EPFL

CIVIL-312: Hydraulic Engineering and Infrastructures

Numerical Modeling in Open Channel Flow

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GC G1 507
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Fall 2025

Announcements

- Late HW submissions will incur a 0.5 deduction from the final grade for every day of delay (e.g., after 2 days your maximum grade would be 5/6)

- The exercise session of Week 11 (Friday 28/11, 10:00–12:00) will be dedicated to Homework 2, which is due on Week 12, Friday 5/12 at 23:59.There will be no new exercises that day; instead, you will have the opportunity to continue working on HW2 (hopefully you will have started it beforehand) and ask us any questions.

- To give you more time, we have decided to release HW3 earlier and extend its deadline.
  - HW3 will be assigned on Week 12, Friday 5/12, and it will be due on 9 January — providing three weeks of work, excluding the holiday break.
  - Exercise session of Week 14 (Friday 14/12) will be dedicated to HW 3 development and questions

Fast announcement:

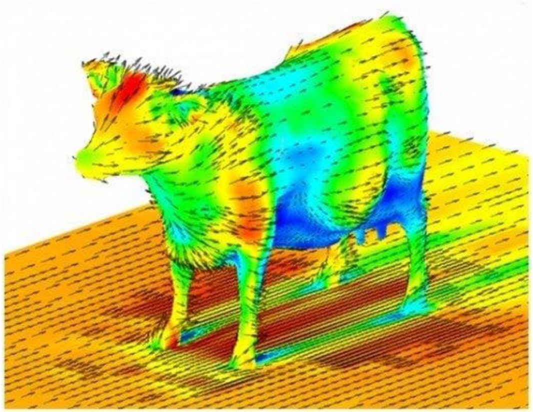
As this is an important workshop, it will be **exceptionally** recorded and published tomorrow on Moodle.

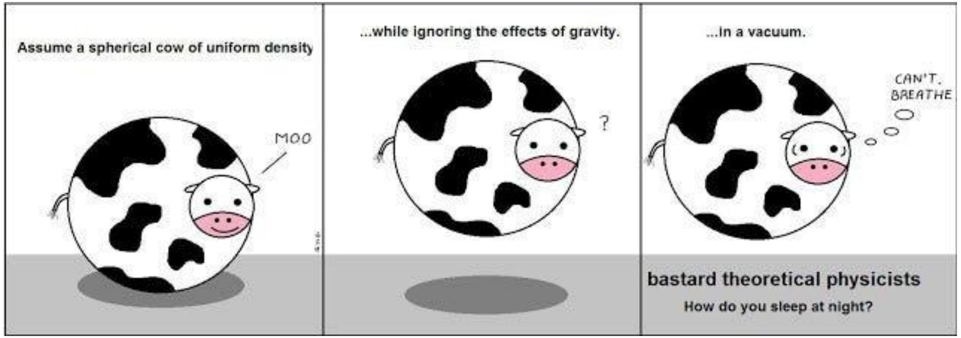
Today's Agenda

- Introduction to Numerical Modeling in Open Channel Flow
  - Why to model?
  - Different types of models
- Introduction to HEC-RAS
- Homework 2 😅
  - Discussion
  - If time allows, Q&A

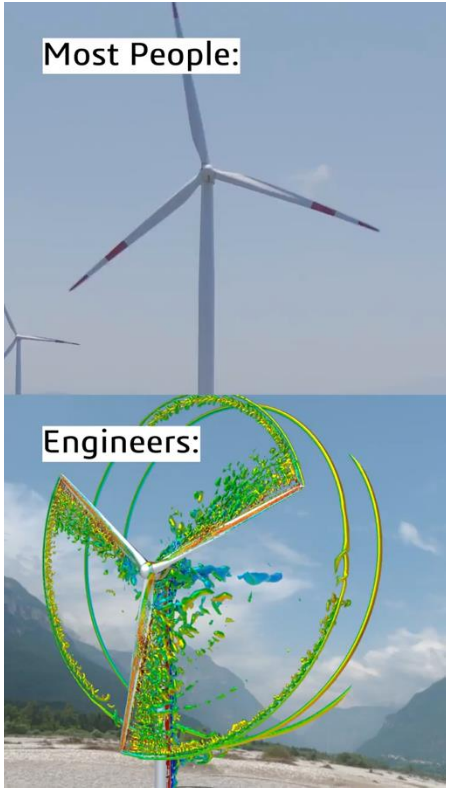
What is a Model?

- A model as a **simplified mathematical representation** of physical laws.
- Purpose:
  - Prediction,
  - Understanding,
  - Hypothesis testing,
  - Design support.
- The trade-off between **complexity**, **accuracy**, and **computational cost**.

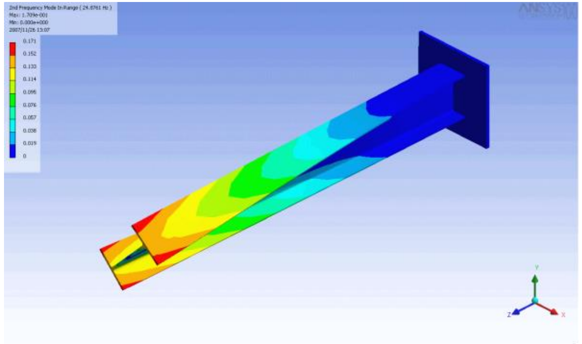




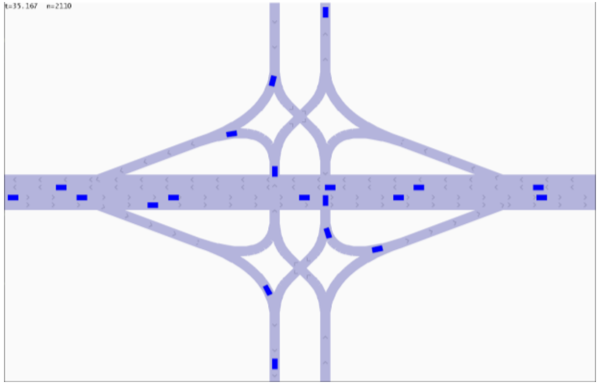
Models in Engineering



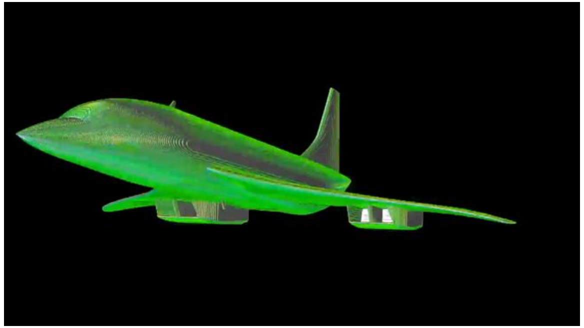
Energy



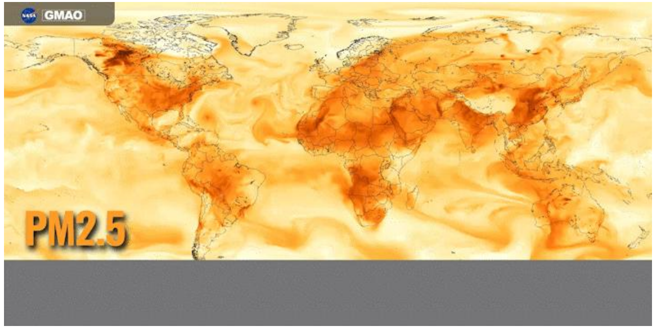
Structures



Transport

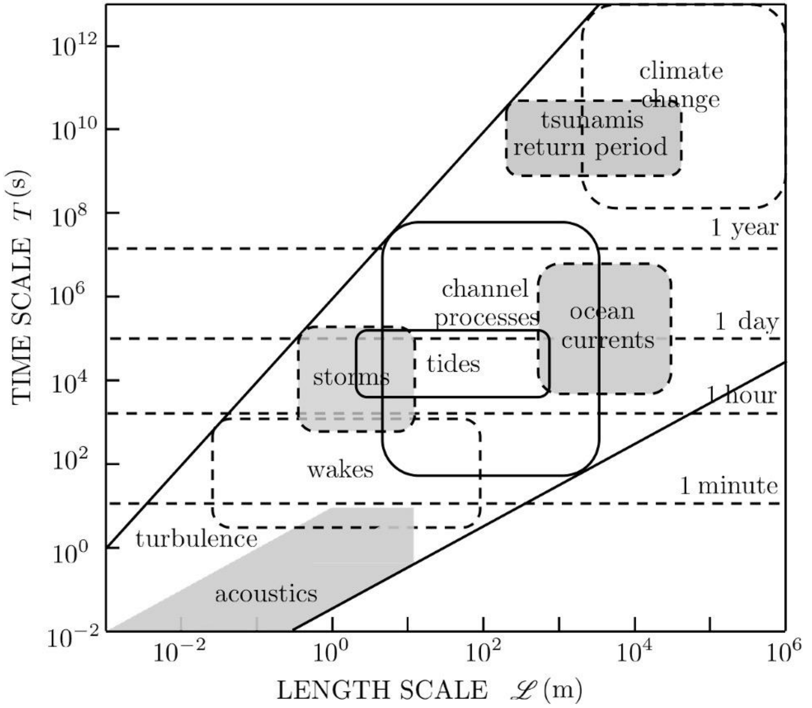


Aerospace



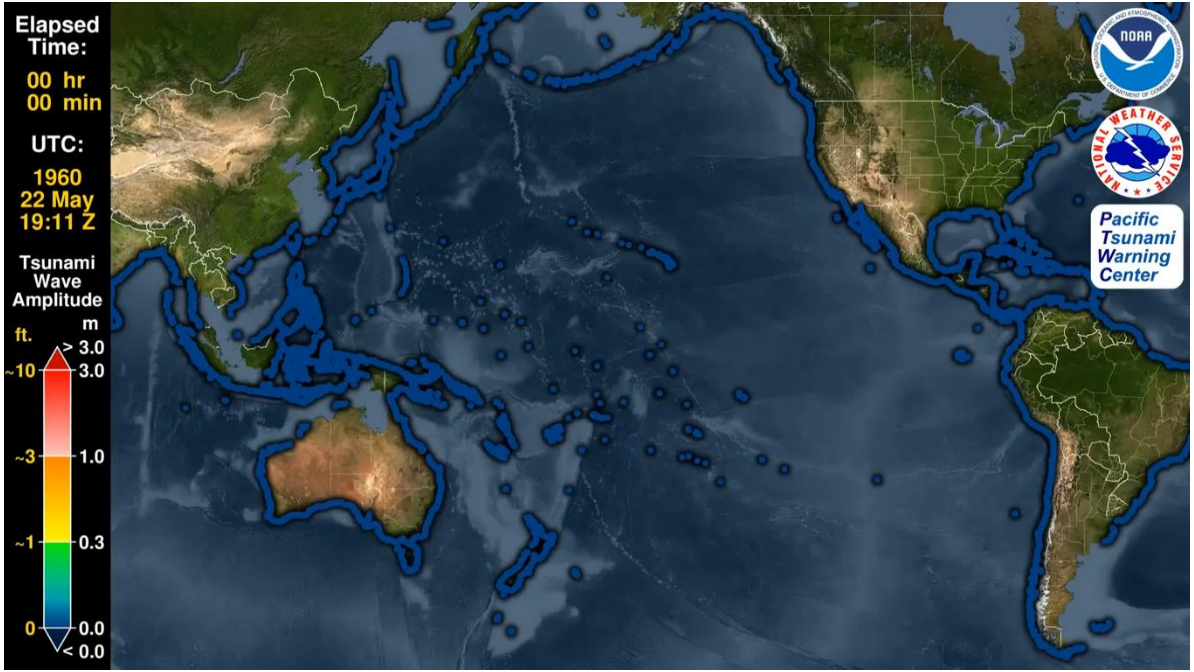
Environment

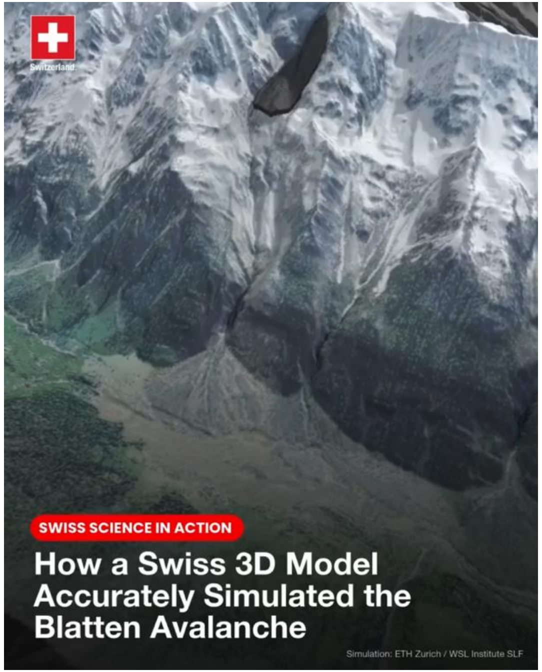
Models for Geophysical Flows



We face problems that vary in both **scale** and **nature**

Models for Geophysical Flows

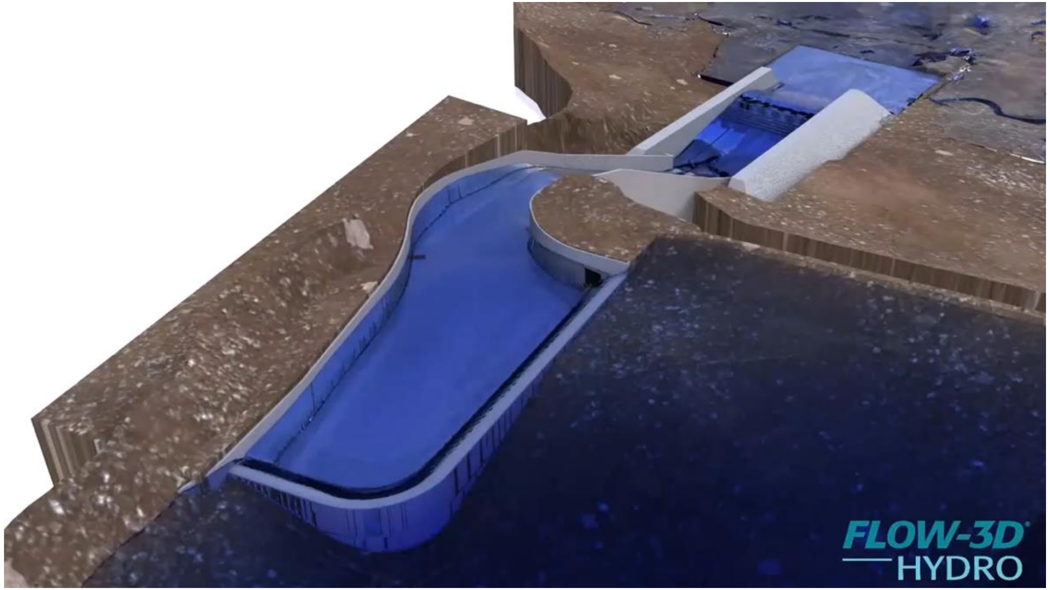




We face problems that vary in both **scale** and **nature**

Models in Open Channel

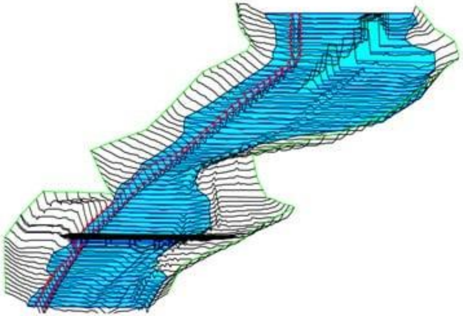
- Why Do We Need Models in Open-Channel Hydraulics?
  - Laboratory and field data are limited in time and scale.
  - Models allow exploring “what-if” scenarios under controlled conditions.
  - **The importance of calibration and validation: comparing with measurements.**

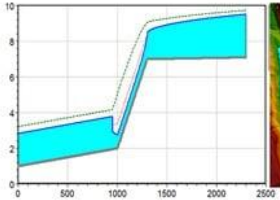


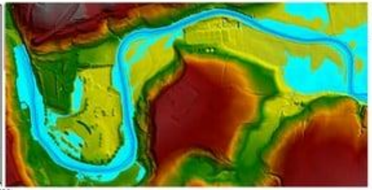
- Models are never 100% reliable
- Input data may require assumptions
- Mathematical models may be inadequate
- Accuracy limited by available computing power
- Interpretation and skill of the modeler/engineer

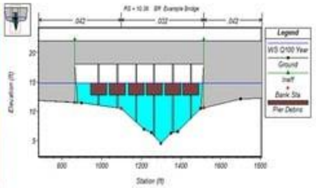
Models in Open Channel

- We solve the same physics with different levels of detail
- In 1D
  - First models available in “software” appeared during the 70’s
  - Still used in professional world for engineering design and regulatory studies with channelized flow.









Equations to solve for a 1D free surface simulation:

$$Q_1 = Q_2 = Q$$

$$z_1 + y_1 + \alpha_1 \frac{V_1^2}{2g} = z_2 + y_2 + \alpha_2 \frac{V_2^2}{2g} + h_f + h_L$$

$$h_f = L\, S_f$$

$$S_f = \frac{n^2\, Q^2}{A^2\, R^{4/3}}$$

$$h_L = C\, \frac{(V_2^2 - V_1^2)}{2g}$$

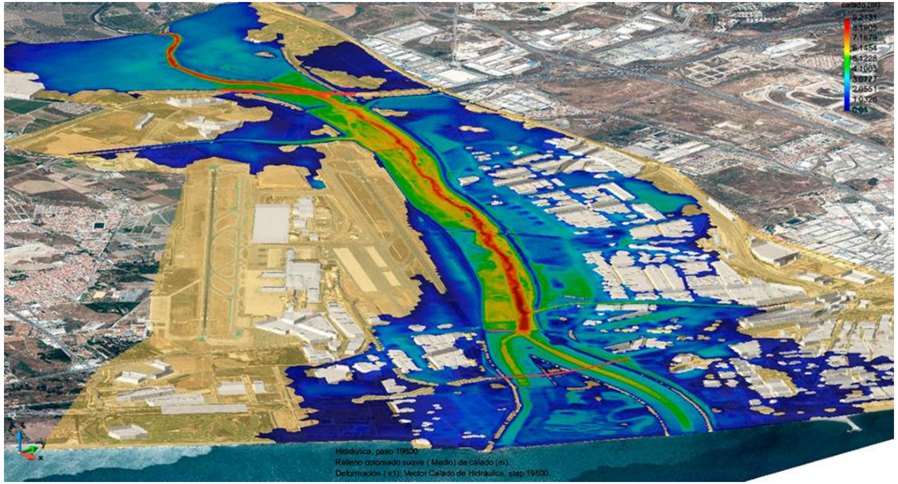
$$S_0 = \frac{z_1 - z_2}{L}$$

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - \mathrm{Fr}^2}$$

$$\mathrm{Fr}^2 = \frac{V^2}{gD}, \qquad D = \frac{A}{T}$$

Models in Open Channel

- In 2D
  - Current standard for industry for realistic flood behavior, complex terrain, and safety assessments.
  - Still research being done to improve efficiency and include new features



Equations to solve for a 2D free surface simulation:

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = q$$

$$\frac{\partial (hu)}{\partial t} + \frac{\partial}{\partial x}\left(hu^2 + \tfrac{1}{2}gh^2\right) + \frac{\partial (huv)}{\partial y} = -gh\frac{\partial z_b}{\partial x} - \tau_{bx}/\rho + qu_s$$

