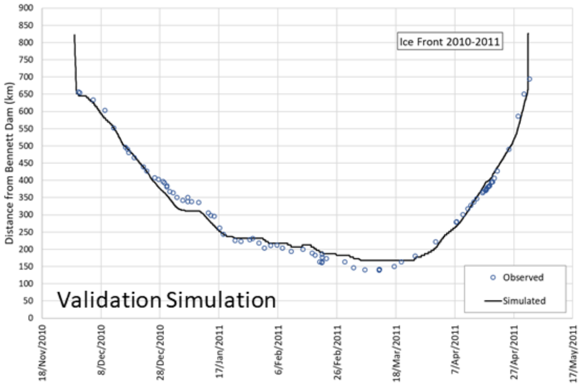
Calibration and Validation Results

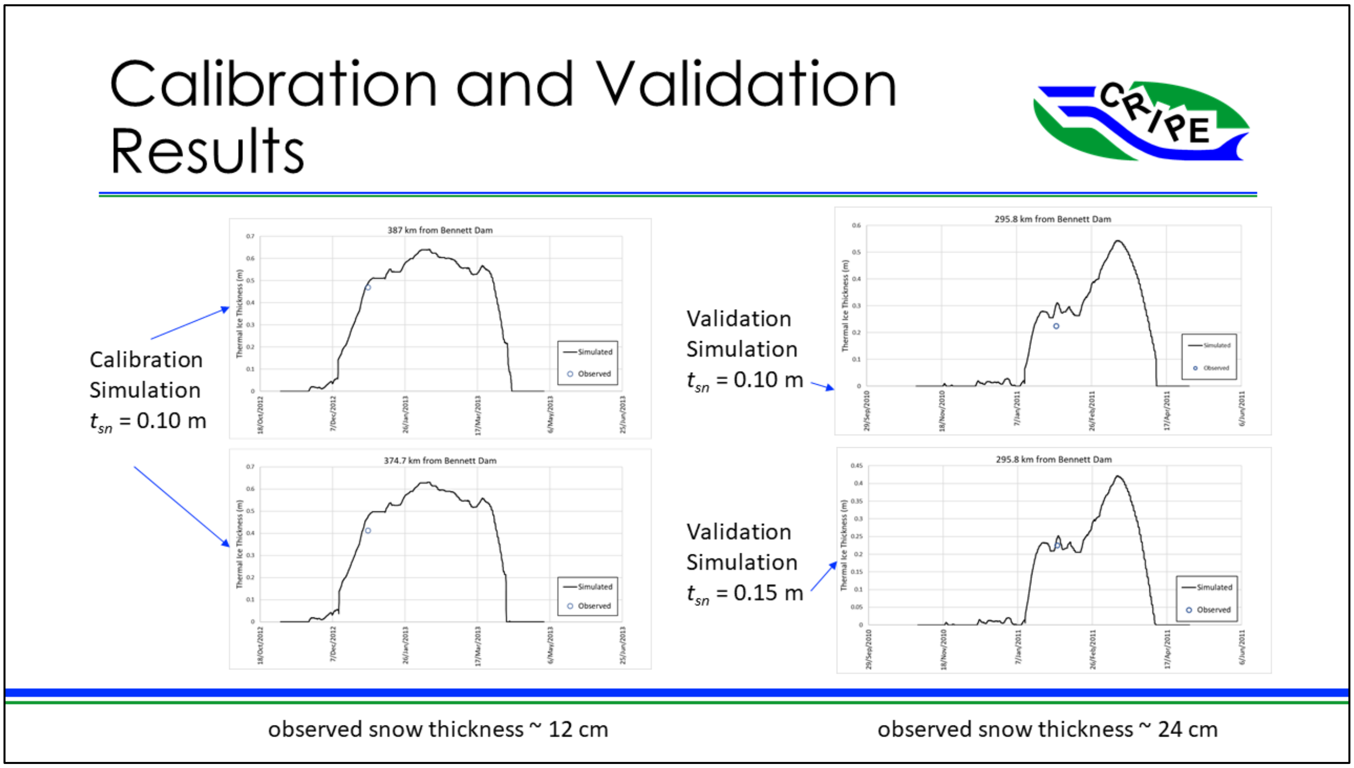




Calibration and Validation Results







Calibration and Validation Results

Calibration Simulation t_{sn} = 0.10 m

Validation Simulation t_{sn} = 0.10 m

Validation Simulation t_{sn} = 0.15 m

observed snow thickness ~ 12 cm

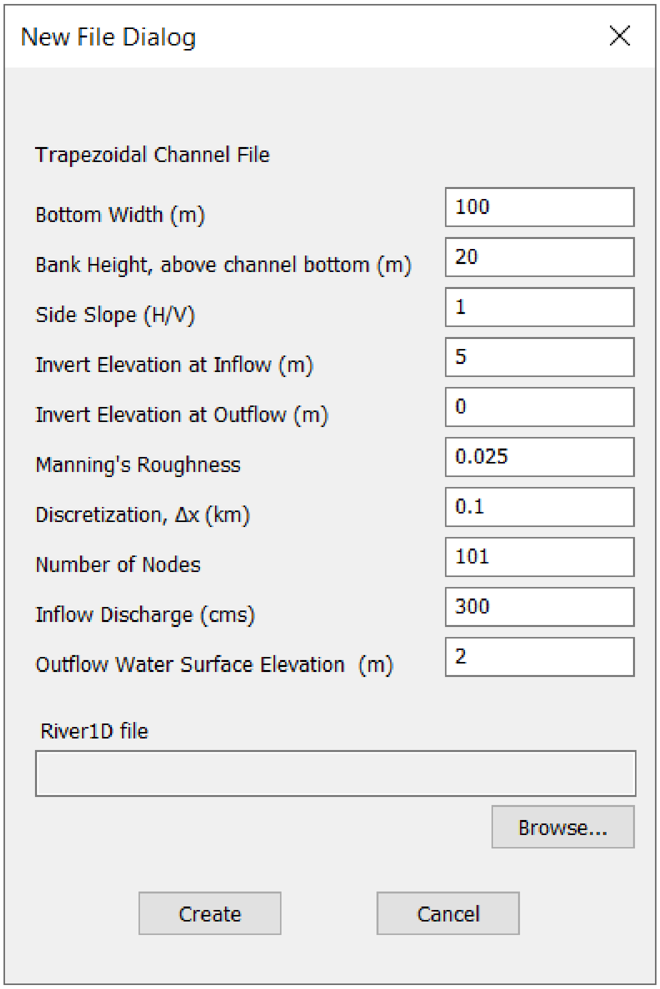
observed snow thickness ~ 24 cm

Module 4: OPTIONAL – Other River1D Features

Task 4A: Starting a New River1D Project using the File Builder

River1D now has a file builder to simplify the process of starting a new project with simple, trapezoidal geometry. To use the file builder:

1. Launch River1D.exe River1D.exe from the desktop, or from “Documents\River1D Peace River Model\River1D”.
2. Go to File and select *‘New’* or click the icon. The ‘New File’ Dialogue will open. Here you can enter simple model parameters to use in generating cross-sections for a trapezoidal channel.
    - If you would like, you can try changing these parameters. However, we will leave the default values for the rest of this tutorial.