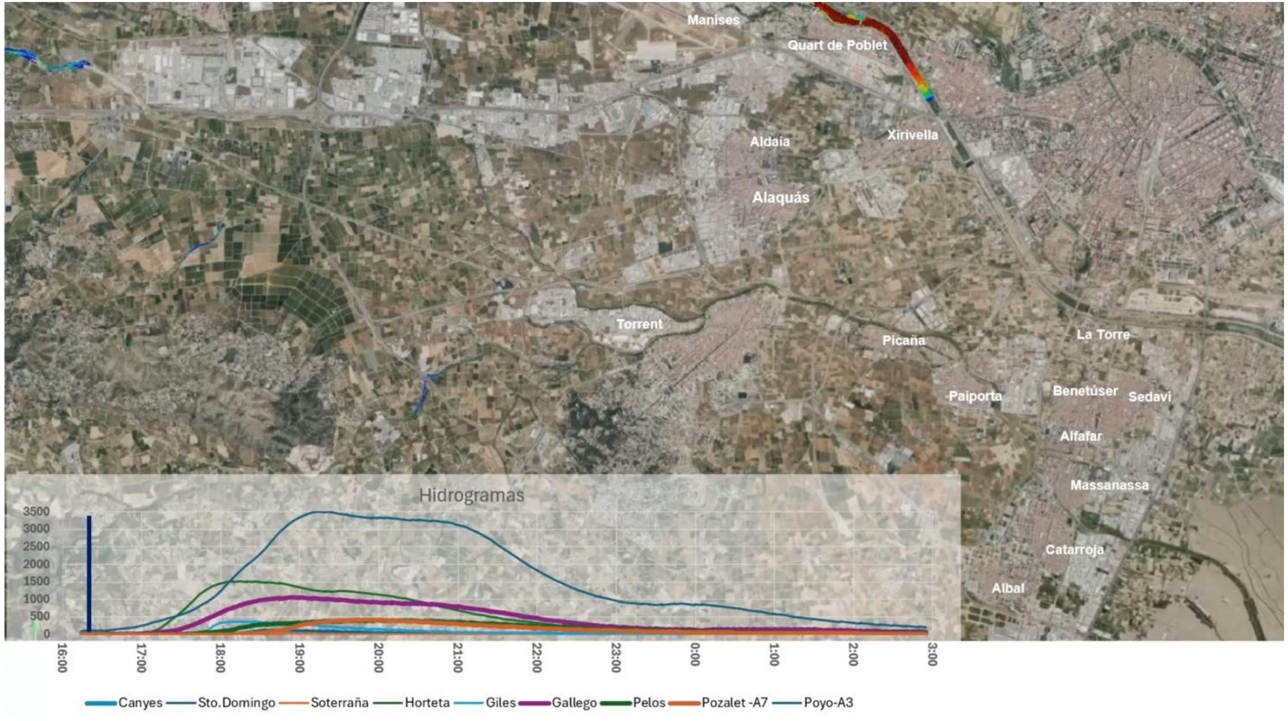
$$\frac{\partial (hv)}{\partial t} + \frac{\partial (huv)}{\partial x} + \frac{\partial}{\partial y}\left(hv^2 + \tfrac{1}{2}gh^2\right) = -gh\frac{\partial z_b}{\partial y} - \tau_{by}/\rho + qv_s$$

$$\tau_{bx} = \rho g n^2 \frac{u\sqrt{u^2+v^2}}{h^{1/3}}, \qquad \tau_{by} = \rho g n^2 \frac{v\sqrt{u^2+v^2}}{h^{1/3}}$$

$$S_{fx} = \frac{n^2 u\sqrt{u^2+v^2}}{h^{4/3}}, \qquad S_{fy} = \frac{n^2 v\sqrt{u^2+v^2}}{h^{4/3}}$$

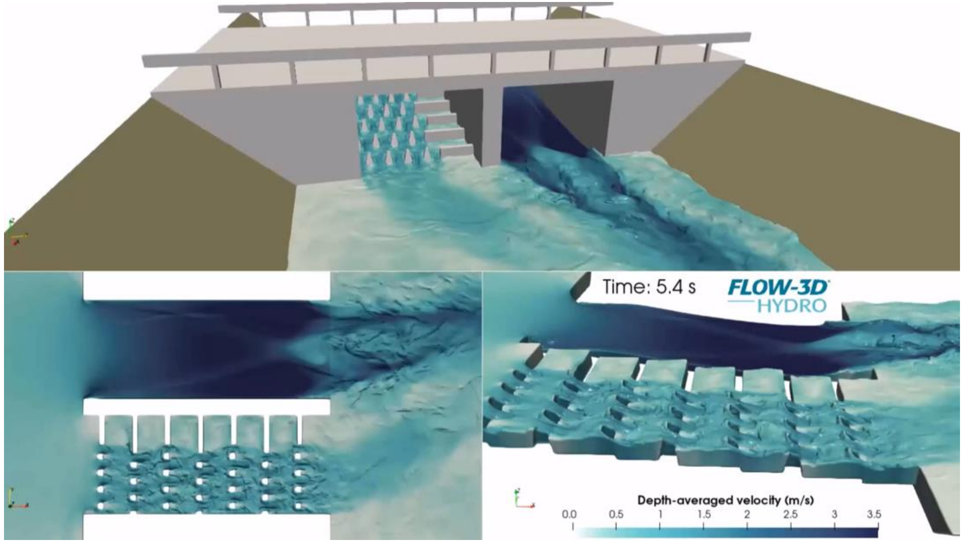
Models in Open Channel

- In 2D
  - Current standard for industry for realistic flood behavior, complex terrain, and safety assessments.
  - Still research being done to improve efficiency and include new features



Models in Open Channel

- In 3D
  - Mostly for research or very specific small scale professional applications
  - Very expensive in computation power



Equations to solve for a 3D free surface simulation:

$$\nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial(\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u} \otimes \mathbf{u}) = -\nabla p + \nabla \cdot \left[\mu_{\text{eff}}(\nabla \mathbf{u} + (\nabla \mathbf{u})^T)\right] + \rho \mathbf{g} + \mathbf{F}_\sigma$$

$$\mathbf{F}_\sigma = \sigma \kappa \nabla \alpha$$

$$\kappa = -\nabla \cdot \left(\frac{\nabla \alpha}{|\nabla \alpha|}\right)$$

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (\alpha \mathbf{u}) = 0$$

$$\rho = \alpha \rho_1 + (1 - \alpha)\rho_2$$

$$\mu = \alpha \mu_1 + (1 - \alpha)\mu_2$$

$$\frac{\partial(\rho k)}{\partial t} + \nabla \cdot (\rho k \mathbf{u}) = \nabla \cdot \left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\nabla k\right] + P_k - \rho \varepsilon$$

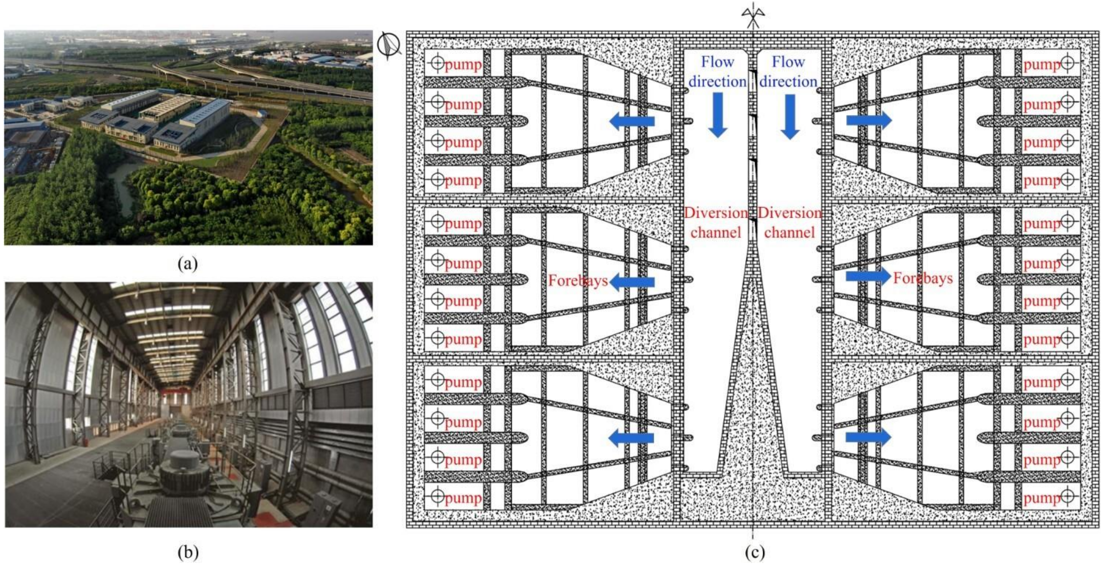
$$\frac{\partial(\rho \varepsilon)}{\partial t} + \nabla \cdot (\rho \varepsilon \mathbf{u}) = \nabla \cdot \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\nabla \varepsilon\right] + C_{1\varepsilon}\frac{\varepsilon}{k}P_k - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

$$\mu_t = C_\mu \rho \frac{k^2}{\varepsilon}$$

$$\frac{\partial(\rho h)}{\partial t} + \nabla \cdot (\rho \mathbf{u} h) = \nabla \cdot (k_{\text{eff}} \nabla T) + S_h$$

Models in Open Channel

- In 3D: example



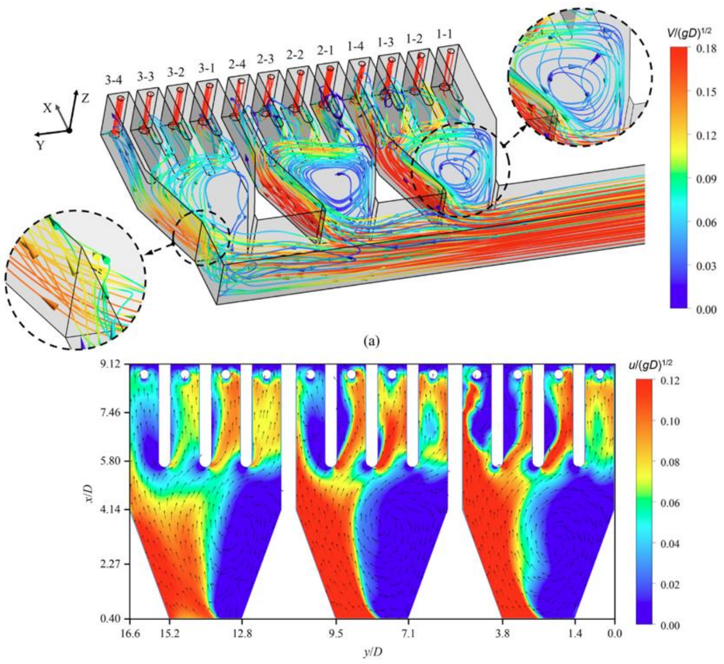
Wuhaogou Pumping Station in China

Reasons for the deterioration of hydraulic characteristics in the forebays:

- Flow recirculation,
- Helical mainstream and
- Vortex strip

Models in Open Channel

- In 3D: example



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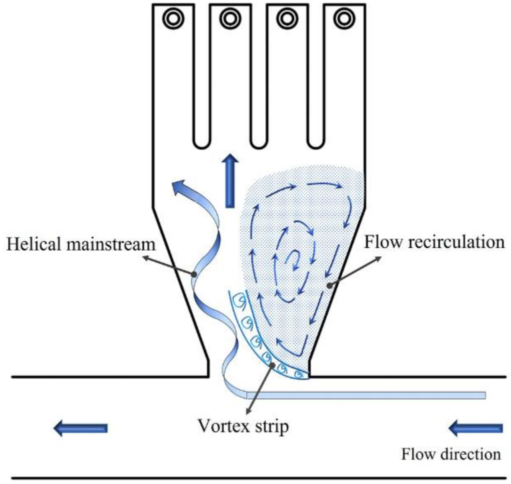
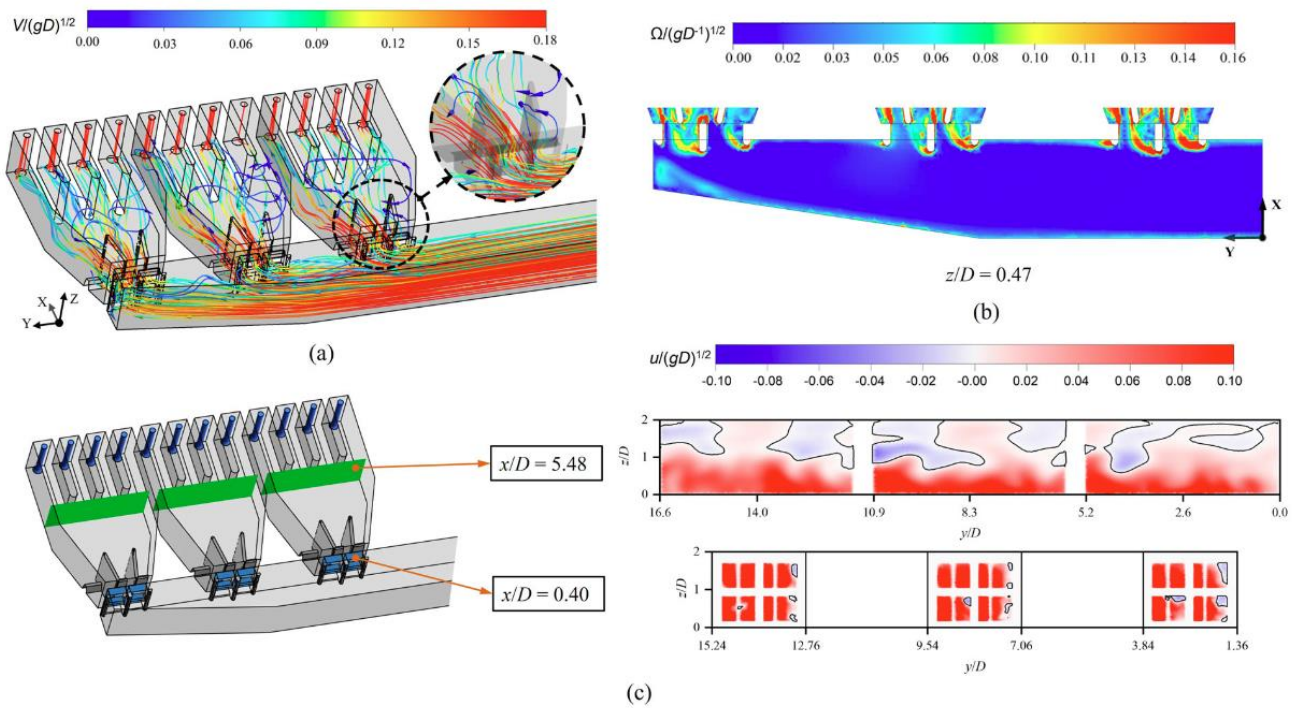


Models in Open Channel

- In 3D: example

We can test multiple options that would otherwise be very costly.



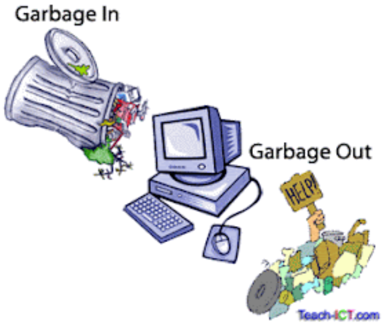
Models in Open Channel

- Many software programs
- All of them with different:
  - Set of equations
  - Boundary conditions
  - Extra features
  - Performance
  - Accuracy
  - **Assumptions**

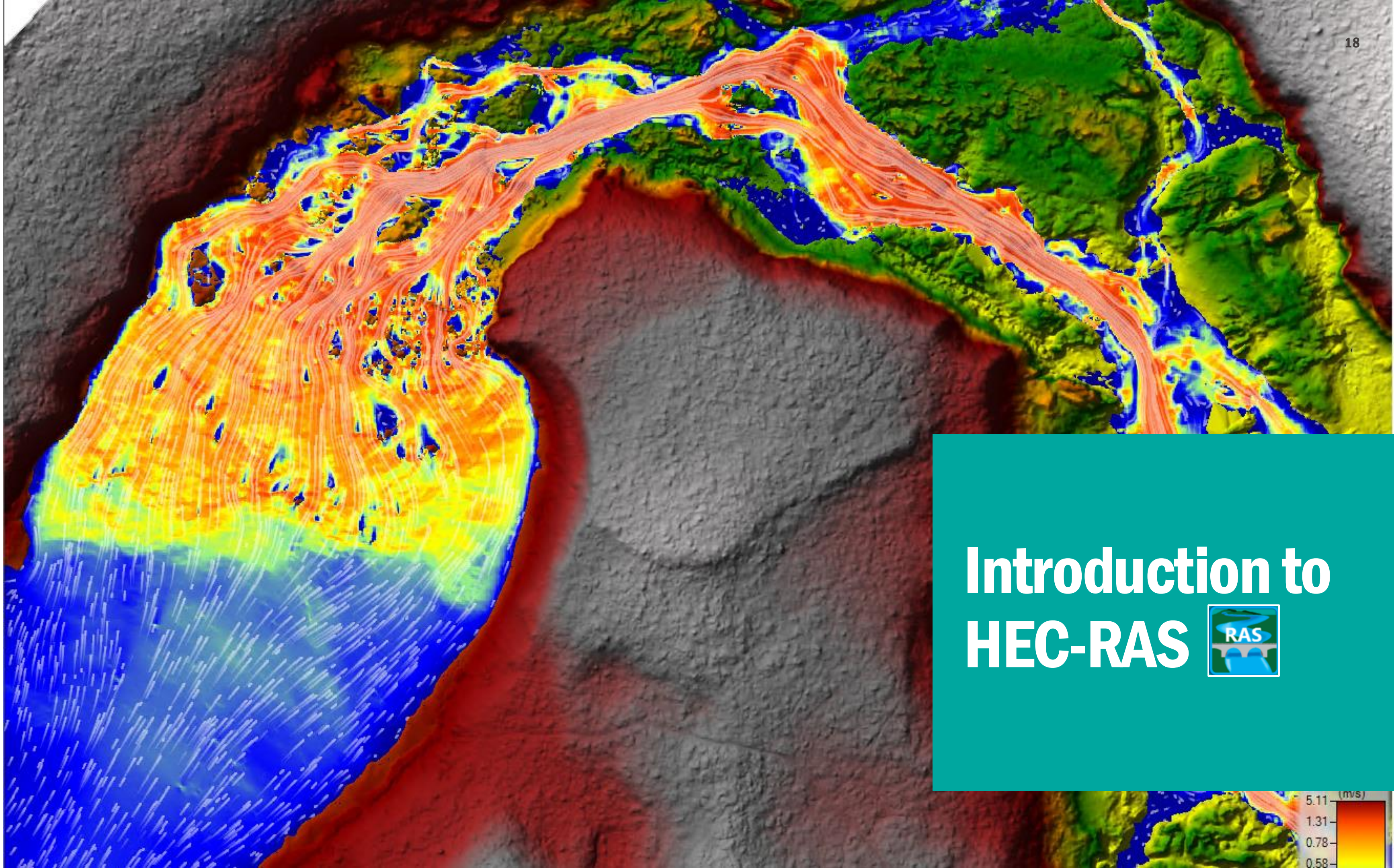
US CH NL

ES DK

- We must understand **how the model operates** and **what assumptions it makes** to:
  - **Decide when each model is appropriate** for the problem we want to solve.
  - **Recognize its limitations** and avoid interpreting results beyond its scope.
  - **Select meaningful input data** that are consistent with the model's assumptions.
  - **Interpret outputs critically**, knowing what processes are included and what are not.
- And remember: **don't believe everything that comes out of a software**



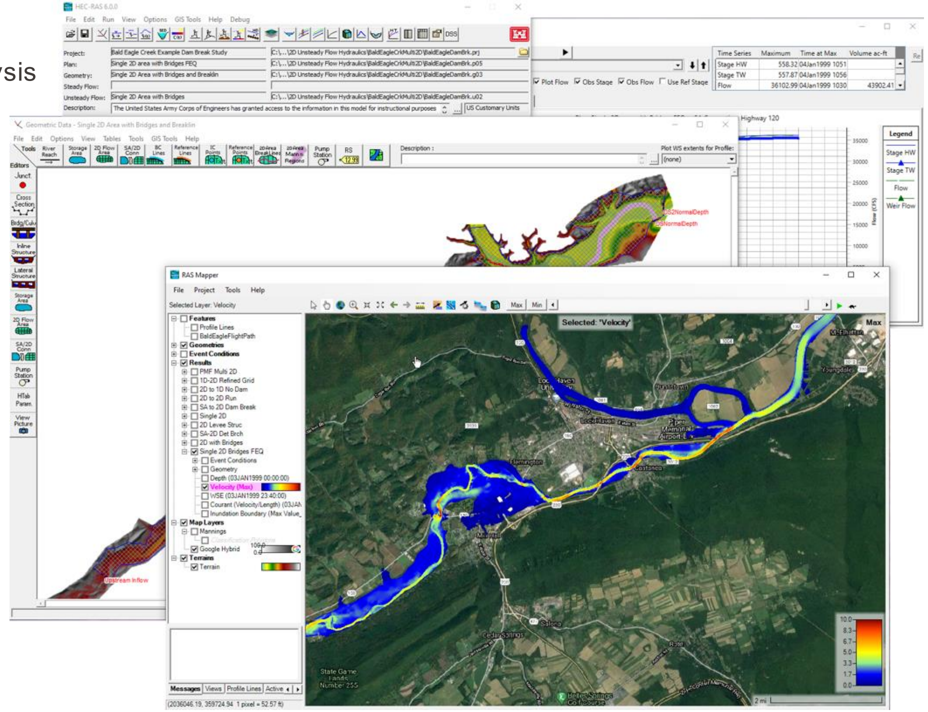
All models are wrong, but some are useful." — **George Box**



Introduction to HEC-RAS

What is HEC-RAS?

- Hydrologic Engineering Center's River Analysis System (HEC-RAS)
- Developed by the U.S. Army Corps of Engineers (USACE): **it's free!**
- Key Capabilities:
  - One-dimensional (1D) **steady** and **unsteady** flow analysis
  - Two-dimensional (2D) unsteady flow modeling
  - Sediment transport and mobile bed computations
  - Water quality and temperature modeling
  - Floodplain mapping and inundation visualization
- Applications:
  - Flood risk assessment and management
  - Bridge and culvert hydraulic design
  - Dam break and levee breach simulations
  - Environmental and restoration studies
- Widely used worldwide in both academic research and professional engineering practice



Steady vs Unsteady flow simulations

- **Steady Flow** ➡ For this course

Use when conditions are **relatively constant over time**

Ideal for:

- **Bridge/Culvert design**
- **Floodplain mapping (regulatory studies)**
- **Simple canal systems**

Advantages: Quick setup, fast computation, easier calibration

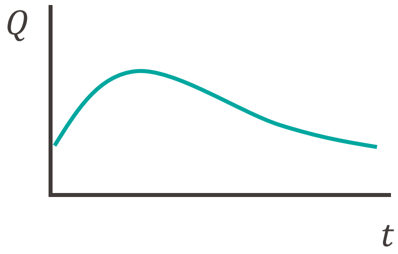
- **Unsteady Flow** ➡ During the Master's (?)

Use when flow or stage **changes with time**

Ideal for:

- **Flood routing / storm events**
- **Dam break or levee breach analysis**
- **Reservoir or tidal system modeling**

Advantages: Captures dynamic flow behavior, storage, and wave effects



Steady flow simulations

- **Steady Flow**

Use when conditions are **relatively constant over time**

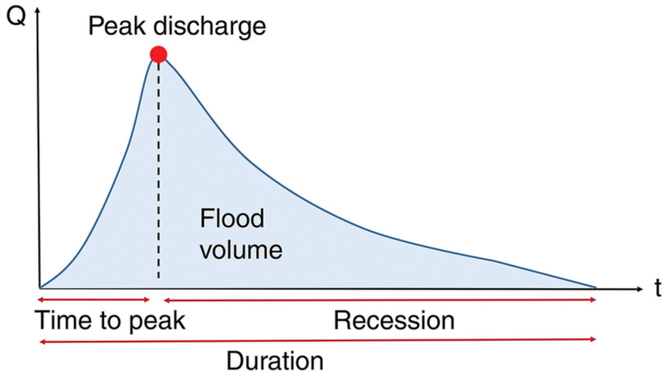
Ideal for:

- **Bridge/Culvert design**
- **Floodplain mapping (regulatory studies)**
- **Simple canal systems**

Advantages: Quick setup, fast computation, easier calibration

Limitations of 1D steady flow conditions:

- Simple canal systems
- Dominant flows in x direction (1-D)
- Channel slopes less than 10%
- Velocity and WS constant across cross-section
- Cross-section does not change (no erosion or deposition).



Steady flow theory

- Before we computed the hydraulic profile with

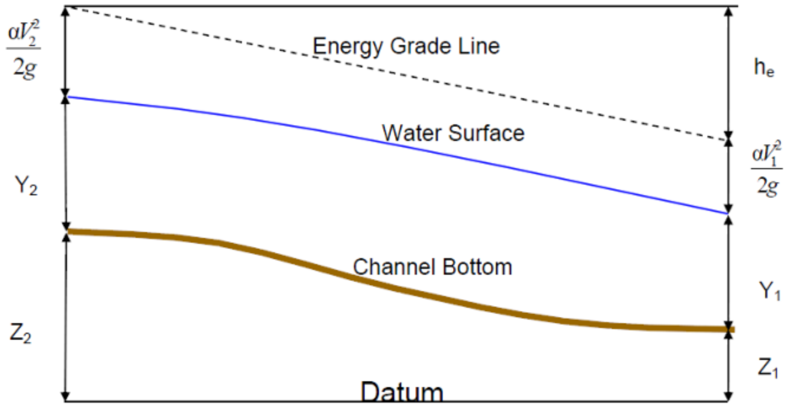
$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$

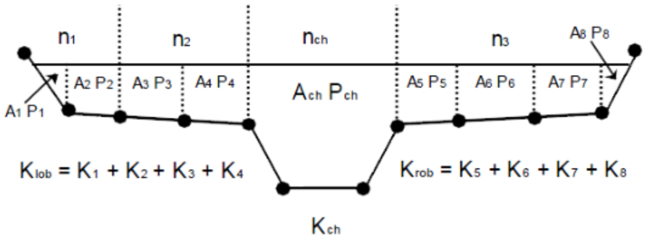
- In HEC-RAS, water surface profiles are computed by solving the Energy equation between two consecutive cross-sections (1 and 2) using an iterative procedure called **standard step method**

$$Z_2 + Y_2 + \alpha \frac{U^{\,2}}{2g} = Z_1 + Y_1 + \alpha \frac{U_1}{2g} + h_e$$

- **Energy losses** include:
  - Friction (from Manning's equation)
  - Local losses (expansion/contraction)

$$h_e = LS_f + C\left[\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right]$$



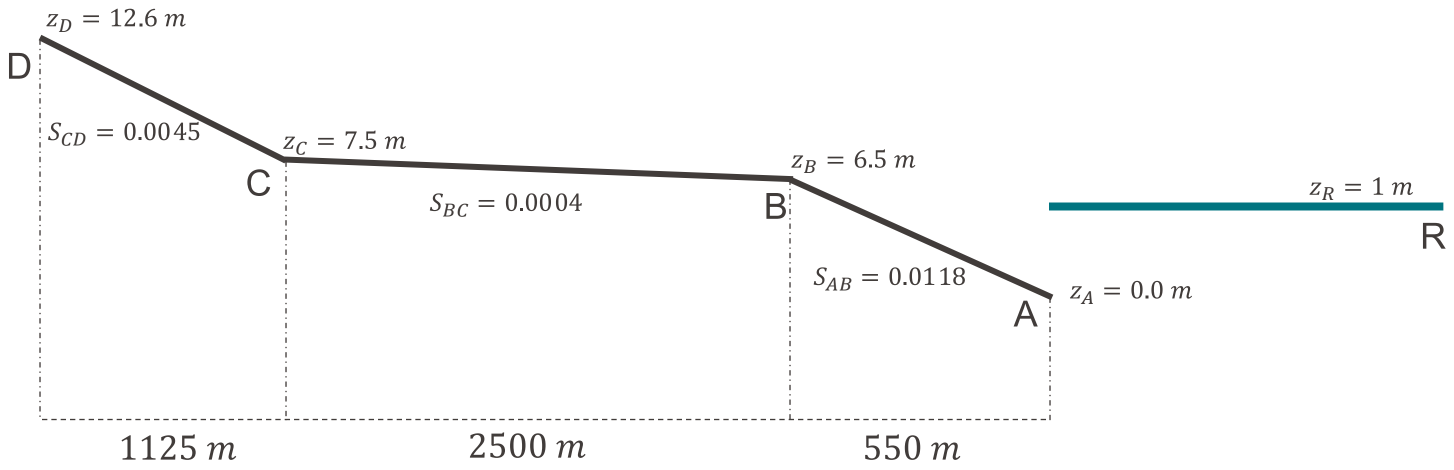


$$Q = KS_f^{1/2}$$

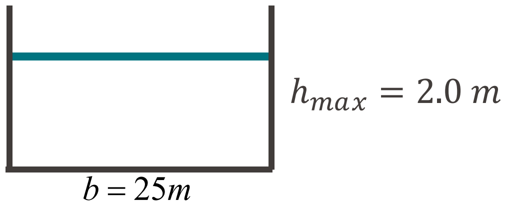
$$K = \frac{1.486}{n} AR^{2/3}$$

Modeling Example

- The regulated irrigation channel has a flow rate of 35 m^3/s. The elevation of the water surface at the end of the channel is fixed by a reservoir. Draw the hydraulic profiles and simulate the system in HEC-RAS 1D.



Cross section:



Modeling Example

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Parameter	Magnitude	Units
Q	35	m^3/s
Width b	25	m
Roughness	0.01	

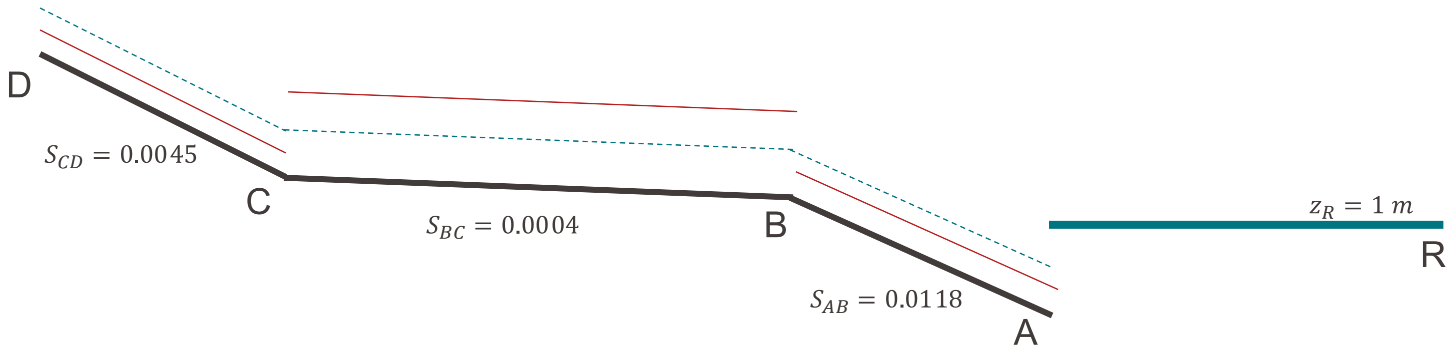
Critical Depth

$$y_c = \sqrt[3]{\frac{q^2}{g}} = \sqrt[3]{\frac{Q^2}{b^2 g}} = 0.59\ m$$

Normal Depth

$$Q = \frac{1}{n} \frac{(b \cdot y_n)^{5/3}}{(b + 2 \cdot y_n)^{2/3}} S_o^{1/2}$$

Subreach	(m)
CD	0.395
BC	0.828
AB	0.295



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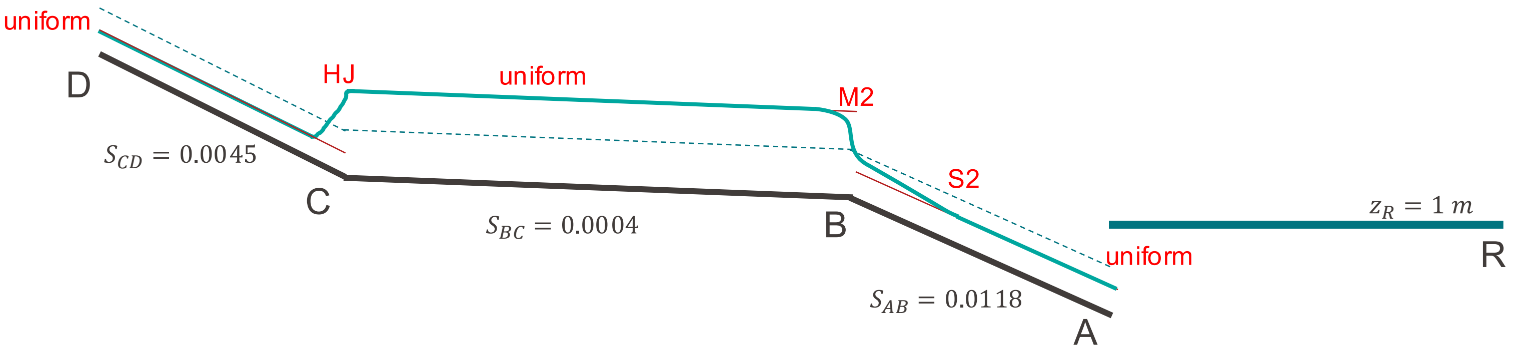
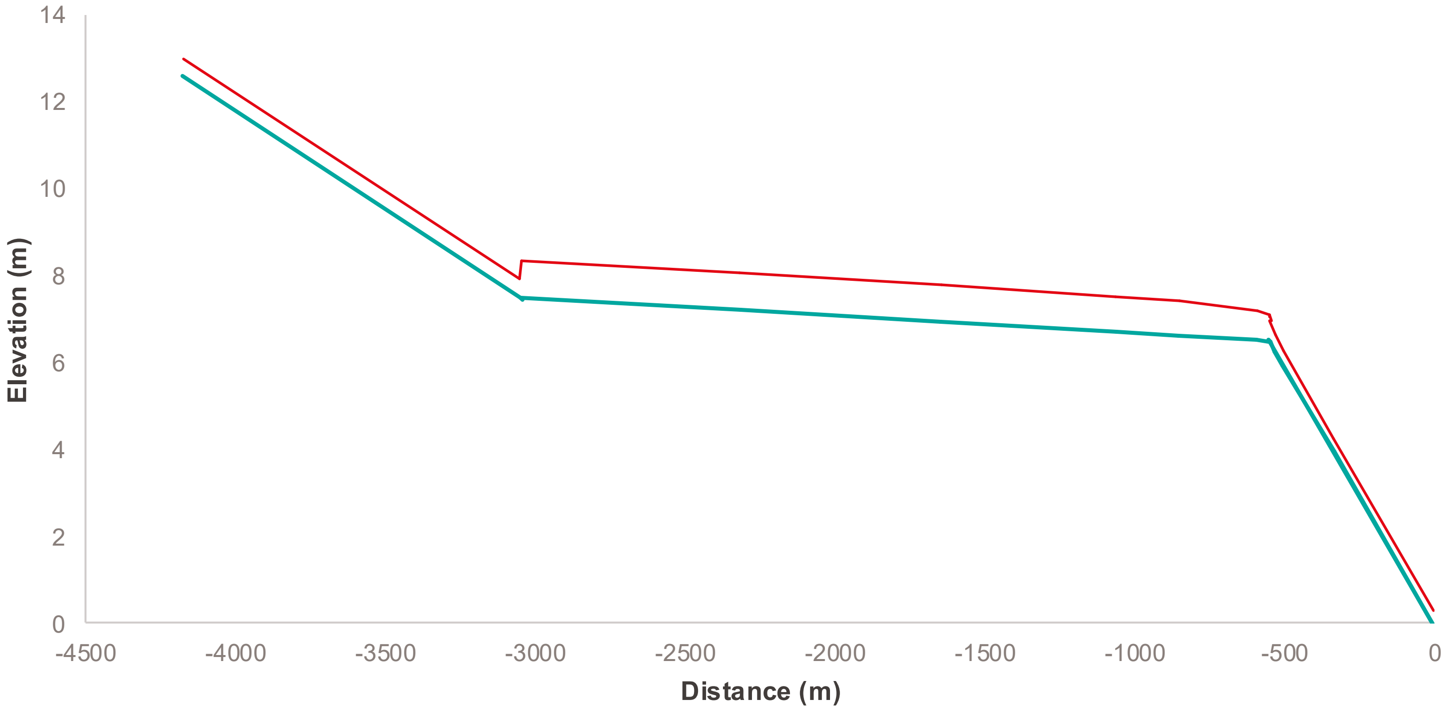


Modeling Example

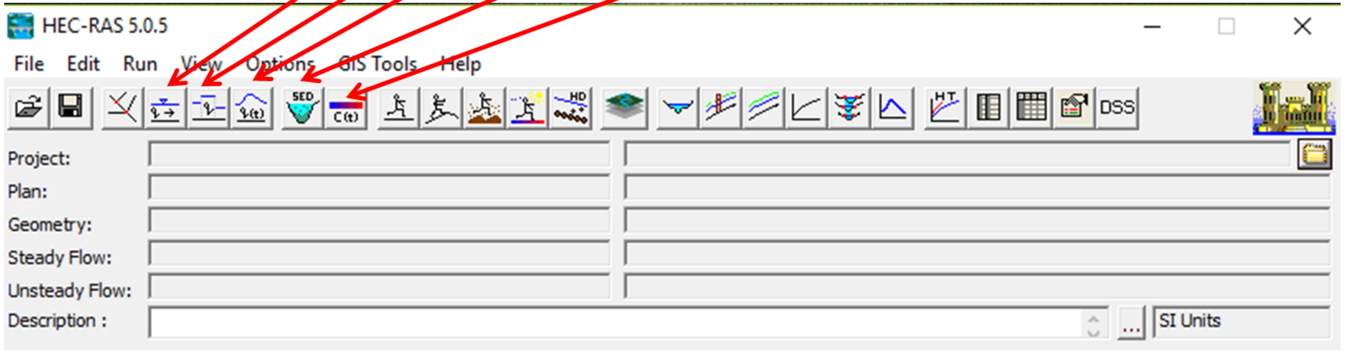
- Solving with Direct-Step Method we get:



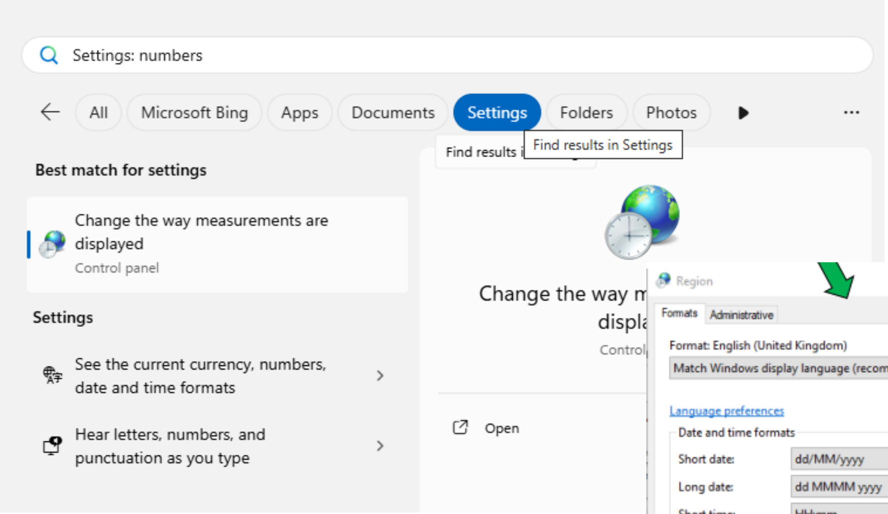
HEC-RAS GUI

HEC-RAS Modules

1. Hydraulic Analysis
   - Steady state
   - Quasi-unsteady state
   - Unsteady state
2. Sediment Transport
3. Water Quality