New File Dialog

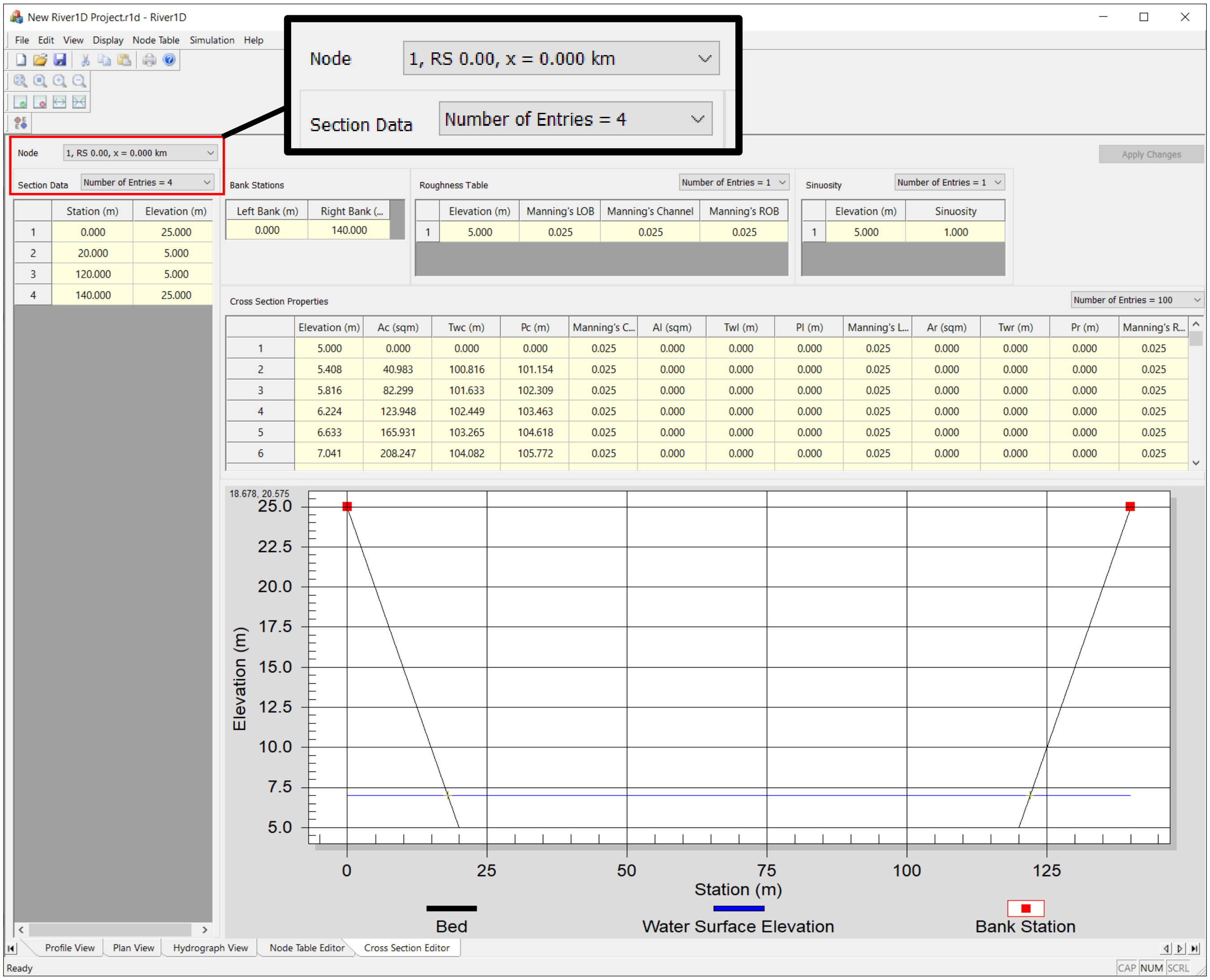
Trapezoidal Channel File

Bottom Width (m): 100
Bank Height, above channel bottom (m): 20
Side Slope (H/V): 1
Invert Elevation at Inflow (m): 5
Invert Elevation at Outflow (m): 0
Manning's Roughness: 0.025
Discretization, Δx (km): 0.1
Number of Nodes: 101
Inflow Discharge (cms): 300
Outflow Water Surface Elevation (m): 2

River1D file

3. Click Browse... to give your new project a name. Navigate to the “Working Files” folder and save your new project as “**New River1D Project.r1d**”.

4. Click Create.
5. On the Profile View tab you will see the model has been generated. You can now run this model to steady state by going to Simulation then selecting *'Steady…'* and clicking Run. The water surface elevation will not change visibly using the default parameters.
6. Try starting another new project. This time, set the "Inflow Discharge (cms)" to 100 instead of 300. Leave all other parameters as the default values.
7. Go to the Profile View tab and run a steady simulation. Note how the decreased discharge with the fixed outflow water surface elevation resulted in a backwater profile.
8. You can now edit this simple geometry using the Cross Section Editor tab in River1D.
    - Individual cross-sections can be selected and the number of data points for each section can be set using the drop-down menus in the top left.
    - The cross-section data can be entered in the tables.
    - Try playing around with the interface to see how the cross-sections change. Once you are done with a cross-section, click Apply Changes in the top right.



Node 1, RS 0.00, x = 0.000 km

Section Data Number of Entries = 4

	Station (m)	Elevation (m)
1	0.000	25.000
2	20.000	5.000
3	120.000	5.000
4	140.000	25.000

Bank Stations

Left Bank (m)	Right Bank (...
0.000	140.000

Roughness Table Number of Entries = 1

	Elevation (m)	Manning's LOB	Manning's Channel	Manning's ROB
1	5.000	0.025	0.025	0.025

Sinuosity Number of Entries = 1

	Elevation (m)	Sinuosity
1	5.000	1.000

Cross Section Properties Number of Entries = 100

	Elevation (m)	Ac (sqm)	Twc (m)	Pc (m)	Manning's C...	Al (sqm)	Twl (m)	Pl (m)	Manning's L...	Ar (sqm)	Twr (m)	Pr (m)	Manning's R...
1	5.000	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.025
2	5.408	40.983	100.816	101.154	0.025	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.025
3	5.816	82.299	101.633	102.309	0.025	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.025
4	6.224	123.948	102.449	103.463	0.025	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.025
5	6.633	165.931	103.265	104.618	0.025	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.025
6	7.041	208.247	104.082	105.772	0.025	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.025