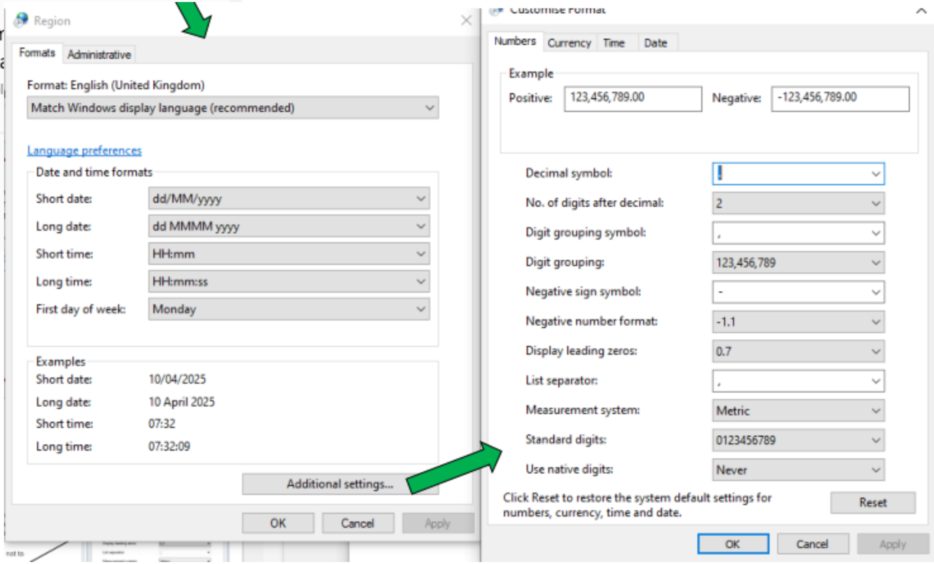


HEC-RAS: Before starting



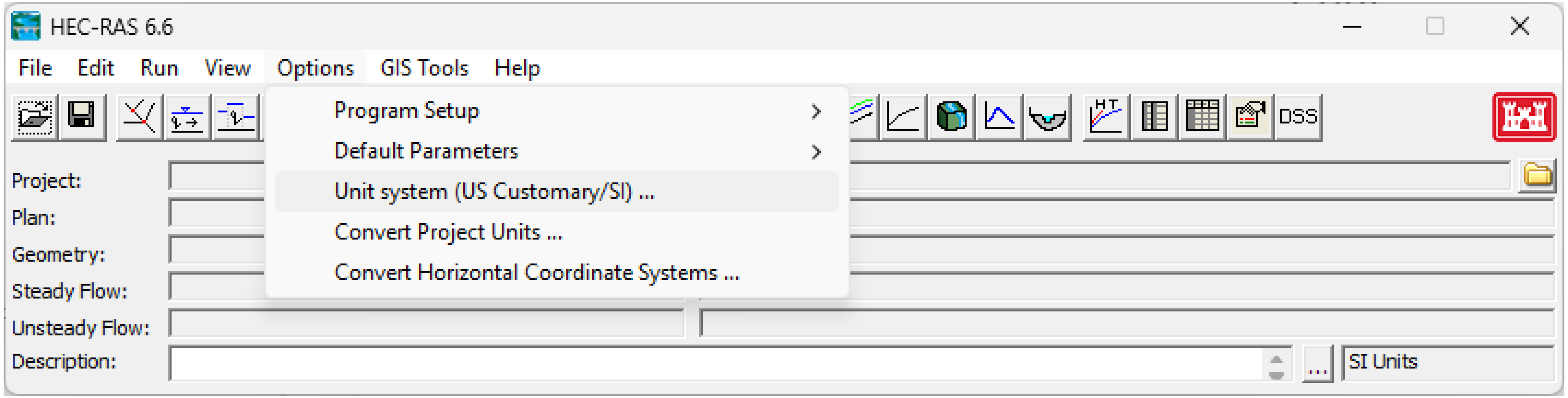
Pay attention to regional format.
It should be set like in the US:

“.” (dot) as decimal symbol

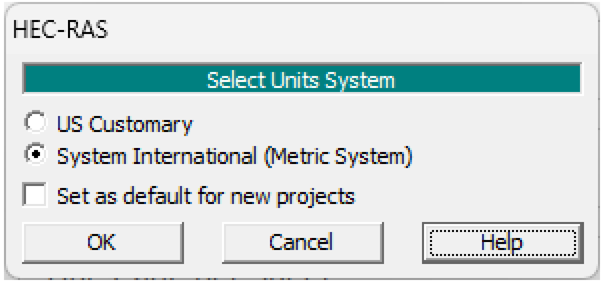


EPFL’s VDI is already in US format

HEC-RAS: Before starting

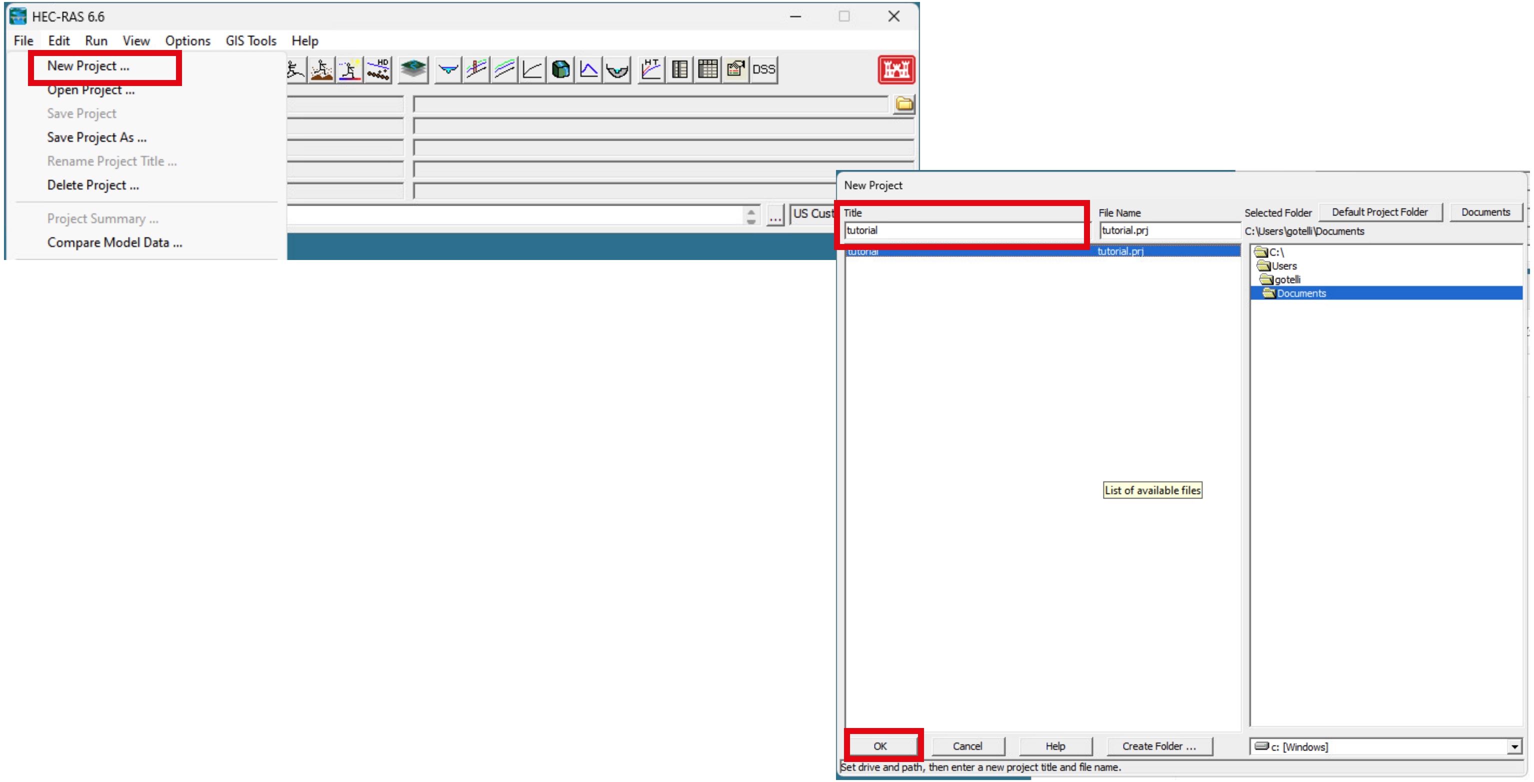


We check the Unit System



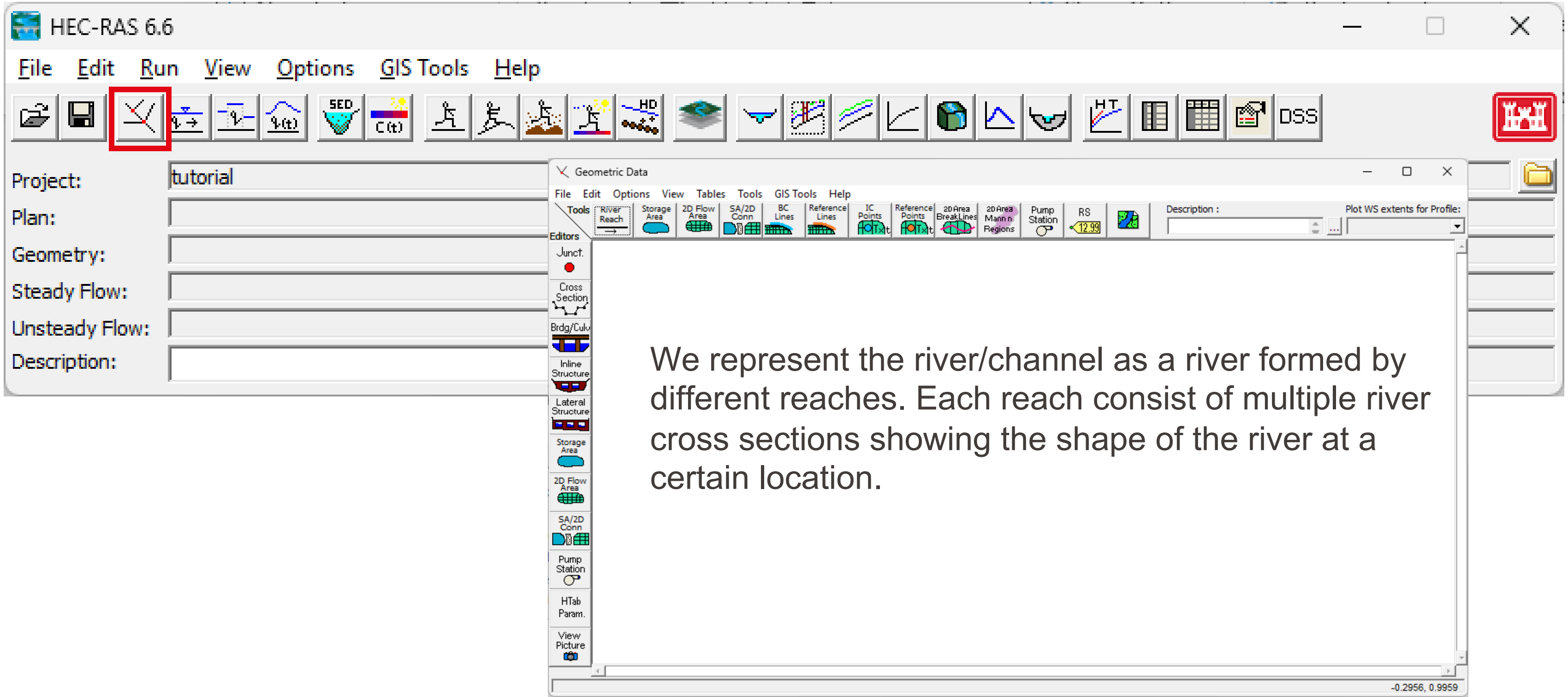
HEC-RAS

New project



HEC-RAS: Geometry

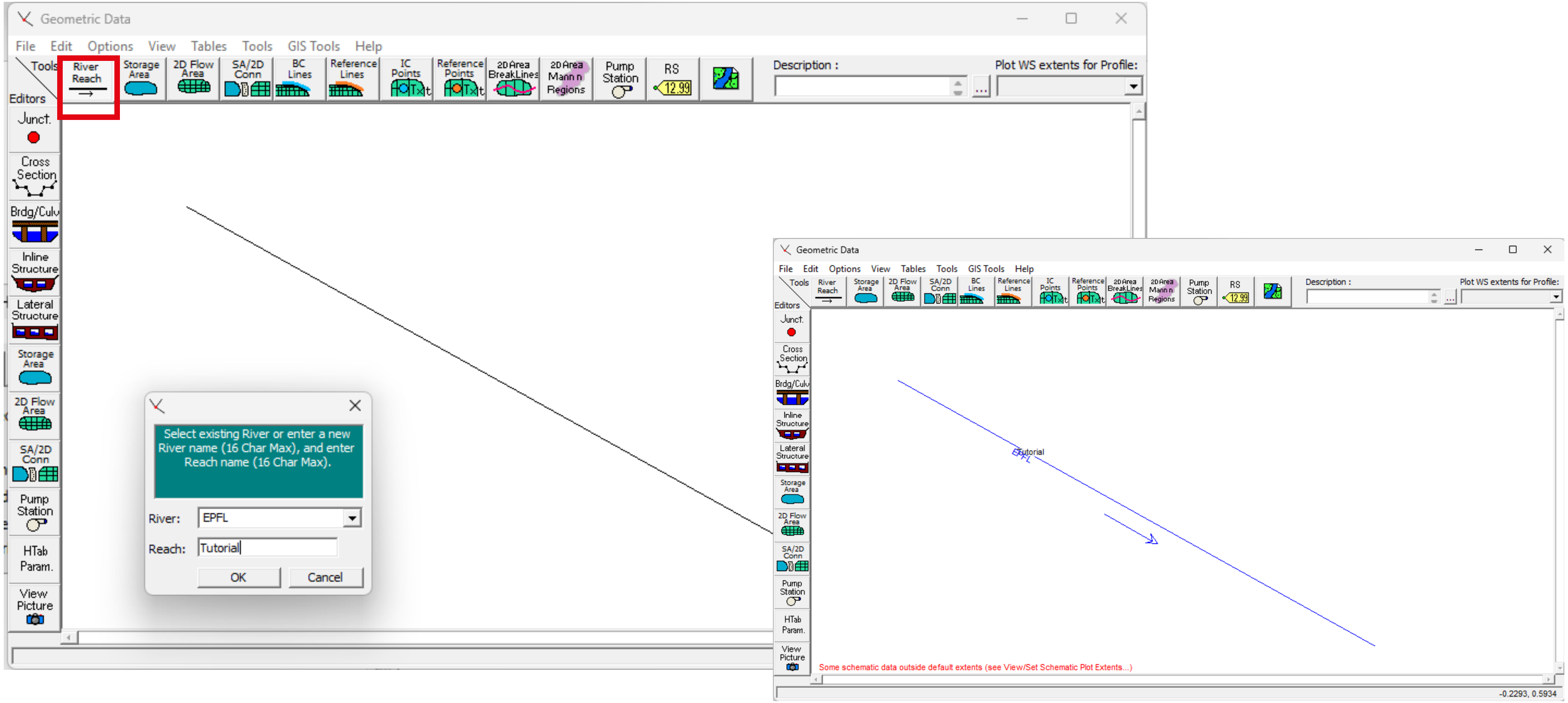
We open the Geometry Editor:



We represent the river/channel as a river formed by different reaches. Each reach consist of multiple river cross sections showing the shape of the river at a certain location.

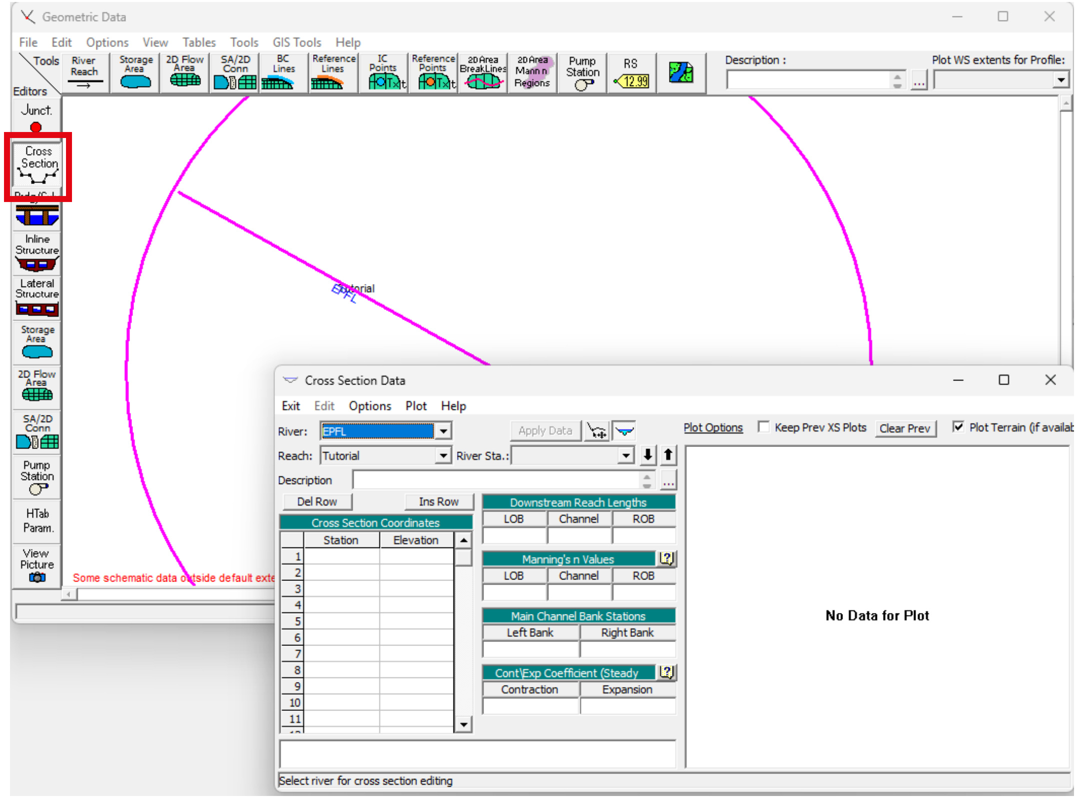
HEC-RAS: Geometry

River Reach → We create the line representing the river. Complete River and Reach names.



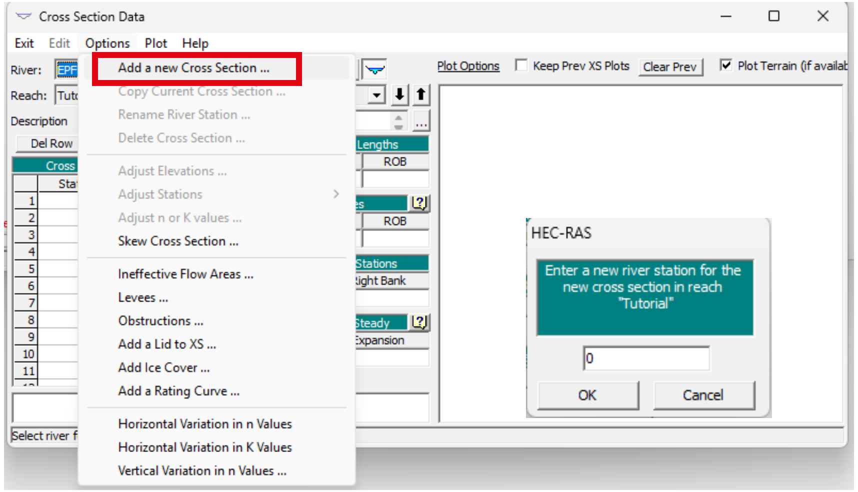
HEC-RAS: Geometry

We open the Cross Section editor

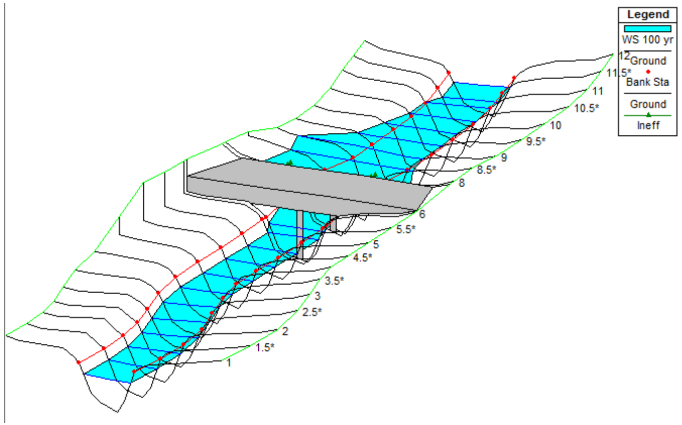


HEC-RAS: Geometry

We add a new Cross Section. The river station should be at “0”.
We then fill the section characteristics: points, manning, reach lengths, etc.

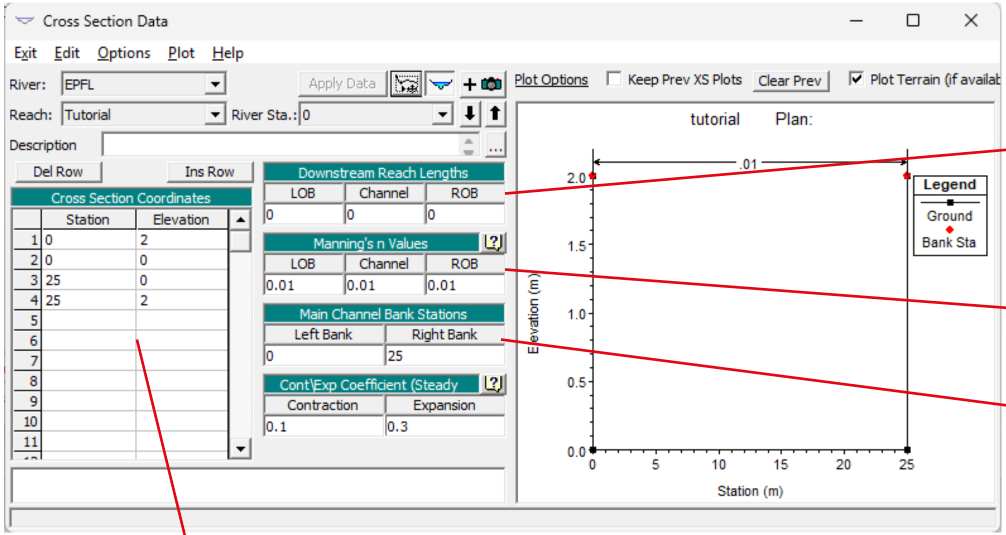


A Cross Section is a transversal “cut” of the river



HEC-RAS: Geometry

We add a new Cross Section. The river station should be at "0".
We then fill the section characteristics: points, manning, reach lengths, etc.

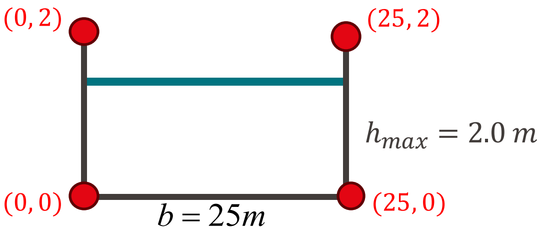


Distance from this section to the next downstream section. We build the channel from downstream to upstream.

Manning values for main channel and flooding zones ($n = 0.01$)

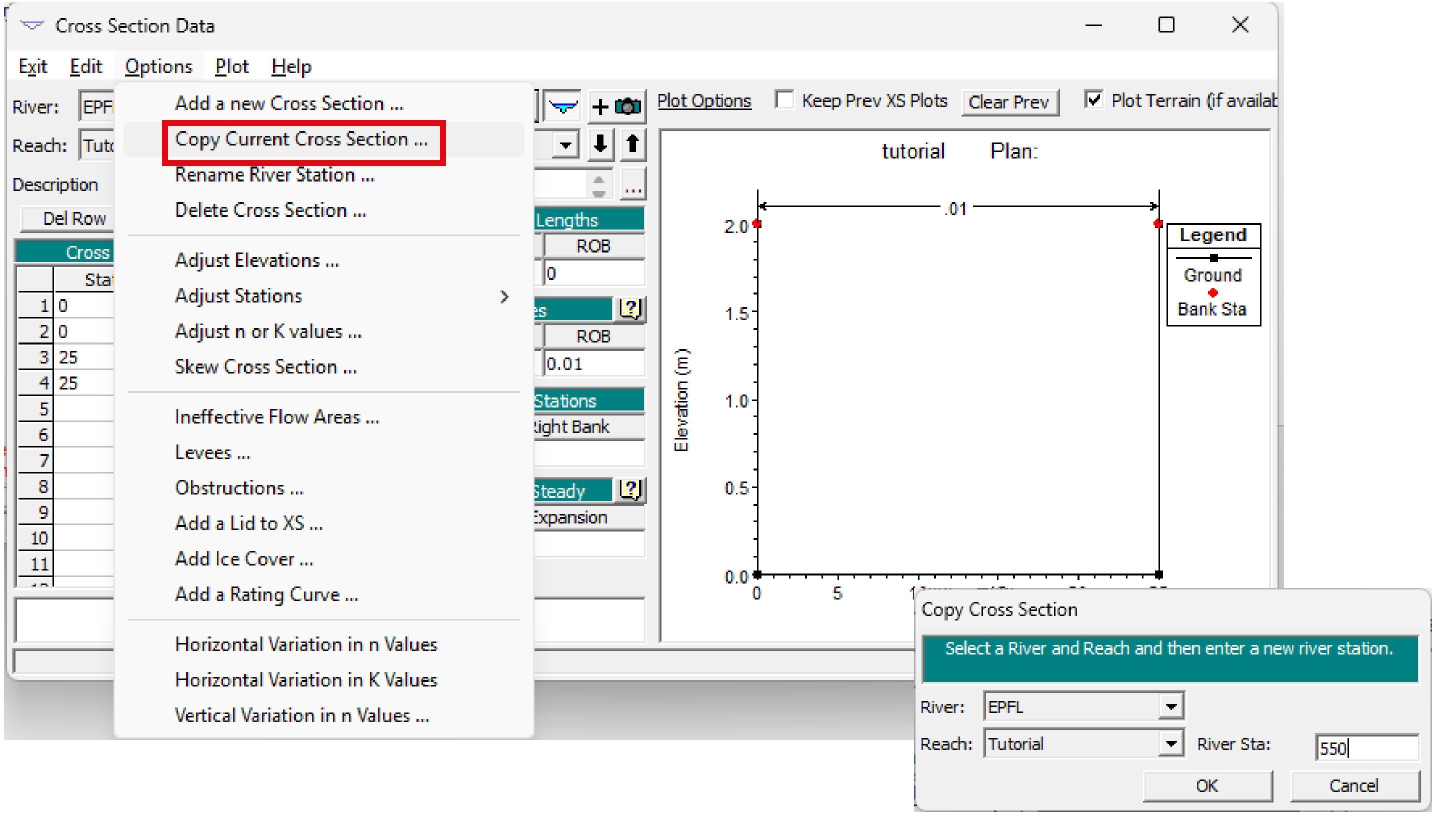
Stations defining main channel

We start building the section from the left bank looking downstream.



HEC-RAS: Geometry

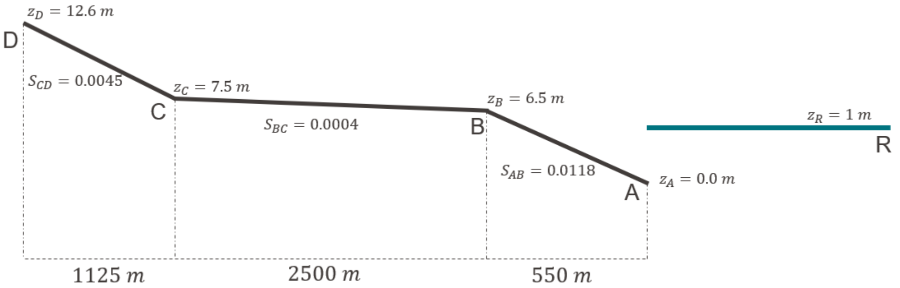
We add another Cross Section. The new river station should be at “550”.

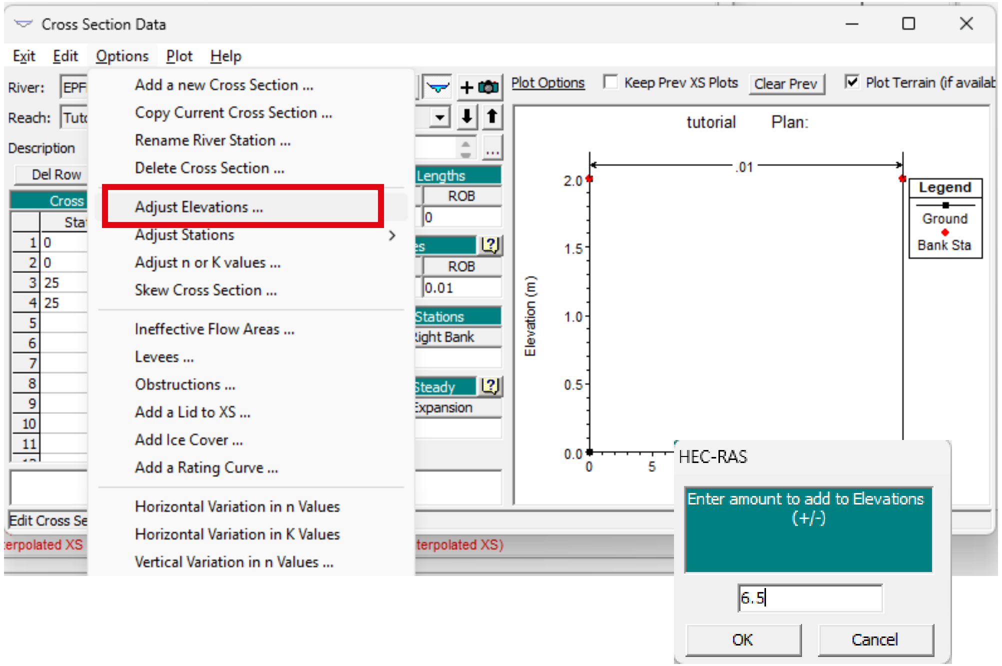


EPFL

HEC-RAS: Geometry

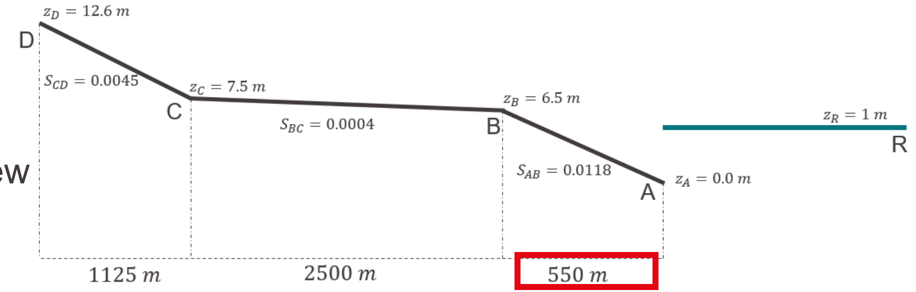
As the section shape is the same, we just ne to adjust the elevation.

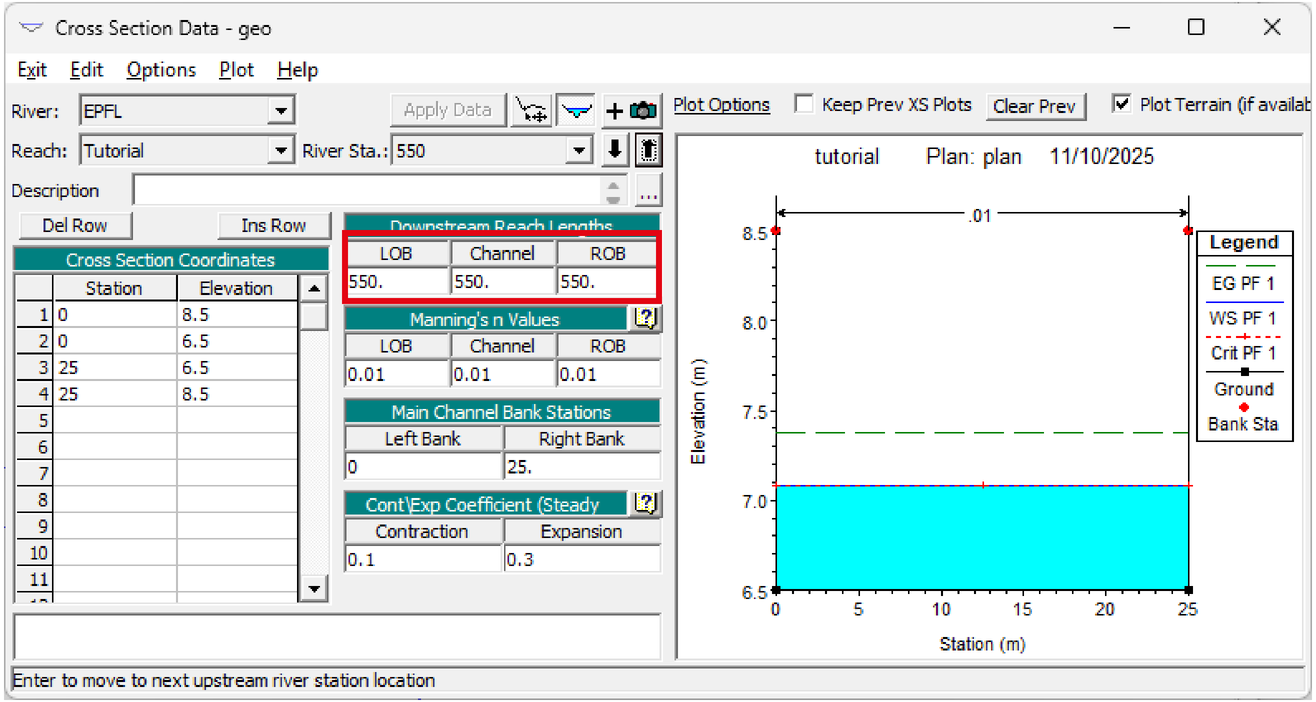




HEC-RAS: Geometry

Now we need to set the distance from this new cross section to the previous.

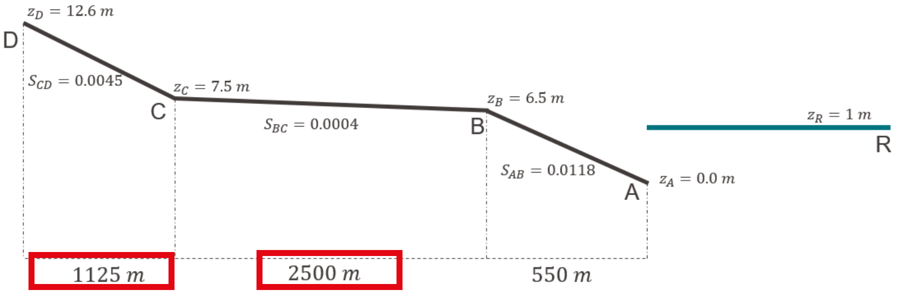


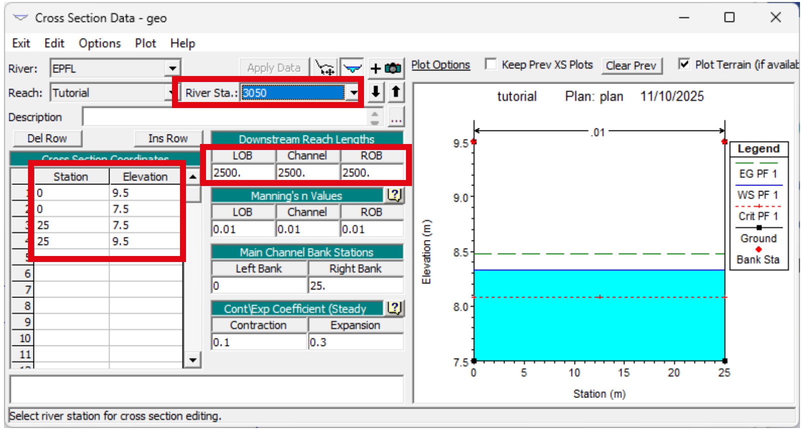


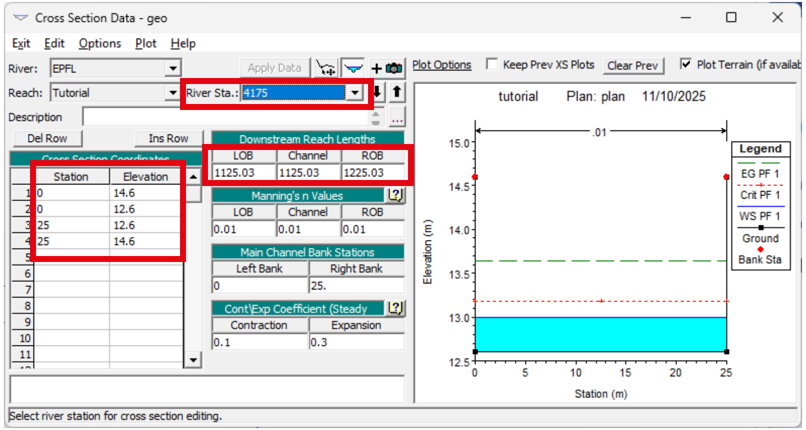
EPFL

HEC-RAS: Geometry

We repeat for sections at C and D, naming them “3050” and “4175”, respectively.