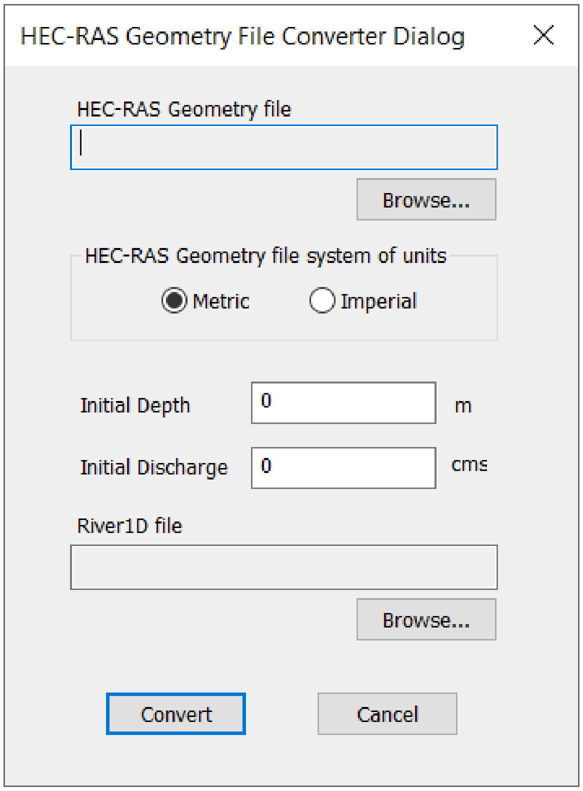
Task 4B: Converting a HEC-RAS File into a River1D File

River 1D has a built-in HEC-RAS Geometry Converter to convert HEC-RAS *.g* files into River1D open water files. However, the *.g* file must meet the following requirements:

- Contain only a single branch of a channel / river
- Cannot contain any structures
- The bed roughness must be defined using the LOB / channel / ROB format.

With a file in this format, the steps are as follows.

1. Go to File and select *'Convert HEC-RAS Geometry File…'* to open the 'HEC-RAS Geometry File Converter' Dialogue.



HEC-RAS Geometry file

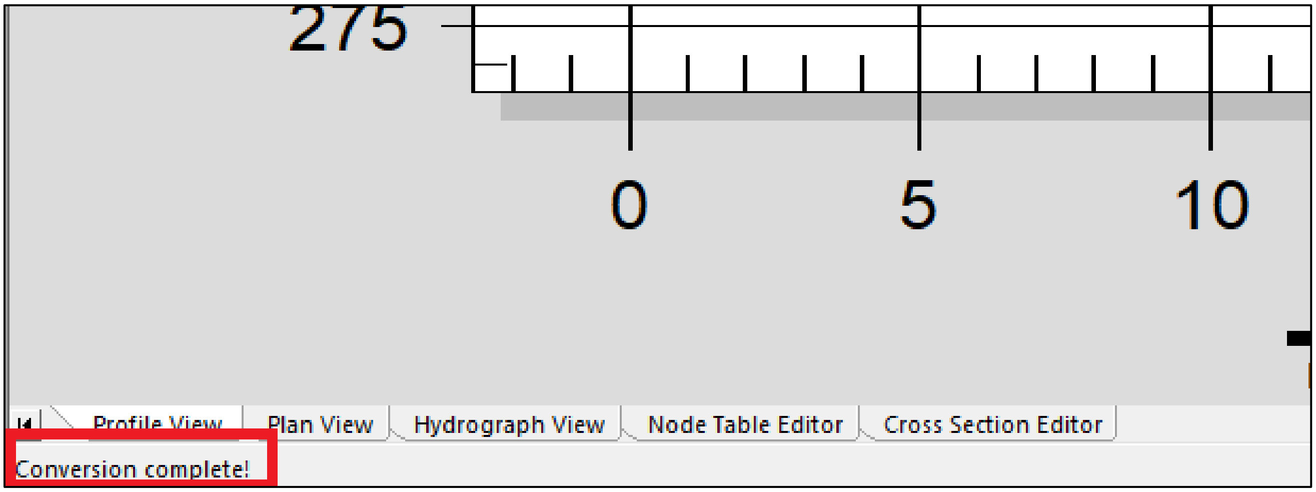
HEC-RAS Geometry file system of units ● Metric ○ Imperial

Initial Depth 0 m

Initial Discharge 0 cms

River1D file

2. Select your HEC-RAS geometry file by clicking Browse... under the 'HEC-RAS Geometry file name' field. Navigate to the location of the file "**ICEJAM_EXAMPLE.g02**" – this is from the HEC-RAS project for the short course. It is also found in the "HEC-RAS" folder. Select it and click Open.
3. Select the system of units for the HEC-RAS geometry file. For this file, it is '*Metric'*.
4. Specify an initial depth (*10* m) and initial discharge (*1600* cms).
5. For the 'River 1D file name' field, click Browse... to navigate to an appropriate folder. Save the converted .r1d file. For this task, save as "**Peace River from HEC-RAS.r1D**".
6. Click Convert.
7. When the file is converted, a message will appear in the bottom left corner of the application 'Conversion complete!'



Conversion complete!

8. Open the converted file.

The converted file should run to steady state. See "**Peace River from HEC-RAS – steady.r1d**".

It can now be converted to a 'Static Ice Conditions' file type and then can be set up to simulate an ice jam. See "**Peace River from HEC-RAS – static ice.r1d**" and "**Peace River from HEC-RAS – static ice jam converged.r1d**".

8. Helpful Resources

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- Beltaos, S. (Ed.) 1995. River Ice Jams. Water Resources Publications, Highlands Ranch, Colorado. 390 pp.
- Beltaos, S. (Ed.) 2008. River Ice Breakup. Water Resources Publications, LLC. 480 pp.
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- Lindenschmidt, K.-E. 2020. River ice processes and ice flood forecasting - a guide for practitioners and students. Springer Nature Switzerland AG. 267 pp.
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- Committee on River Ice Processes and the Environment (CRIPE) Publications and Workshop Proceedings: http://www.cripe.ca/en/publications

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Appendix A: River1D Model Parameters

River1D Ice Process Modelling Parameters

Ice modelling parameter	Default Value	Values in Literature
Density of ice, ρ_i (kg/m³)	917	Lal and Shen (1991)
Heat transfer coefficient, h_{wa} (W/m²/°C)	20	19.7 (Lal and Shen,1991) 15 (Andrishak and Hicks, 2008) 14 (Howley et al., 2020) 20 (Blackburn and She, 2019; Timalsina et al., 2013; Calkins, 1984) 8 – 20 (Andres, 1988)
Heat transfer coefficient, h_{ia} (W/m²/°C)	20	12.8 (Shen, 2005) 12.2 (Malenchak, 2011) 12 (Howley et al., 2020) 10 – 20 (Ashton, 2011)
Frazil seeding concentration, C_{fo}	0.00001	0.00001 (Blackburn and She, 2019)
Typical frazil particle thickness, d_e (m)	0.0003	0.0003 (Wang, et al., 1995) 0.00013 (Malenchak, 2011)
Typical frazil particle radius, r_o (m)	0.001	0.001 (Wang et al., 1995; Malenchak, 2011)
Nusselt number for typical suspended frazil particle, N_u^f	4.0	4.0 (Wang et al., 1995; Malenchak, 2011)
Coefficient of turbulent heat exchange, α_{wi} (Ws$^{0.8}$/m$^{2.6}$/°C)	1187	1187 (Ashton, 1973; Andrishak and Hicks, 2008)
Rate of frazil rise, η (m/s)	0.0001	0.001(Wang et al., 1995; Howley et al., 2020) 0.0001 (Andrishak and Hicks, 2008) 0.0004 (Jasek et al., 2011) 0.00009 (Timalsina et al., 2013)

Ice modelling parameter	Default Value	Values in Literature
Rate of surface ice re-entrainment, β_{re} (1/s)	0.00001	0.00001 (Wang et al., 1995; Malenchak, 2011)
Re-entrainment velocity threshold, U_{i_re} (m/s)	1.5	1.5 (Blackburn and She, 2023)
Porosity of frazil slush layer, p_f	0.4	0.5 (Andrishak and Hicks, 2008) 0.4 (Lal and Shen, 1991; Wang et al., 1995) 0.6 (Howley et al., 2020)
New frazil pan thickness, t'_f (m)	0.3	0.3 (Andrishak and Hicks, 2008; Blackburn and She, 2019) 0.2 (Timalsina et al., 2013) 0.23 (Jasek et al., 2011) 0.14 (Howley et al., 2020)
Solid ice initial thickness, t'_{si} (m)	0.001	0.001 (Lal and Shen, 1991)
Water albedo	0.15	0.15 (Howley et al., 2020) 0.05 – 0.15 (Hicks, 2016)
Ice cover albedo	0.5	0.10 – 0.46 (snow free) (Bolsenga, 1969) 0.4 – 0.9 (snow) (Hicks, 2016)
Snow thickness (m)	0	
Frazil particle shape factor, F	1.0	1.00 ± 0.03 (Beltaos, 2013) 1.0 (Shen and Wang, 1995)
Average diameter of frazil granules in cover load, d_f (m)	0.01	0.01 (Shen and Wang, 1995) 0.002 (Malenchak, 2011)
Critical flow strength for under-cover frazil transport, Θ_c	0.041	0.041 (Shen and Wang, 1995)

Ice modelling parameter	Default Value	Values in Literature
Porosity of anchor ice, p_a	0.4	0.4 (Malenchak, 2011)
Frazil accretion rate, γ (m/s)	0.00001	0.000001 (Wang et al., 1995) 0.000005-0.00025 (Malenchak, 2011) 0.0001 (Timalsina et al., 2013) 0.0 (Jasek et al., 2011)
Fraction of bed covered by anchor ice, C_{an}	0.25	0.25 (Blackburn and She, 2019)
Bed material average diameter, d_s (m)	0.05	0.05 (Blackburn and She, 2019)
Bed material density, ρ_s (kg/m^3)	2650	2650 (Malenchak, 2011)
Border ice equation coefficient, a	14.1	14.1 (Michel et al., 1982)
Border ice equation coefficient, b	1.08	1.08 (Michel et al., 1982)
Border ice equation coefficient, d	-0.93	-0.93 (Michel et al., 1982)
Border ice equation coefficient, e	0	
Maximum fraction of channel covered by border ice, f_{bmax}	0.7	0.7 (Blackburn and She, 2019) 0.75 (Howley et al., 2020)
Maximum velocity for dynamic border ice growth, U_{cr} (m/s)	1.2	1.2 (Michel et al., 1982) 0.8 (Howley et al., 2020)
Maximum Froude number for juxtaposition, F_{r_jux}	0.06	0.06 (Lal and Shen, 1991) 0.04 (Wang et al., 1995)

Ice modelling parameter	Default Value	Values in Literature
Maximum Froude number for ice cover progression, F_{r_max}	0.09	0.08 to 0.13 (Ashton, 1986) 0.09 (Lal and Shen, 1991) 0.094 (Calkins, 1984) 0.08 (Timalsina et al., 2013) 0.09 (Wang et al., 1995) 0.13 (Howley et al., 2020)
Space between ice floes in newly formed cover, p_c	0.4	0.4 (Shen, 2016) 0.6 (Howley et al., 2020; Jasek et al., 2011)
Composite jam stress parameter, μ	1.28	1.28 (Pariset and Hausser, 1961; Pariset et al., 1966; Lal and Shen, 1991; Wang et al., 1995)
Ice cohesion, τ_c (Pa)	0	700 (Calkins, 1984) 980 (Lal and Shen, 1991) 800 (Wang et al., 1995)

Appendix A References

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Appendix B: River Ice Model Summaries

CGU HS Committee on River Ice Processes and the Environment
Short Course on River Ice Modelling
Canmore, Alberta, Canada, July 13, 2023

Definitions to Accompany Model Summaries

Steady / Unsteady (Ice Processes): Refers to whether the model introduces ice into the model at a boundary and/or calculates ice volumes and accumulations within the model domain in a time-varying fashion.

Steady / Unsteady (Hydraulics): Refers to whether the model performs time-varying hydraulic calculations based on time-varying flows at a boundary.

Network Representation: Refers to capabilities to represent multiple channels, nodes, etc.

Numerical Scheme: Refers to algorithmic descriptions that yield a solution to one or more mathematical equations.

Water Cooling**:** Refers to the process of lowering the temperature of water to near/at/below its freezing point.

Frazil and Ice Floe Generation: Refers to formation of ice (frazil ice, frazil pans, skim ice, etc.) as a result of effectively supercooled conditions.

Border Ice and Static Ice Cover*:* Border ice refers to ice that originates at the channel banks and grows laterally into the channel (either thermally, or mechanically due to deposition/buttering). Similar to border/skim ice, static ice cover refers to a thermally grown ice cover that spans the entire water body.

Dynamic Surface Ice Cover Formation: Refers to the formation of either a surface jam, wide channel jam, or narrow channel jam.

Thermal Ice Growth/Decay**:** Refers to the thickening/thinning of an ice cover, and can include surface ice covers, border ice, static ice, or even ice floes.

Undercover Deposition and Transport of Ice**:** Refers to the submergence, depositing, and movement of ice floes under a static ice cover or dynamic surface ice cover. This can lead to the formation of a hanging dam.

Anchor Ice**:** Refers to ice that is attached to the bed of a channel or other submerged surface.

Ice Jam Seepage and Ice Cover Seepage Flow**:** Refers to water conveyance through the ice units that comprise an ice cover.