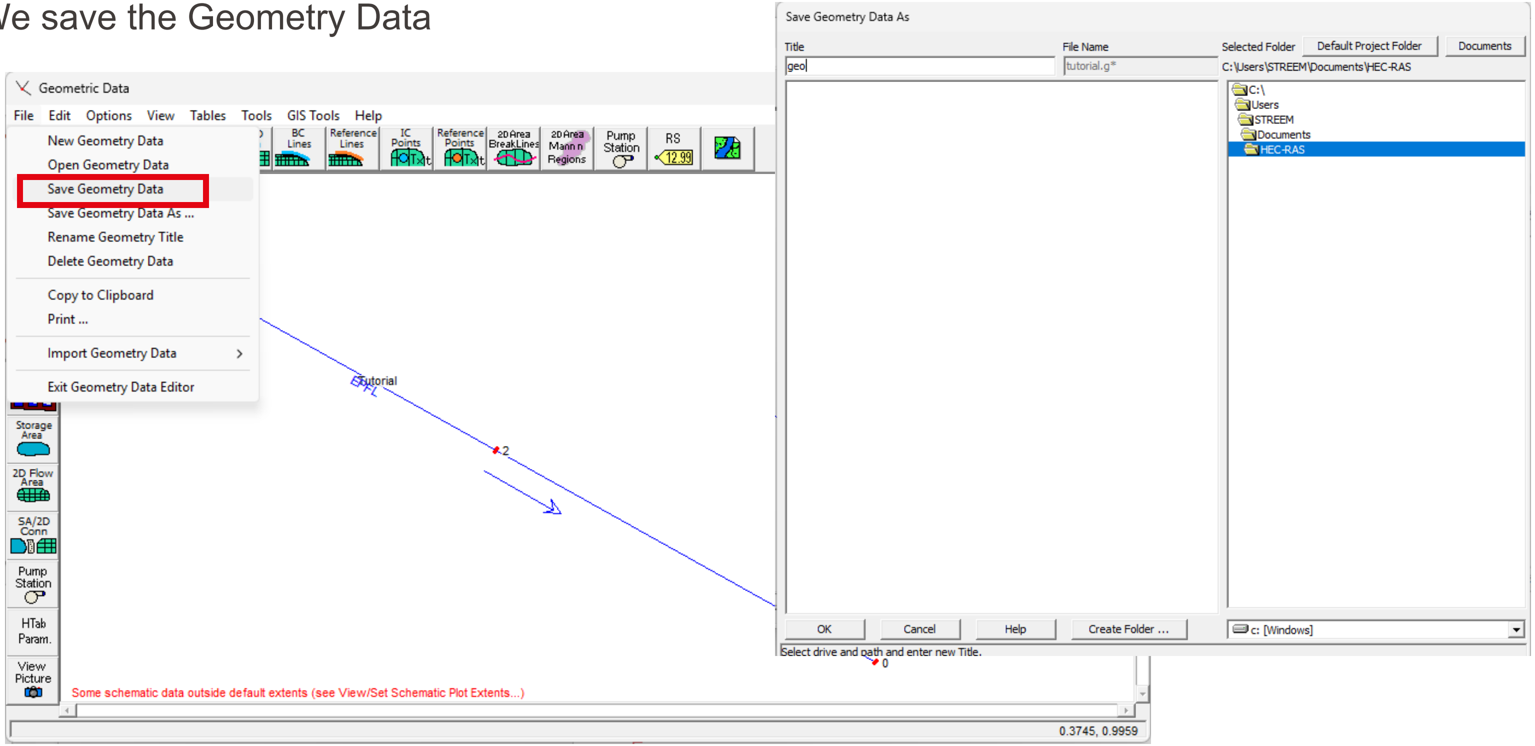






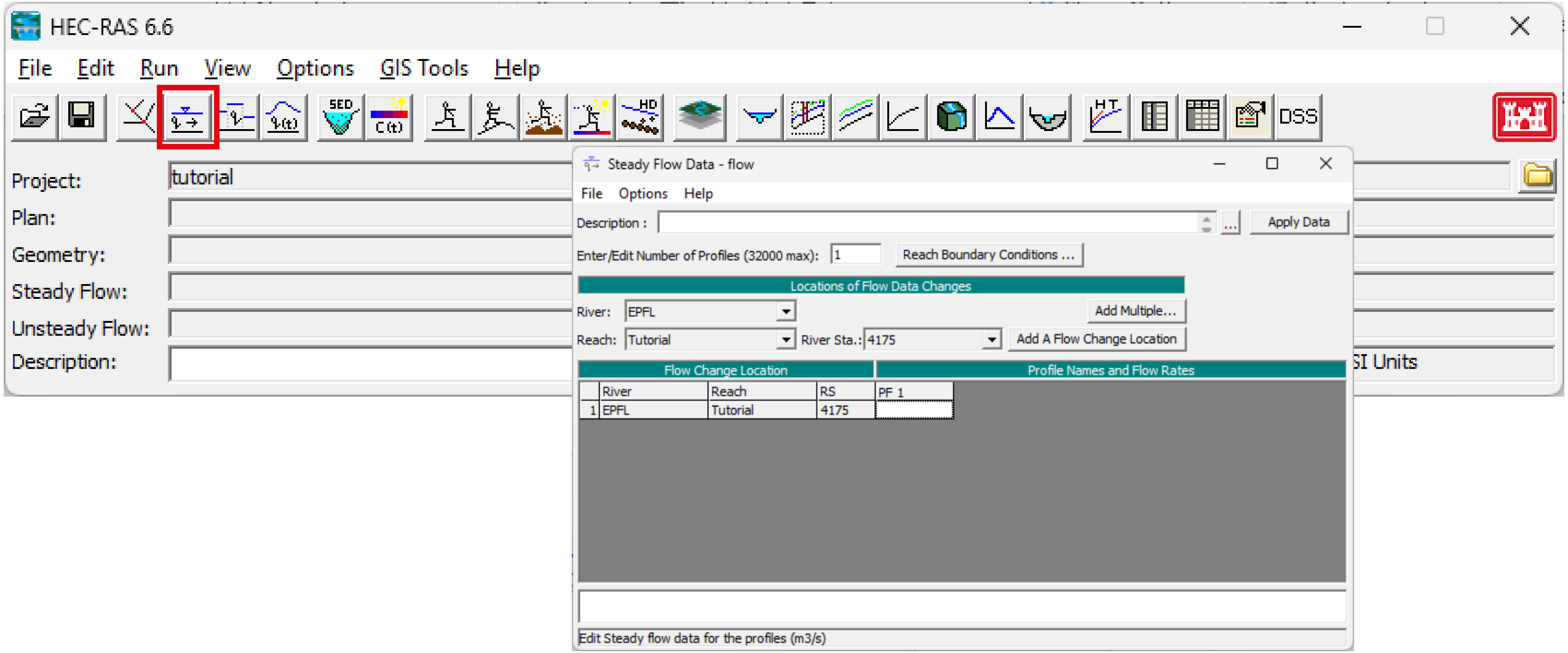
HEC-RAS: Geometry

We save the Geometry Data



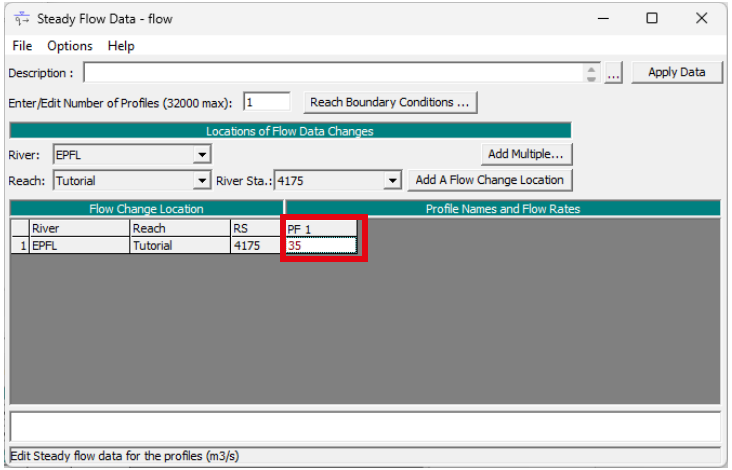
HEC-RAS: Flow Conditions

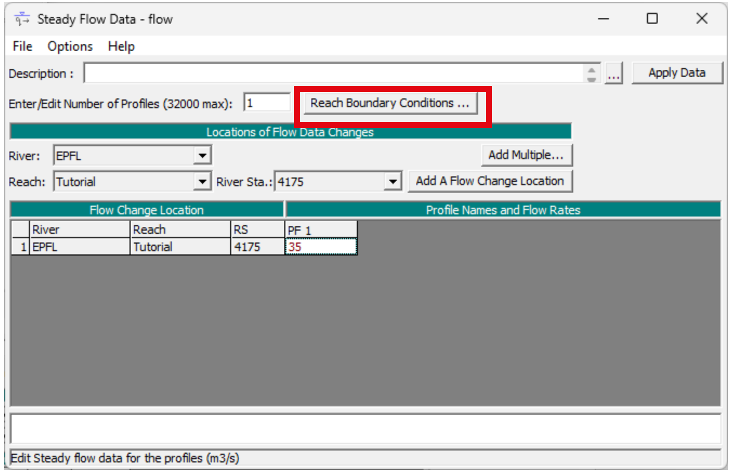
Now we add water to the channel. Steady flow simulation.



HEC-RAS: Flow Conditions

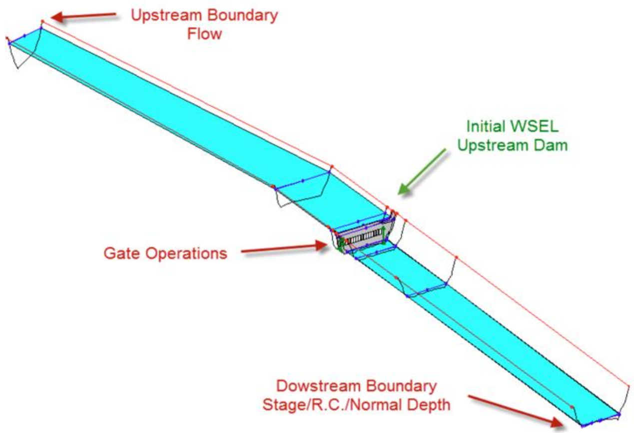
We can try several discharges simultaneously. Now we must enter the Boundary Conditions.





Boundary Conditions

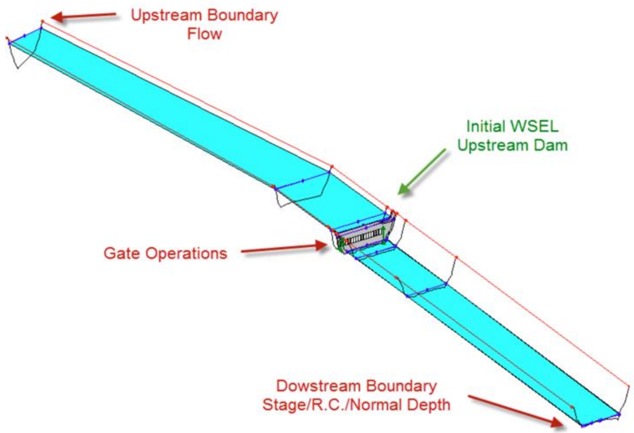
- Define how **flow enters and exits** the modeled system
- Required at **upstream and downstream** ends
- **Upstream Boundary:**
  - Specify **discharge (Q)** for each reach
- **Downstream Boundary:**
  - Specify **water surface or energy condition**, such as:
    - Known water surface elevation
    - Normal depth (energy slope)
    - Rating curve (stage–discharge relationship)



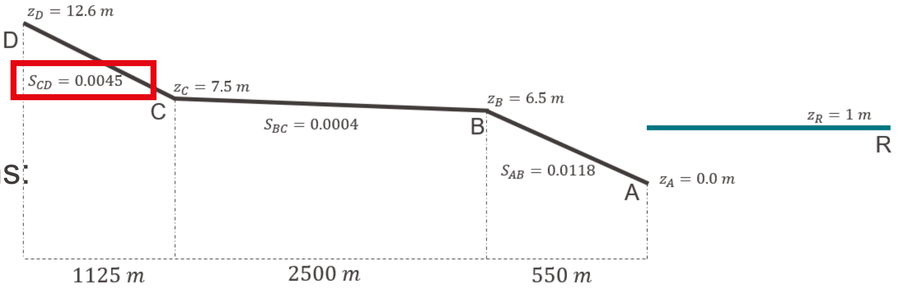
- **Analogy with the Direct Step Method**
  - Both require:
    - **Discharge (Q)** → like the **upstream boundary**
    - **Depth or energy** → like the **downstream boundary**
  - Both compute **gradually varied flow profiles** using known hydraulic states
  - HEC-RAS automates and extends the **Direct Step Method** using detailed geometry and iterative energy balance

Internal Conditions

- Represent **hydraulic controls or transitions** *within* the modeled reach
- Define how flow behavior changes **between cross sections**
- **Common Internal Conditions:**
  - **Bridges & Culverts:** create local energy losses and flow contractions
  - **Weirs, Spillways, and Gates:** control water levels or flow rates
  - **Junctions / Confluences**: split or combine discharges between reaches
  - **Inline or lateral structures**: alter headwater and tailwater relationships
- **Purpose:**
  - Ensure realistic **energy balance** and **flow continuity** at internal locations
  - Capture effects of **obstructions, control structures, and geometry changes**
- **Key Idea:**
  - While external boundaries set **inlet/outlet conditions**, **internal conditions define what happens in between.**

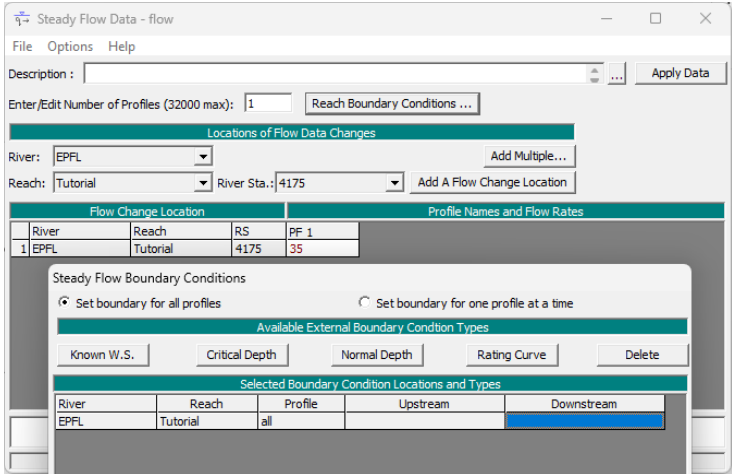


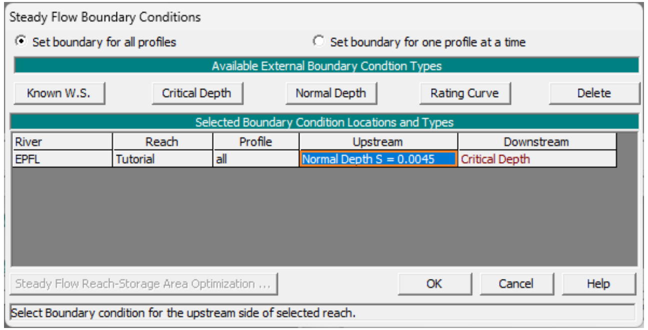
Boundary Conditions



We have different options for Boundary Conditions:

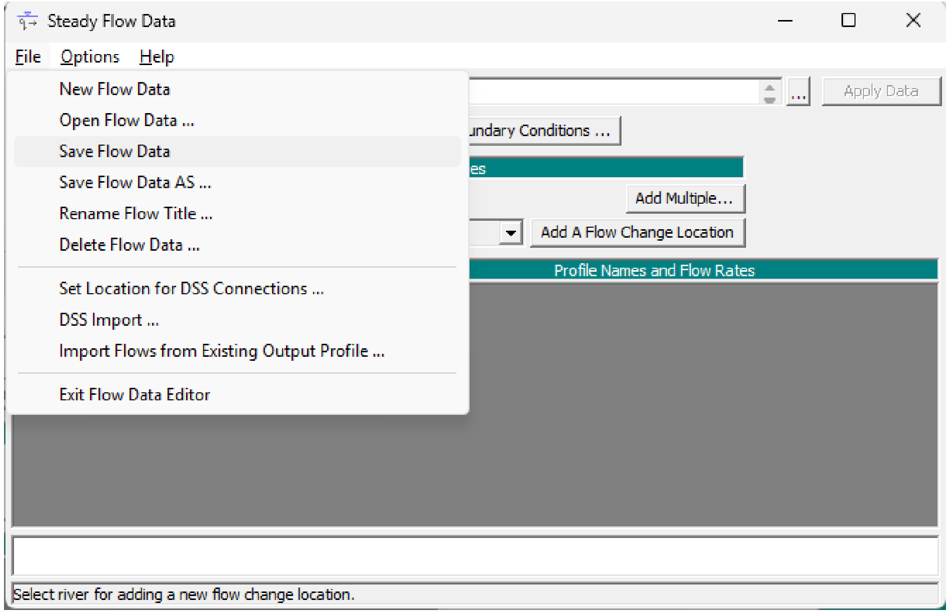
- Known Water Surface level
- Critical Depth
- Normal Depth → Requires slope
- Rating Curve ($Q(h)$)

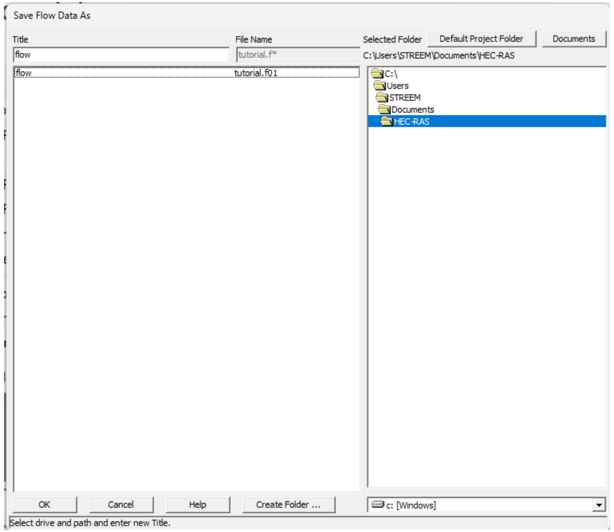




HEC-RAS: Flow Conditions

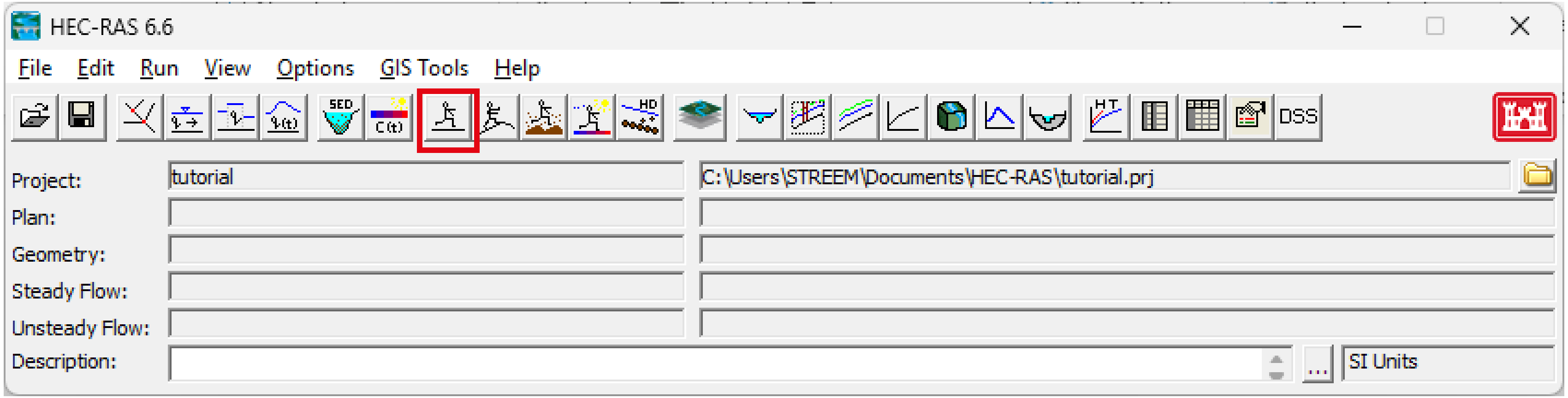
We save the flow data





HEC-RAS: Running

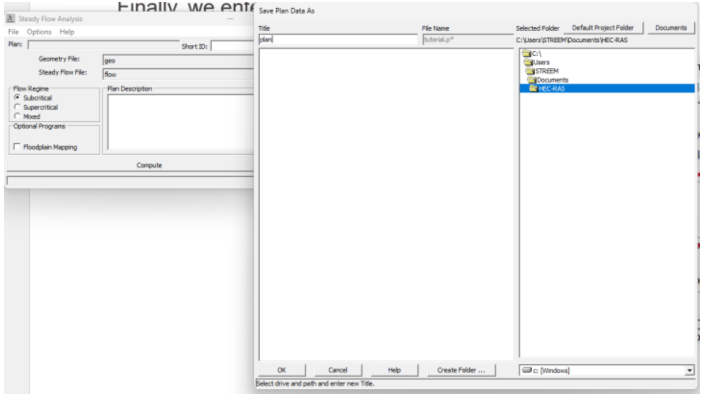
Finally, we enter the “Plan” data

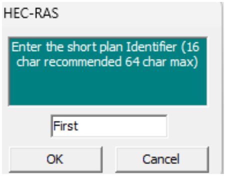


HEC-RAS: Running

Finally, we enter the “Plan” data

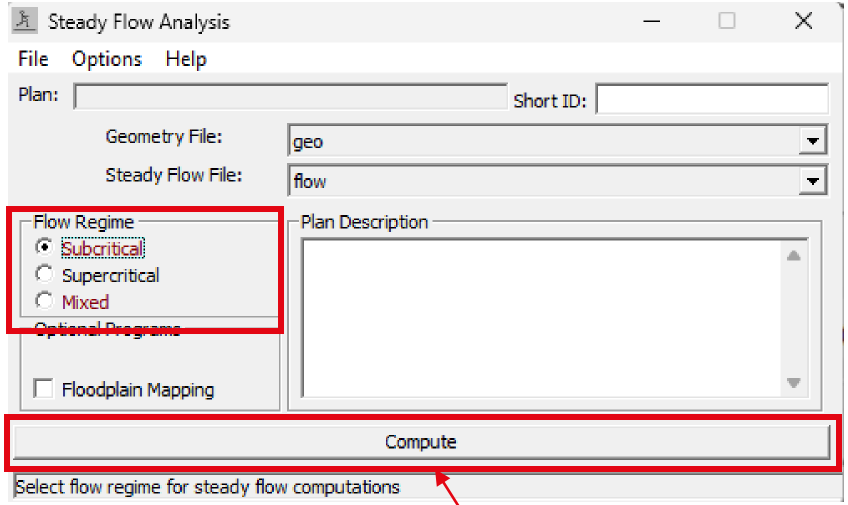
We save it immediately





You can name the Case/Plan

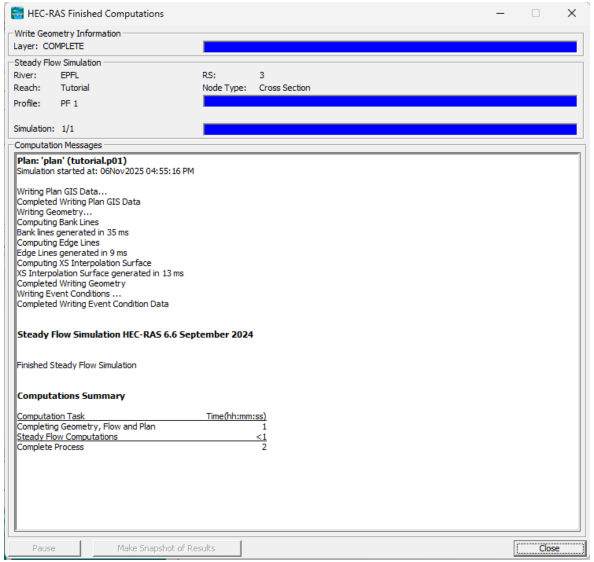
Then we choose the Flow Regime



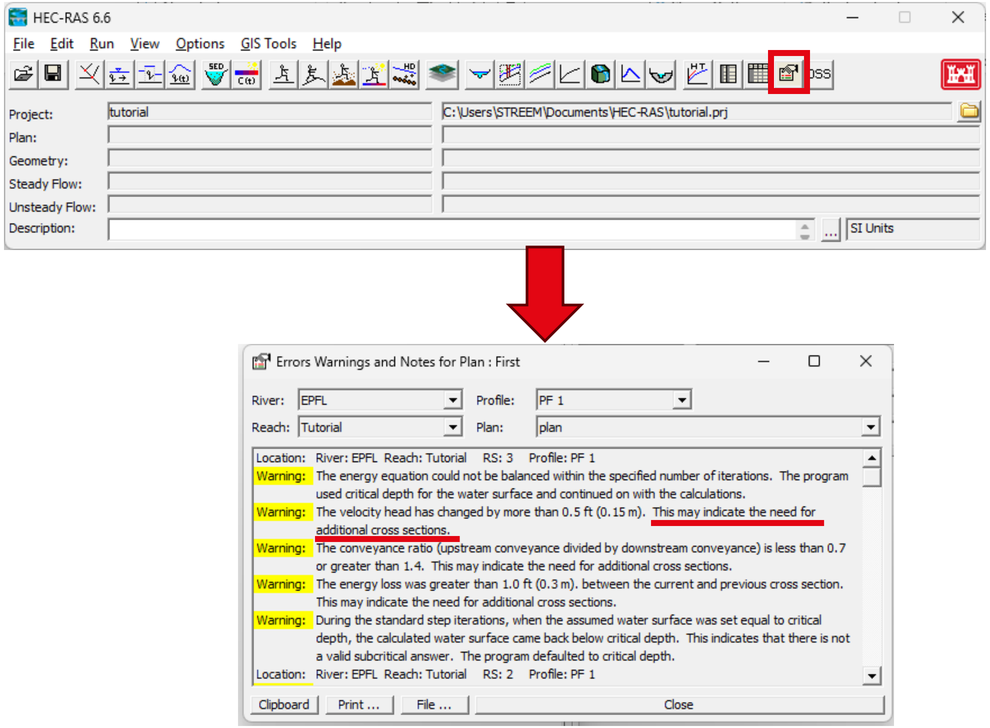
And press “Compute”