CRISSP1D

Developer(s): Clarkson University
Initial Year of Development: 2005
Current Status of Development: Ongoing
Version Number / Date: 2005
Associated Models: RICE, RICEN

Proprietary Status / Availability for Use: Proprietary
Key Contact / Access Link: Dr. Hung Tao Shen (Clarkson University)
Model Dimension: One-Dimensional
Computational Method: Finite Difference (Hydraulics) and Lagrangian (Thermal/Ice)

MODEL DESCRIPTION		
Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Unsteady
Steady / Unsteady (Hydraulics)		Unsteady
Network Representation		Can model channel networks by assuming equal water levels at junctions
Numerical Scheme(s)		Weighted Four-Point Implicit Scheme, Local Partial Inertia (LPI) for model stability in mixed flow regimes (Potok & Quinn, 1979).
Simulation Capabilities	Water Cooling	Heat loss from water column calculated using linear heat-transfer approach, or detailed energy budget approach. Model simulates supercooling (accounts for heat flux between water and suspended frazil ice).
	Frazil and Ice Floe Generation	Volumetric ice production determined numerically, model simulates suspended frazil ice and frazil ice rise.
	Border Ice and Static Ice Cover	Border and skim ice simulated using criteria proposed by Matoušek (1984a). Model also includes dynamic border ice treatment.
	Dynamic Surface Ice Cover Formation	Given that the Froude number is less than a user-defined maximum Froude number, ice cover progression will occur either via: (1) juxtaposition (if Froude number less than user-defined threshold for juxtaposition), or (2) by either hydraulic thickening and mechanical thickening (Pariset and Hausser, 1961), depending on which approach yields a larger ice thickness (Shen, 2005).
	Thermal Ice Growth/Decay	Both thermal thickening and thinning of an ice cover is represented.
	Undercover Deposition and Transport of Ice	Deposition and erosion of under ice deposits simulated based on ice transport capacity developed by Shen and Wang (1995).
	Anchor Ice	Model simulates anchor ice formation, decay, and release (Wang and Shen, 1993), released anchor ice assumed to become part of surface ice run.
	Ice Jam Seepage and Ice Cover Seepage Flow	N/A
Other features, processes, notable characteristics		Model employs stream-tube method to calculate water velocities.
Examples of Recent Application(s)		St. Lawrence River, Niagara River, Yellow River, Ohio River, etc.

Notes:
N/A = no simulation capability

CRISSP2D

Developer(s): Clarkson University, University of Manitoba, Manitoba Hydro
Initial Year of Development: 2004
Current Status of Development: Ongoing
Version Number / Date: 1.3
Associated Models: DynaRICE, RICE, RICEN, CRISSP1D

Proprietary Status / Availability for Use: Proprietary / Available on request
Key Contact / Access Link: Dr. Jarrod Malenchak (Manitoba Hydro)
Model Dimension: Two-Dimensional
Computational Method: Finite Element, Discrete Parcel Method

MODEL DESCRIPTION

Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Unsteady
Steady / Unsteady (Hydraulics)		Unsteady (subcritical, supercritical, and transitional flows)
Network Representation		Fully capable of modelling channel networks and irregular channel geometries using a triangular finite element mesh.
Numerical Scheme(s)		Hydrodynamics – Streamline Upwind Petrov-Galerkin formulation (Liu and Shen, 2003); Ice Dynamics – Lagrangian Discrete Parcel Method with Smooth Particle Hydrodynamics (Shen et al, 2000)
Simulation Capabilities	Water Cooling	Heat loss from water column calculated using linear heat-transfer approach, or detailed energy budget approach. Model simulates supercooling conditions (accounts for heat flux between water and suspended frazil ice).
	Frazil and Ice Floe Generation	Volumetric ice production determined numerically, model simulates suspended frazil ice generation and rise to contribute to surface ice layer.
	Border Ice and Static Ice Cover	Border and skim ice simulated using criteria proposed by Matoušek (1984a). Model also includes dynamic border ice treatment Michel (1980).
	Dynamic Surface Ice Cover Formation	Properties of ice ‘parcels’ are calculated using Smoothed Particle Hydrodynamics, which calculate applied forces as parcels converge and jam. Both applied and resistance forces are represented by the momentum equation, with internal stresses on ice parcels calculated using a Kelvin-Voigt viscoelastic constitutive model (Ji et al., 2005) with a Mohr-Coulomb yield criterion.
	Thermal Ice Growth/Decay	Both ice cover thickening and ice cover thinning represented (multi-layer formulation which includes snow, slush, snow ice, black ice, and frazil slush layers), based on method described by Shen & Lal (1986).
	Undercover Deposition and Transport of Ice	When the local Froude number is greater than the user-defined Froude number criteria, incoming ice floes will submerge under an ice cover to become a mobile undercover ice layer. Deposition and erosion of under ice deposits simulated based on ice transport capacity developed by Shen & Wang (1995).
	Anchor Ice	Model simulates anchor ice formation, decay, and release (Wang & Shen, 1993; Malenchak, 2011).
	Ice Jam Seepage and Ice Cover Seepage Flow	Flow through the surface ice layer is modelled using a seepage coefficient (related to porosity, shape, and size of the ice floes).
Other features, processes, notable characteristics		Simulation of the initiation of an ice jam primarily based on convergence of surface ice floes and without user intervention; Capable of simulating ice jam forces on river banks and in-water structures; Reach specific ice cover breakup can be automatic (water level or discharge change criteria) or at a user specified time and location.
Examples of Recent Application(s)		Upper Nelson River (Lees et al., 2023), Lower Vistula River (Kolerski & Raban, 2022), Lower Nelson River (Peters, 2021), Dauphin River (Wazney, 2018)

HEC-RAS

Developer(s): Hydrologic Engineering Centre of the US Army Corps of Engineers
Initial Year of Development: 1995
Current Status of Development: Ongoing
Version Number / Date: Version 6.4 Beta (June 2023)
Associated Models: ICEJAM

Proprietary Status / Availability for Use: Model in the public domain, currently available for use
Key Contact / Access Link: https://www.hec.usace.army.mil/software/hec-ras/
Model Dimension: One-Dimensional
Computational Method: Finite Difference

MODEL DESCRIPTION

Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Steady State (ice modelling only[1])
Steady / Unsteady (Hydraulics)		Steady State (ice modelling only[1])
Network Representation		A continuous ice jam and/or ice cover cannot be calculated across junction nodes
Numerical Scheme(s)		Steady flow: Standard step backwater method Unsteady flow: four-point implicit scheme
Simulation Capabilities	Water Cooling	Water temperature can be simulated when the temperature is above 0°C based on a full energy balance at the water surface. Once the water temperature reaches 0°C further declines in water temperature cannot be modeled.
	Frazil and Ice Floe Generation	N/A
	Border Ice and Static Ice Cover	Thickness and roughness of a static ice cover can be user specified at each river section.
	Dynamic Surface Ice Cover Formation	Only wide-channel jams can be simulated (using an initial condition of a user-specified minimum thickness at each cross-section).
	Thermal Ice Growth/Decay	N/A
	Undercover Deposition and Transport of Ice	N/A
	Anchor Ice	N/A
	Ice Jam Seepage and Ice Cover Seepage Flow	N/A
Other features, processes, notable characteristics		Wide-channel jam solution approach based on Flato and Gerard (1986). The ice jam roughness can be user-specified or automatically estimated based on ice jam thickness.
Examples of Recent Applications		Peace River and Athabasca Rivers (Hatch and Golder Associates, 2022; Northwest Hydraulic Consultants, 2021a and 2021b). Ice Management Operations on the Pend Oreille River (Giovando et al, 2019). Several case studies summarized in Daly & Vuyovich (2003). See also Zufelt (2005).

Notes:

N/A = no simulation capability

1. HEC-RAS modelling system has many capabilities, but ice-cover and ice jam modelling are restricted to steady-state, one-dimensional simulations only.

ICEDYN

Developer(s): Hatch
Initial Year of Development: 1973
Current Status of Development: Ongoing
Version Number / Date: not available
Associated Models: ICESIM, ICESIMAT, JAMSIM

Proprietary Status / Availability for Use: Proprietary
Key Contact / Access Link: Joe Groeneveld (Hatch)
Model Dimension: One-Dimensional
Computational Method: Finite Difference

MODEL DESCRIPTION		
Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Quasi-Steady
Steady / Unsteady (Hydraulics)		Steady (ICESIM), Unsteady (ICEDYN)
Network Representation		Single channel only
Numerical Scheme(s)		Weighted Four-Point Implicit Scheme
Simulation Capabilities	Water Cooling	Heat transfer uses daily temperatures as proposed by Michel (1971). Equations can be customized to represent specific climatological settings. No capability to directly utilize full energy budget.
	Frazil and Ice Floe Generation	Volumetric ice production estimated analytically (Ashton, 1986).
	Border Ice and Static Ice Cover	Border ice extent based on ice growth equations (Newbury, 1968), no explicit skim ice calculations, user can specify static ice cover (extent and thickness).
	Dynamic Surface Ice Cover Formation	Simulates both wide channel and narrow channel jams (Michel, 1971).
	Thermal Ice Growth/Decay	Applies heat-transfer and degree-days coefficients (Ashton, 1986) to simulate ice growth and decay.
	Undercover Deposition and Transport of Ice	Undercover frazil accumulation is governed by user input deposition and erosion velocity thresholds (Michel, 1971). Advancement by juxtaposition is governed by a user input limiting Froude number.
	Anchor Ice	ICEDYN has a capability to include a user specified anchor ice growth at a specified series of cross sections through bed elevation modification.
	Ice Jam Seepage and Ice Cover Seepage Flow	N/A
Other features, processes, notable characteristics		Sediment transport calculations included[2]. The model is also able to simulate the temporal smoothing of an ice cover/ice jam. The JAMSIM model includes the capability to identify possible ice jam lodgment locations. It does so by simulating the development of a jam assuming that any cross section in the reach could form the toe of the jam. Jam profiles are simulated and ice jam toe forces are computed for each possible toe location. Those with particularly low toe forces are considered to be possible candidate locations for an ice jam.
Examples of Recent Application(s)		Lower Churchill River (Zare et al., 2019), Nelson River, Saint John River, Yukon River, Churchill River, Saskatchewan River, Boyne River

Notes:
N/A = no simulation capability
1. Growth/Decay calculations are only applicable for ICESIMAT.
2. Sediment transport calculations are only applicable for ICESIMAT.

ICEJAM

Developer(s): Flato and Gerard
Initial Year of Development: 1986
Current Status of Development: None
Version Number / Date: Version 1.5, March 1987
Associated Models: None

Proprietary Status / Availability for Use: Available for Use (No Longer Supported)
Key Contact / Access Link: None / Flato 1988 (MSc Thesis, Appendix B)
Model Dimension: One-Dimensional
Computational Method: Finite Difference

MODEL DESCRIPTION

Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Steady
Steady / Unsteady (Hydraulics)		Steady
Network Representation		Single channel only
Numerical Scheme(s)		Iterative calculation procedure. Upstream-to-downstream: Ice jam thickness profile computation (solving ice jam stability equation) by *forward difference* scheme. Downstream-to-upstream: Gradually varied flow profile computation by a *standard step* algorithm with previously calculated ice jam thickness profile.
Simulation Capabilities	Water Cooling	N/A
	Frazil and Ice Floe Generation	N/A
	Border Ice and Static Ice Cover	N/A
	Dynamic Surface Ice Cover Formation	N/A
	Thermal Ice Growth/Decay[1]	N/A
	Undercover Deposition and Transport of Ice	N/A
	Anchor Ice	N/A
	Ice Jam Seepage and Ice Cover Seepage Flow	N/A
Other features, processes, notable characteristics		Calculates thickness in the toe region using a maximum velocity criterion where ice is "floated" up from the downstream boundary in the upstream direction until ice jam stability criterion are satisfied.
Examples of Recent Applications		None

Notes:
N/A = no simulation capability

JJT[1,2] – The Finnish Ice Model

Developer(s): The Finnish River Ice Project (Mikko Huokuna) for Association of Finnish Power Stations and National Board of Waters, Finland
Initial Year of Development: 1985
Current Status of Development: Only minor changes since the 1990s.
Version Number / Date: 2019 (For real-time use)

Proprietary Status / Availability for Use: Not currently publicly-available. Plans to make it available in the future.
Key Contact / Access Link: Mikko Huokuna mikko.huokuna@syke.fi and Niklas Dahlberg, Finnish Environment Institute
Model Dimension: One-Dimensional
Computational Method: Finite Difference

MODEL DESCRIPTION		
Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Unsteady
Steady / Unsteady (Hydraulics)		Unsteady[3]
Network Representation		Can work in multi-channel environments.
Numerical Scheme(s)		Weighted Four-Point Implicit Scheme
Simulation Capabilities	Water Cooling	The heat exchange between water and air is calculated using a detailed energy budget approach. A simpler method is also available to the user.
	Frazil and Ice Floe Generation	In addition to frazil ice floe generation within the model (based on user-specified thickness), moving skim ice is included in the model according to the method of Matoušek (1984b). The presence of skim ice also changes the heat transfer.
	Border Ice and Static Ice Cover	Border ice simulated using criteria proposed by Matoušek (1984b).
	Dynamic Surface Ice Cover Formation	Narrow ice jam progression occurs when border ice or moving surface ice bridges across the river (based on empirical criteria and user-specified thresholds – top width, border ice conditions, flow conditions, and floe thickness), or where an ice boom location is specified. Wide channel ice jams are not included in the model.
	Thermal Ice Growth/Decay	Both ice cover thickening and ice cover thinning represented (includes snow, slush, snow ice, black ice, and frazil slush layers), based on method described by Shen & Lal (1986).
	Undercover Deposition and Transport of Ice	Incoming ice floes are submerged when a critical Froude number (calculated or user-specified value) at the upstream edge of the ice cover is exceeded. Erosion of deposited frazil occurs when the under-ice water velocity exceeds a user-input critical velocity.
	Anchor Ice	N/A
	Ice Jam Seepage and Ice Cover Seepage Flow	N/A
Other features, processes, notable characteristics		Heat flux from the bed can be input as a constant value.
Examples of Recent Applications		Kokemäenjoki River, Finland (Houkuna et al. 2021)

Notes:

N/A = no simulation capability

1. The name JJT comes from the Finnish “Jokijää tutkimus” which is the name of the original project.
2. JJT was originally based on the model code of Shen and Yapa (1985).
3. Supercritical flow is forced to be subcritical with a Froude number of 0.98 to avoid trans-critical flow.