HEC-RAS: Running

It runs fast because it's 1D

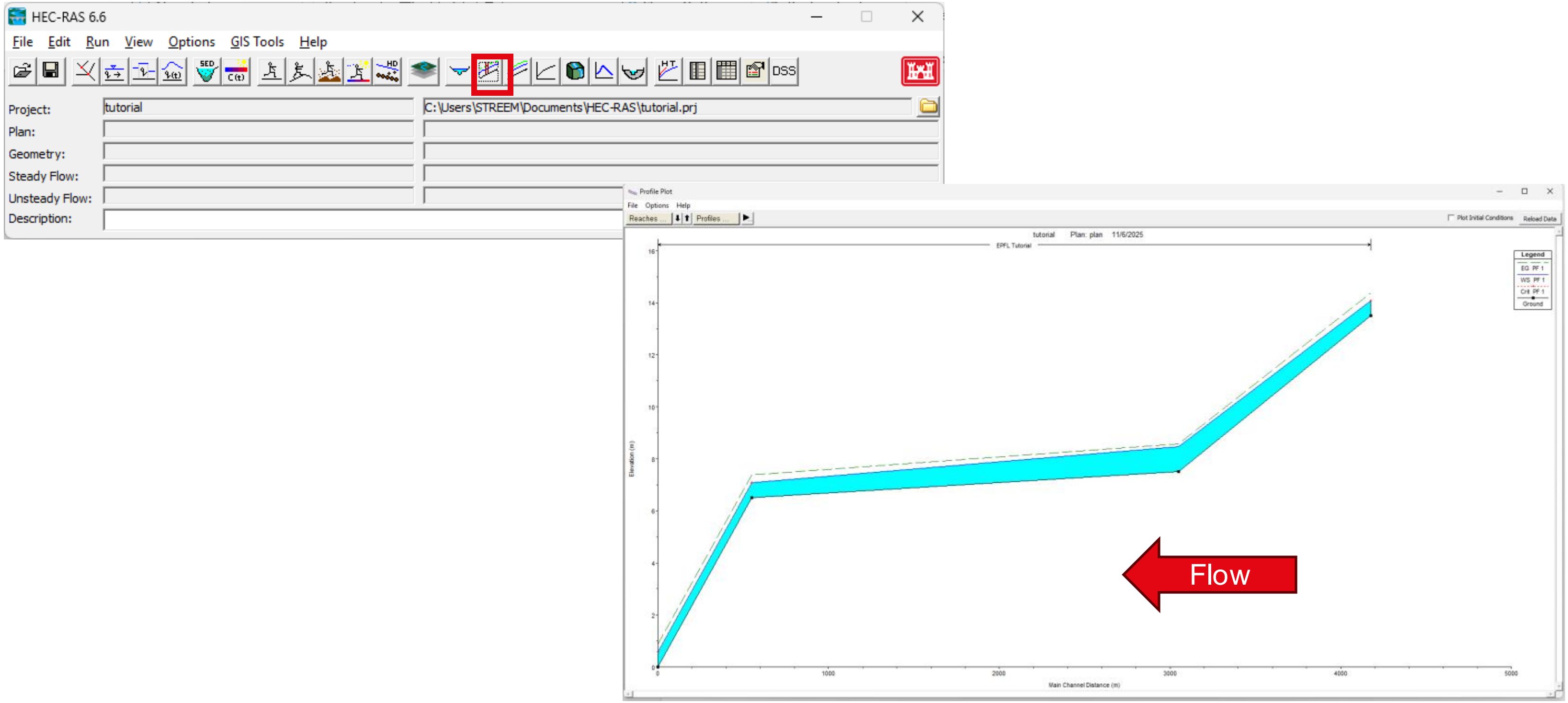


We can check Errors and Warnings



HEC-RAS: Results

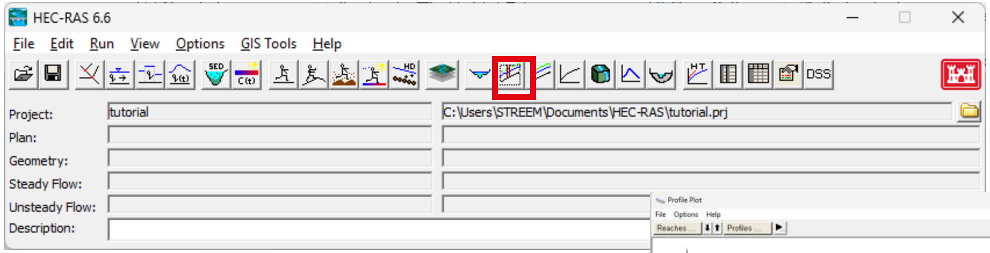
We can see the results:

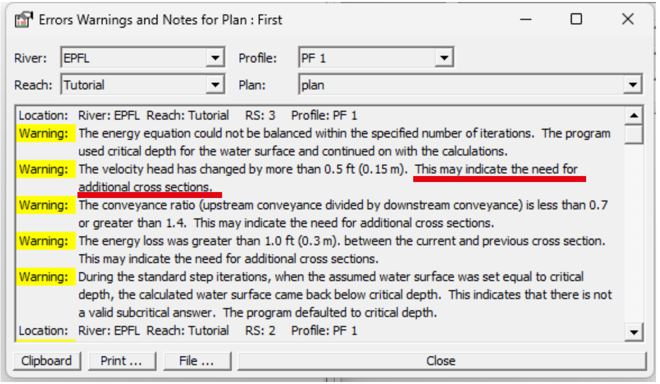


Doesn't look like expected…

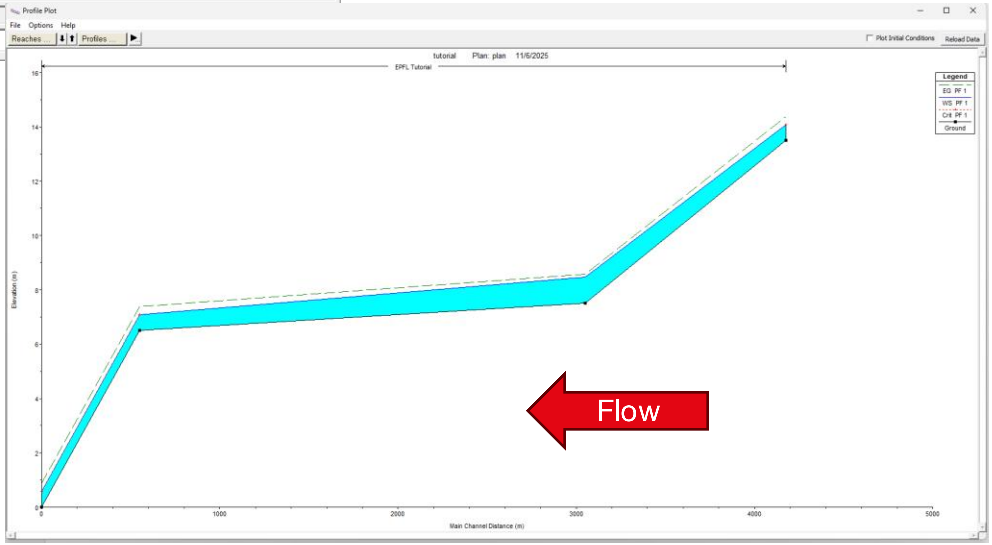
HEC-RAS: Results

We can see the results:





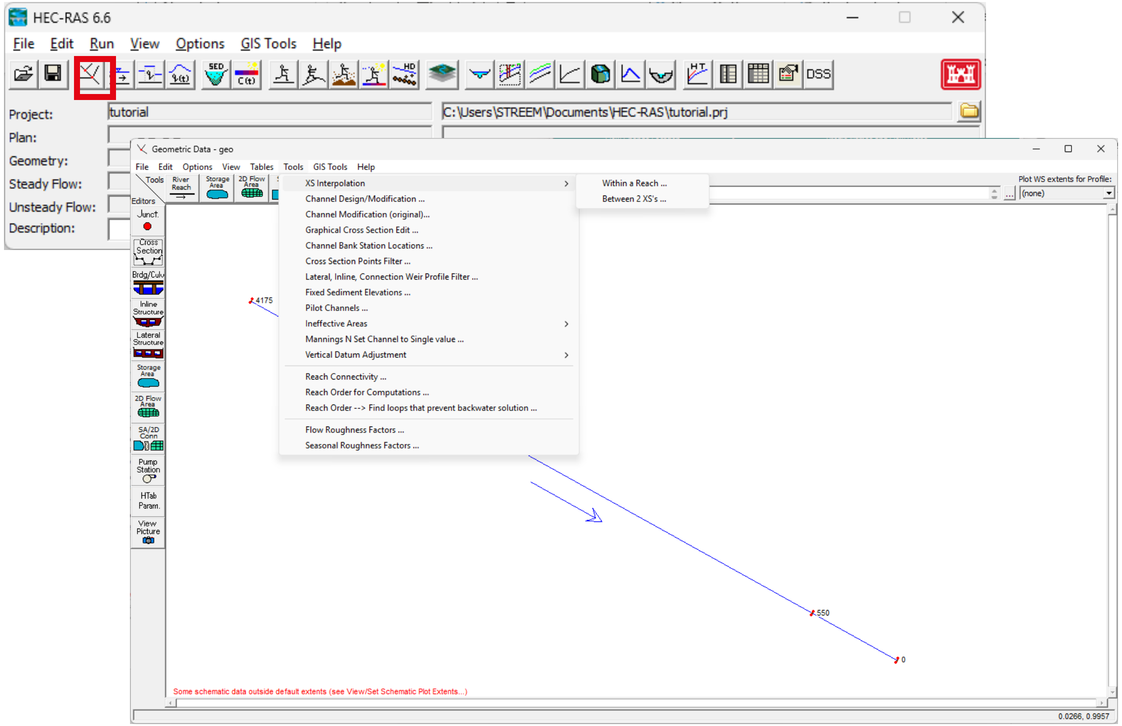
More cross sections :O



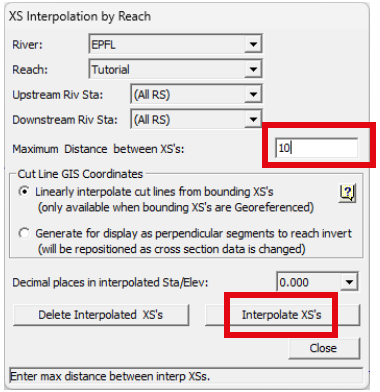
Doesn't look like expected…

HEC-RAS: Interpolation

We go back to Geometry



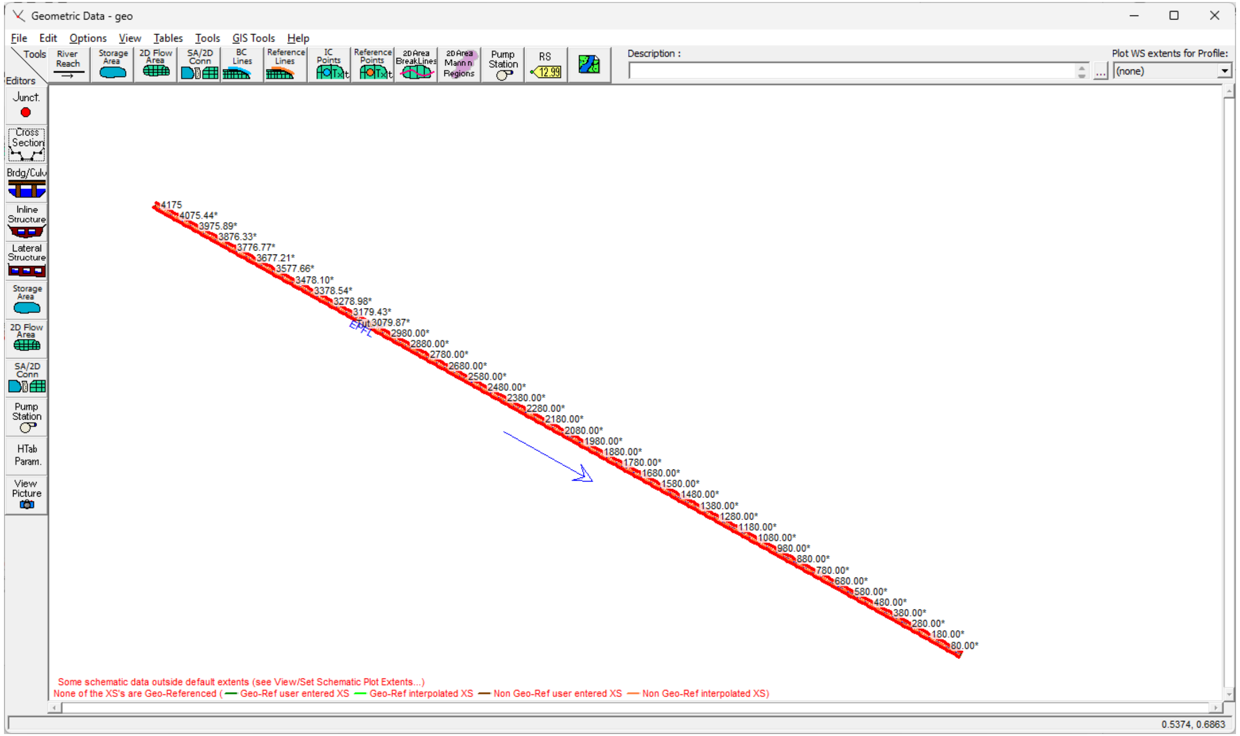
We interpolate Cross Sections (XS's) within a river reach:



Can be done between 2 XS's only

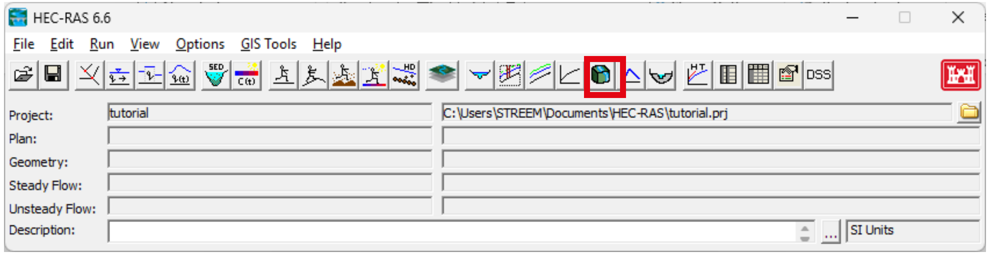
HEC-RAS: Interpolation

Many new sections appeared:

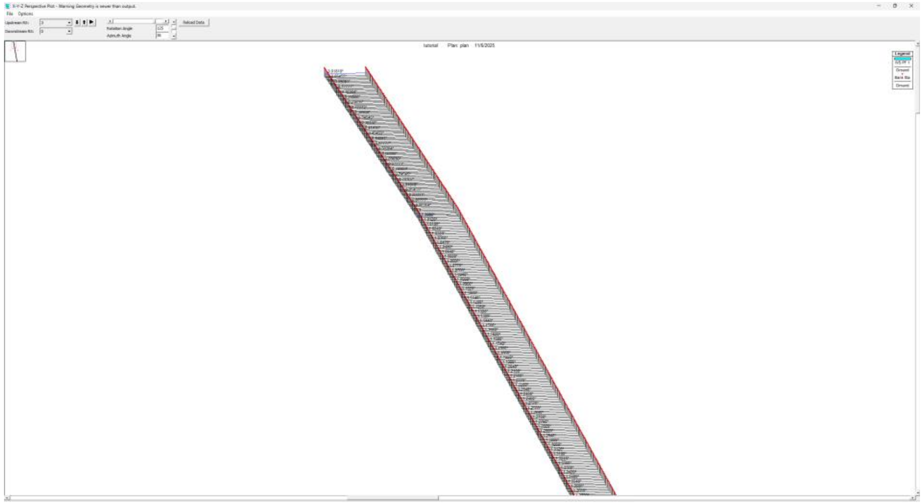


HEC-RAS: Interpolation

We can look at them in “3D”



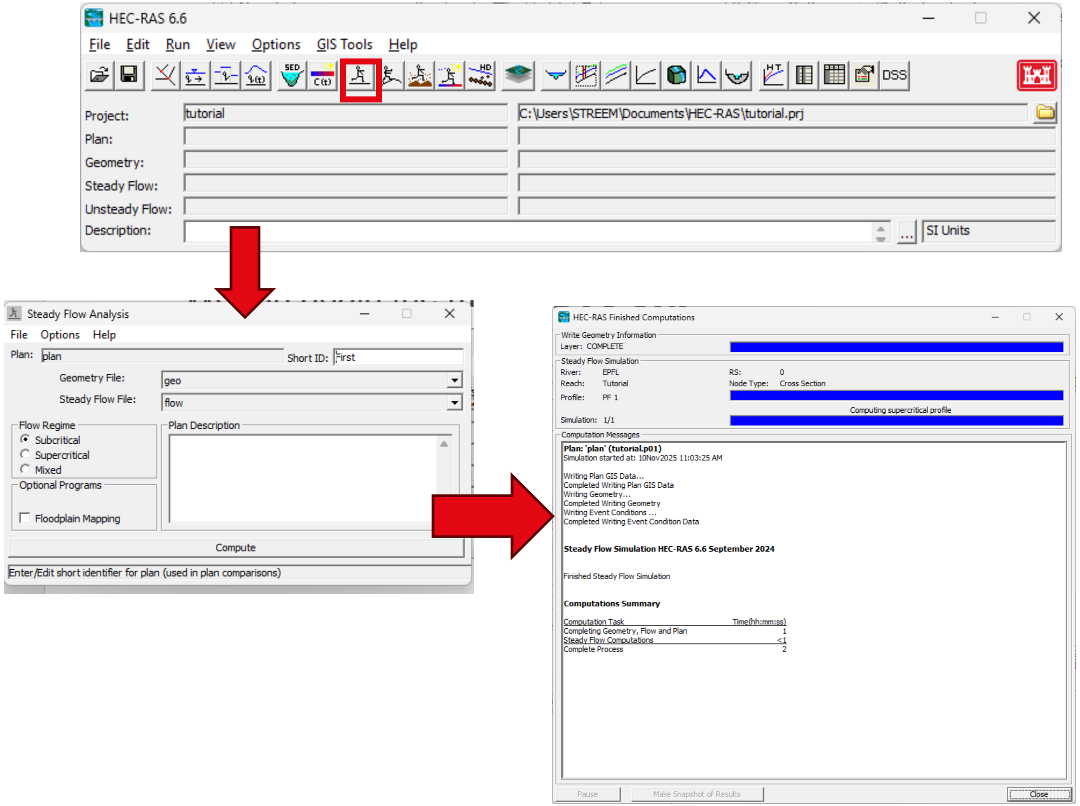
After zooming in and playing with the perspective



The interpolation is linear between sections
We must have sections in areas where sudden changes occur. Otherwise, we’re unable to capture the physics.