MIKE-ICE

Developer(s): Hydro-Quebec, the LaSalle Consulting Group and the Danish Hydraulic Institute (DHI)
Current Status of Development: Last updated in 2013

Proprietary Status / Availability for Use: Proprietary. Requests to access and use MIKE-ICE have been granted by Hydro-Quebec and DHI in the past.
Model Dimension: One-Dimensional
Computational Method: Finite Differences
Version Number / Date: 2013, Works best with MIKE2008 in a Windows XP Environment

<table>
<tr><th colspan="3"><i>MODEL DESCRIPTION</i></th></tr>
<tr><th colspan="2">Attribute</th><th>Description / References</th></tr>
<tr><td colspan="2">Steady / Unsteady (Ice Processes)</td><td>Unsteady</td></tr>
<tr><td colspan="2">Steady / Unsteady (Hydraulics)</td><td>Unsteady</td></tr>
<tr><td colspan="2">Network Representation</td><td>Single channel only</td></tr>
<tr><td colspan="2">Numerical Scheme(s)</td><td>Information not available</td></tr>
<tr><td rowspan="8"><i>Simulation Capabilities</i></td><td>Water Cooling</td><td>Detailed energy budget calculations available, supercooling simulated</td></tr>
<tr><td>Frazil and Ice Floe Generation</td><td>Simulates frazil ice generation and frazil ice rise</td></tr>
<tr><td>Border Ice and Static Ice Cover</td><td>Border ice simulated based on cooling rate and maximum flow velocity criteria (Timalsina et al., 2013)</td></tr>
<tr><td>Dynamic Surface Ice Cover Formation</td><td>Juxtaposition simulated as a function of flow velocity, Froude Number, and ice thickness.</td></tr>
<tr><td>Thermal Ice Growth/Decay</td><td>Model can simulate ice growth and melt</td></tr>
<tr><td>Undercover Deposition and Transport of Ice</td><td>Undercover accumulations of ice simulated using a critical velocity approach</td></tr>
<tr><td>Anchor Ice</td><td>Can simulate anchor ice processes (formation, decay, and release)</td></tr>
<tr><td>Ice Jam Seepage and Ice Cover Seepage Flow</td><td>Can simulate ice jam seepage</td></tr>
<tr><td colspan="2">Other features, processes, notable characteristics</td><td>Model contains 2 modules: one for ice generation/transport/accumulation and one for ice jams. Interfaces with the MIKE model through MIKE ECO Lab.</td></tr>
<tr><td colspan="2">Examples of Recent Applications</td><td>Romaine River, Quebec (Theriault, 2011), Orkla River, Norway (Timalsina et al, 2013; Gebre et al. 2014)</td></tr>
</table>

Notes:
N/A = no simulation capability

River1D

Developer(s): University of Alberta
Initial Year of Development: 1990
Current Status of Development: Ongoing
Version Number / Date: July 28, 2021
Associated Models: CDG1D

Proprietary Status / Availability for Use: Available for Use
Key Contact / Access Link: Yuntong She (University of Alberta) (www.riverice.ca/modeling)
Model Dimension: One-Dimensional
Computational Method: Finite Element

MODEL DESCRIPTION		
Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Unsteady
Steady / Unsteady (Hydraulics)		Unsteady
Network Representation		Single channel and multi-channel networks[1]
Numerical Scheme(s)		Characteristic Dissipative Galerkin (hydraulics) and Streamline Upwind Petrov-Galerkin (ice processes) finite element methods.
Simulation Capabilities	Water Cooling	Supercooling calculated based on air temperature and net solar radiation at user specified time interval using linear heat-transfer (Andrishak and Hicks, 2008). No capability to utilize full energy budget[2].
	Frazil and Ice Floe Generation	Analytical thermal frazil production based on Shen et al. (1995), no skim ice floe capabilities.
	Border Ice and Static Ice Cover	Border ice calculations include both static (Matoušek, 1984a) and dynamic growth (Michel et al., 1982); user can specify static ice cover.
	Dynamic Surface Ice Cover Formation	Ice cover progression rate considers both wide channel and narrow channel jam calculations[3].
	Thermal Ice Growth/Decay	Applies heat-transfer coefficients. Rates of heat exchange based on Andrishak and Hicks (2008).
	Undercover Deposition and Transport of Ice	Undercover frazil transport and accumulation based on Shen and Wang (1995).
	Anchor Ice	Anchor ice growth and decay based on Shen (2010). Includes mechanical and thermal release.
	Ice Jam Seepage and Ice Cover Seepage Flow	N/A
Other features, processes, notable characteristics		Separate module for calculating steady state ice jam profiles in single channel and multi-channel networks. Cohesive sediment transport, contaminant transport, and water quality simulation capabilities for ice-affected rivers currently under development.
Examples of Recent Applications		Ice processes - North Sask. River, AB (Howley et al., 2020; Yang et al., 2021); Alta River, Norway (Alfredsen and Saha, 2021); Susitna River, Alaska (Blackburn and She, 2019); Steady state ice jam profile modelling - Hay River Delta, NWT (Blackburn and She, 2023)

Notes:

N/A = no simulation capability

1. For open water and steady ice conditions (cover or jam) only
2. A version with a full energy budget capabilities (Yang et al., 2023) has been developed and is available upon request for research purposes
3. Does not presently consider ice cover consolidation after initial formation

RIVICE

Developer(s): KGS Group, Environment Canada, University of Saskatchewan
Initial Year of Development: 2003
Current Status of Development: Ongoing
Version Number / Date: 2013
Associated Models: ONE-D, RIVJAM, ICEPRO

Proprietary Status / Availability for Use: Available for Use
Key Contact / Access Link: Prof. Karl-Erich Lindenschmidt (University of Saskatchewan) (http://giws.usask.ca/rivice/)
Model Dimension: One-Dimensional
Computational Method: Finite Difference

MODEL DESCRIPTION		
Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Unsteady (incoming ice volumes permitted)
Steady / Unsteady (Hydraulics)		Unsteady (limited to subcritical conditions)
Network Representation		Cannot perform simulations where multiple reaches are connected to a node
Numerical Scheme(s)		Weighted Four-Point Implicit Scheme
Simulation Capabilities	Water Cooling	Heat loss from water column calculated using linear heat-transfer approach, or detailed energy balance approach (from water quality algorithms in ONE-D). Water temperature cooled down to (and not past) the freezing point.
	Frazil and Ice Floe Generation	Volumetric ice production estimated analytically, no representation of suspended ice (only surface ice).
	Border Ice and Static Ice Cover	Border ice can be defined by: user-input (based on maximum border ice width, and time required to reach maximum border ice width), Newbury method (1968), Matoušek method (1984a).
	Dynamic Surface Ice Cover Formation	Occurrence of ice cover shoving assessed by applied (Michel, 1971; Pariset et al., 1966) and resistive (Michel, 1971) ice cover force; juxtaposition simulated; ability to account for cohesion to river banks.
	Thermal Ice Growth/Decay	No capability for thermal thickening of an ice cover (Lindenschmidt, 2017), ice cover thinning represented.
	Undercover Deposition and Transport of Ice	Deposition and erosion of under ice based on: (1) user-defined velocity, (2) limit based on Meyer-Peter equation, (3) deterministic Froude number.
	Anchor Ice	User-specified representation of anchor ice.
	Ice Jam Seepage and Ice Cover Seepage Flow	N/A
Other features or processes (e.g., aufeis, sediment transport)		Ice cover roughness represented using: (1) KGS method stemming from Nezhikhovskiy method (2) Beltaos method, (3) user-defined Manning's 'n' value; limited model performance for slow velocities (< 0.3 m/s).
Example Application(s)		Athabasca River (Lindenschmidt, 2023), Slave River (Zhang et al., 2022), Red River (Williams et al., 2021), Saint John River (Das et al., 2023), Peace River (Lindenschmidt et al., 2016), Dauphin River (Lindenschmidt et al., 2012)

Notes:
N/A = no simulation capability

RIVJAM

Developer(s): Spyros Beltaos and Jonathan Wong
Initial Year of Development: 1986
Current Status of Development: Not currently in development
Version Number / Date: None
Associated Models: None

Proprietary Status / Availability for Use: Available for Use
Key Contact / Access Link: Spyros Beltaos / National Water Research Institute
Model Dimension: One-Dimensional
Computational Method: Direct solution of two first order partial differential equations by Beltaos and Wong (1986).

<table>
<tr><th colspan="3">MODEL DESCRIPTION</th></tr>
<tr><th colspan="2">Attribute</th><th>Description / References</th></tr>
<tr><td colspan="2">Steady / Unsteady (Ice Processes)</td><td>Steady</td></tr>
<tr><td colspan="2">Steady / Unsteady (Hydraulics)</td><td>Steady</td></tr>
<tr><td colspan="2">Network Representation</td><td>Single channel only</td></tr>
<tr><td colspan="2">Numerical Scheme(s)</td><td>Direct solution of two first order partial differential equations by a Runge-Kutta solution technique.</td></tr>
<tr><td rowspan="8">Simulation Capabilities</td><td>Water Cooling</td><td>N/A</td></tr>
<tr><td>Frazil and Ice Floe Generation</td><td>N/A</td></tr>
<tr><td>Border Ice and Static Ice Cover</td><td>N/A</td></tr>
<tr><td>Dynamic Surface Ice Cover Formation</td><td>N/A</td></tr>
<tr><td>Thermal Ice Growth/Decay</td><td>N/A</td></tr>
<tr><td>Undercover Deposition and Transport of Ice</td><td>N/A</td></tr>
<tr><td>Anchor Ice</td><td>N/A</td></tr>
<tr><td>Ice Jam Seepage and Ice Cover Seepage Flow</td><td>Yes</td></tr>
<tr><td colspan="2">Other features, processes, notable characteristics</td><td>The RIVJAM model is unique in that it allows for seepage flow through the interstices of the ice. Thus, allowing the model to predict grounded toe conditions.</td></tr>
<tr><td colspan="2">Examples of Recent Applications</td><td>Peace-Athabasca delta (2003)</td></tr>
</table>

Notes:
N/A = no simulation capability

SIMGLACE

Developer(s): S. Petryk of Rousseau, Sauve, Warren, Inc.
Initial Year of Development: 1977
Current Status of Development: Not currently under development
Version Number / Date: No longer available.
Associated Models: Original title: "Simulation of Ice Conditions in Channels"
Proprietary Status / Availability for Use: No longer available.
Key Contact / Access Link: None. No longer Available.
Model Dimension: One-Dimensional
Computational Method: Finite Difference

MODEL DESCRIPTION		
Attribute		**Description / References**
Steady / Unsteady (Ice Processes)		Steady – select processes are dynamic or quasi steady, model considers changes in ice cover/ice jams as well as heat transfer conditions.
Steady / Unsteady (Hydraulics)		Quasi-Steady – unsteady hydraulics are approximated with a series of steady-state solutions.
Network Representation		Single channel only
Numerical Scheme(s)		Backwater computations use the standard-step method. Computational steps outlined in Petryk et al. (1981)
Simulation Capabilities	Water Cooling	Heat transfer calculated by a detailed energy budget or by a simple heat transfer coefficient and the accumulated degree days of freezing (Petryk, 1995; Petryk et al., 1981).
	Frazil and Ice Floe Generation	Once water temperature drops to 0°C, the bulk volume of frazil ice is calculated using the latent heat of fusion for ice, and a porosity value (0.5 to 0.65) (Petryk, 1995).
	Border Ice and Static Ice Cover	A stable border ice cover can be simulated. The stability of such a cover is controlled by a user-input limiting average flow velocity (Petryk, 1995).
	Dynamic Surface Ice Cover Formation	Narrow and wide channel jams can be simulated. Stability of wide channel jams is governed by equations developed in Pariset et al. (1966).
	Thermal Ice Growth/Decay	Thermal growth not captured. Thermal melting of the ice cover is simulated at the bottom by friction-generated heat, if the ice is thicker than a specified thickness. If the inflowing water is above 0°C, a length of ice cover is melted until the water temperature drops to 0°C at the new ice cover edge (Petryk, 1995).
	Undercover Deposition and Transport of Ice	Ice cover erosion based on Meyer-Peter sediment transport relation from Pariset & Hausser (1961) (Petryk, 1995).
	Anchor Ice	N/A
	Ice Jam Seepage and Ice Cover Seepage Flow	Unknown.
Other features, processes, notable characteristics		None
Examples of Recent Applications		Historically has been applied to the Peace River in BC/Alberta, and the La Grande River and Eastmain River among other rivers in Quebec (see Petryk, 1995).

Notes:
N/A = no simulation capability

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