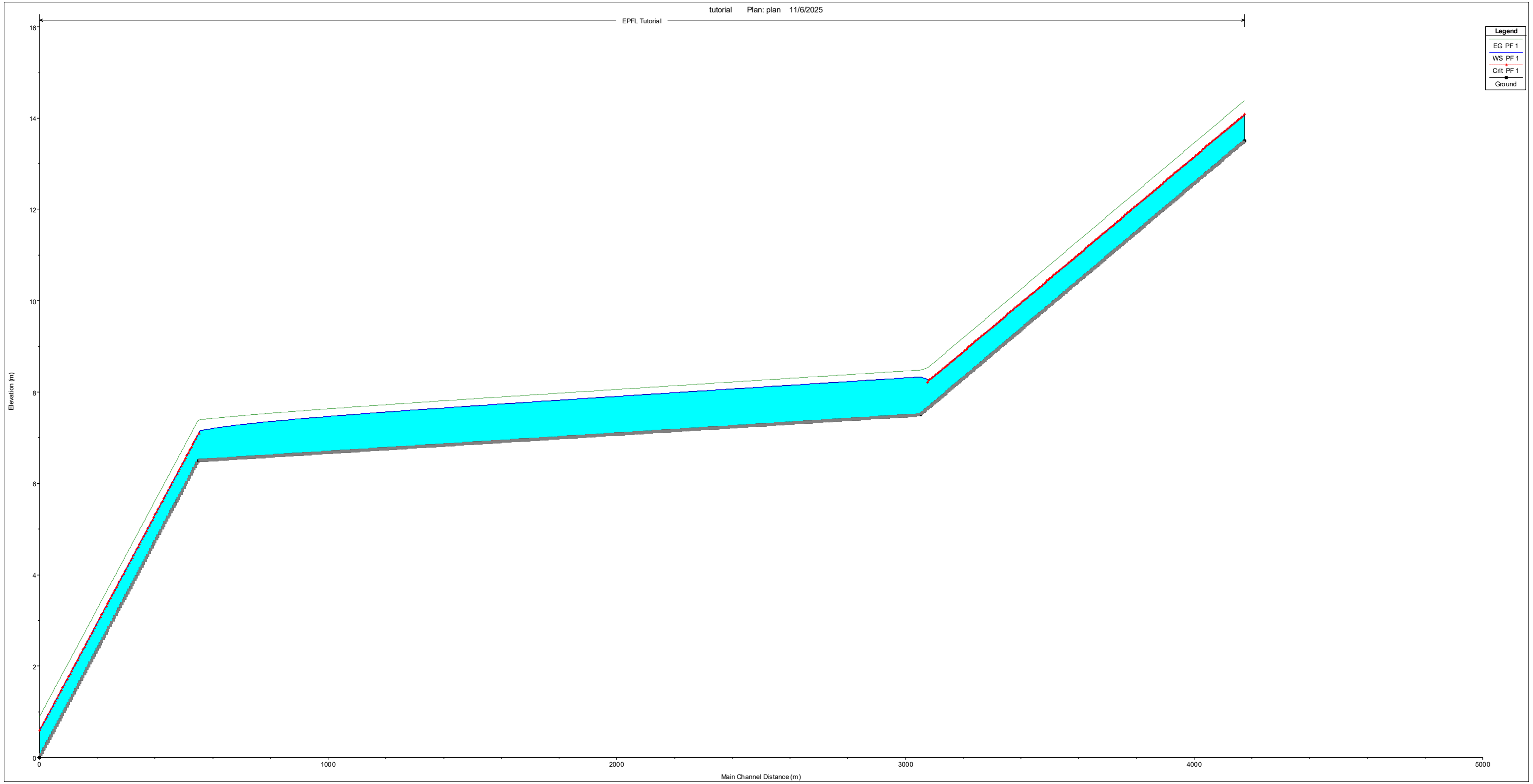
HEC-RAS GUI

We run again the model



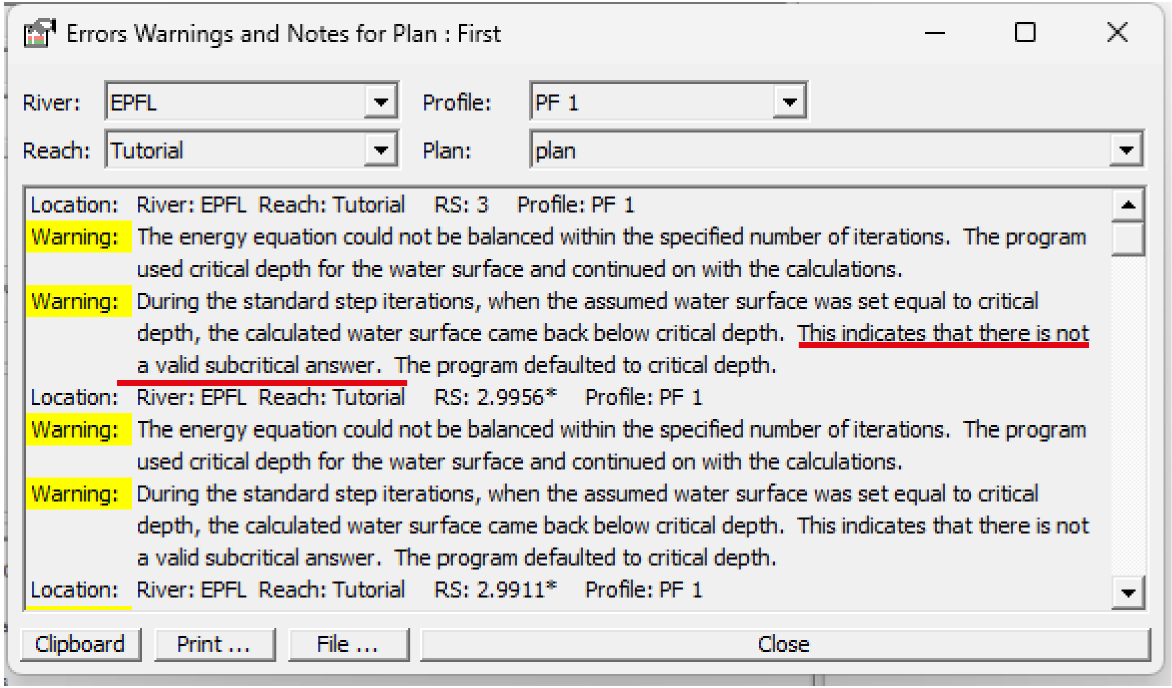
HEC-RAS: Results

It looks better

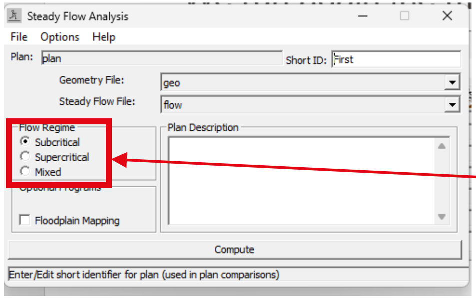


But if we check the warnings…

HEC-RAS: Results



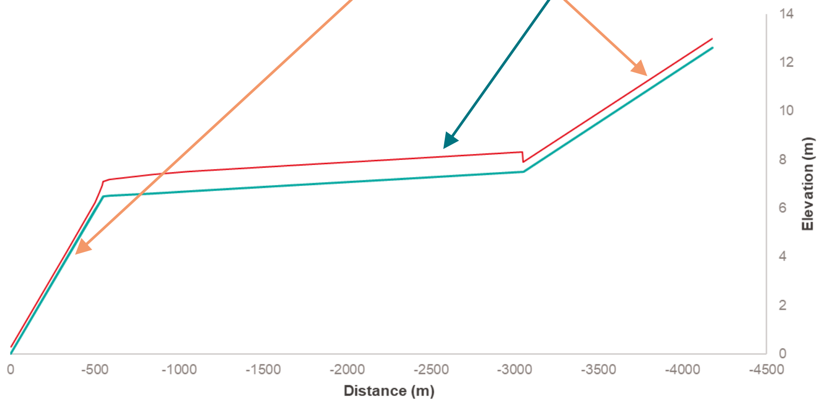
HEC-RAS: Flow Regime



This assumption of subcritical flow everywhere seems to be incorrect :O

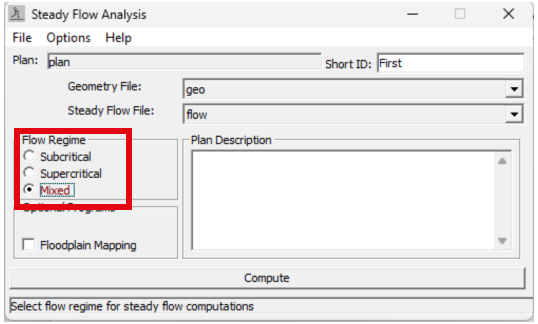
Remember how we said the profile should be?

It's a mix between **super** and **sub** critical flows.



HEC-RAS: Flow Regime

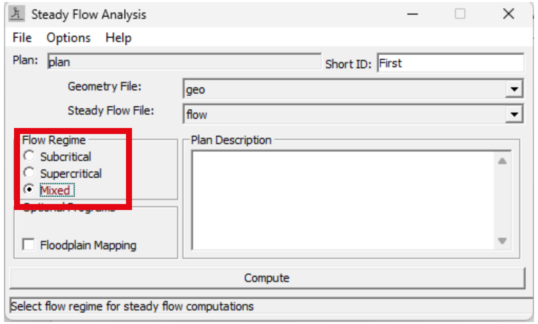
We change it to mixed:



And Compute again.

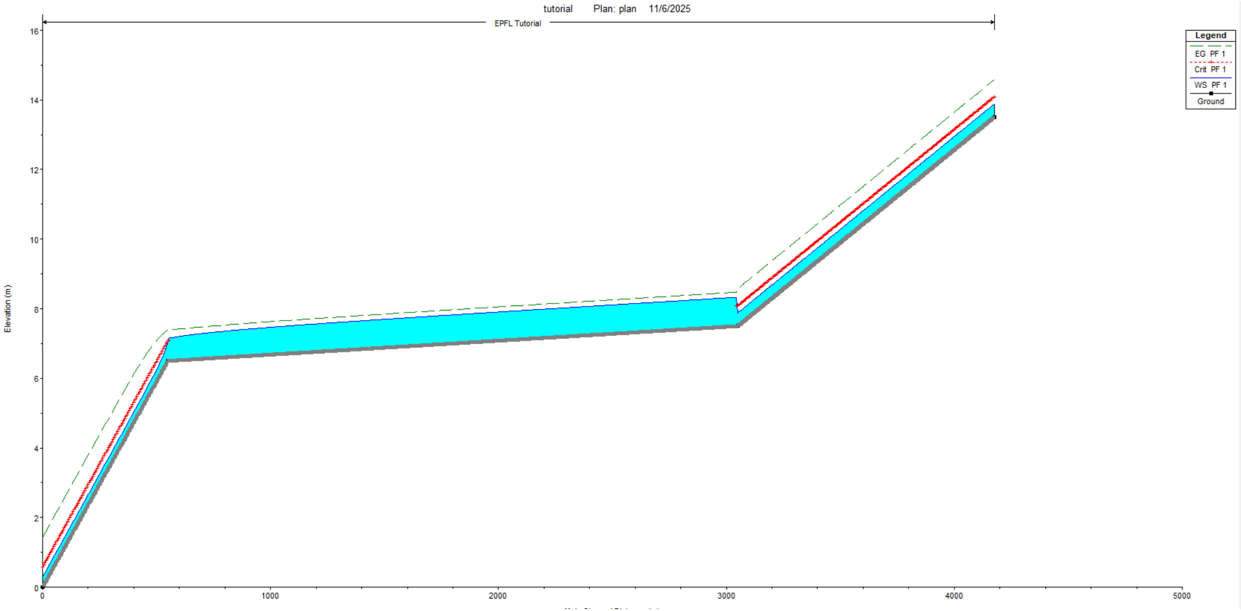
HEC-RAS: Flow Regime

We change it to mixed:



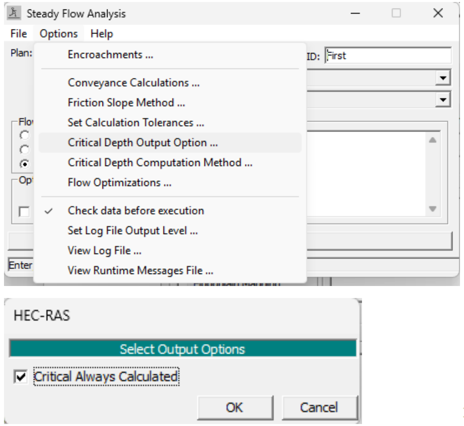
And Compute again.

Now it looks as we said:

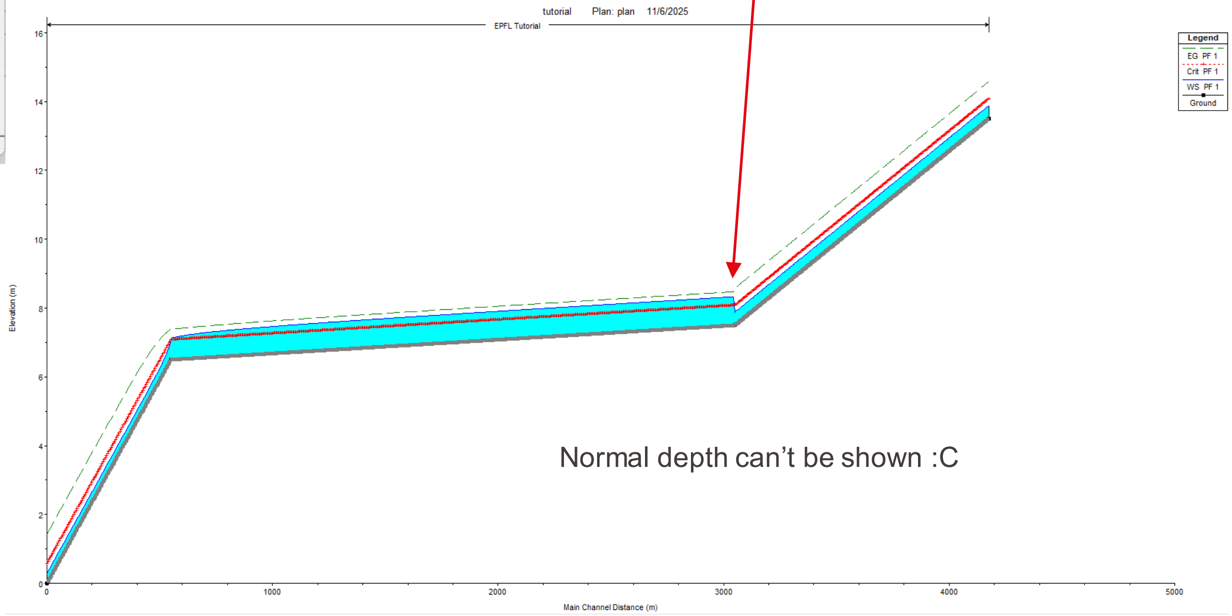


HEC-RAS: Results

We can also force the critical depth to show everywhere:



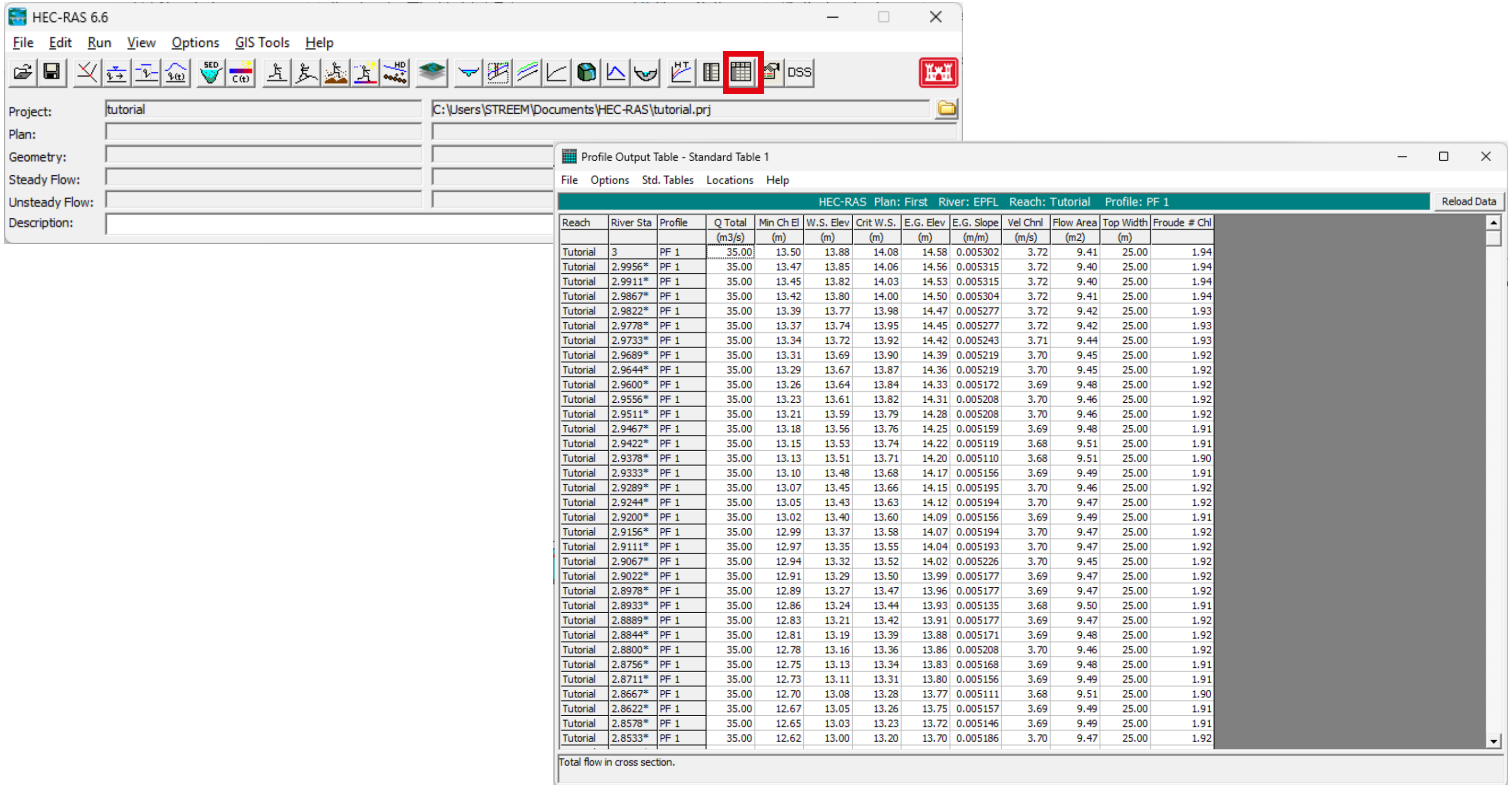
Hydraulic jumps are always plotted between 2 sections only, even if the length is greater than the separation between those 2 XS's



Normal depth can't be shown :C

HEC-RAS: Results

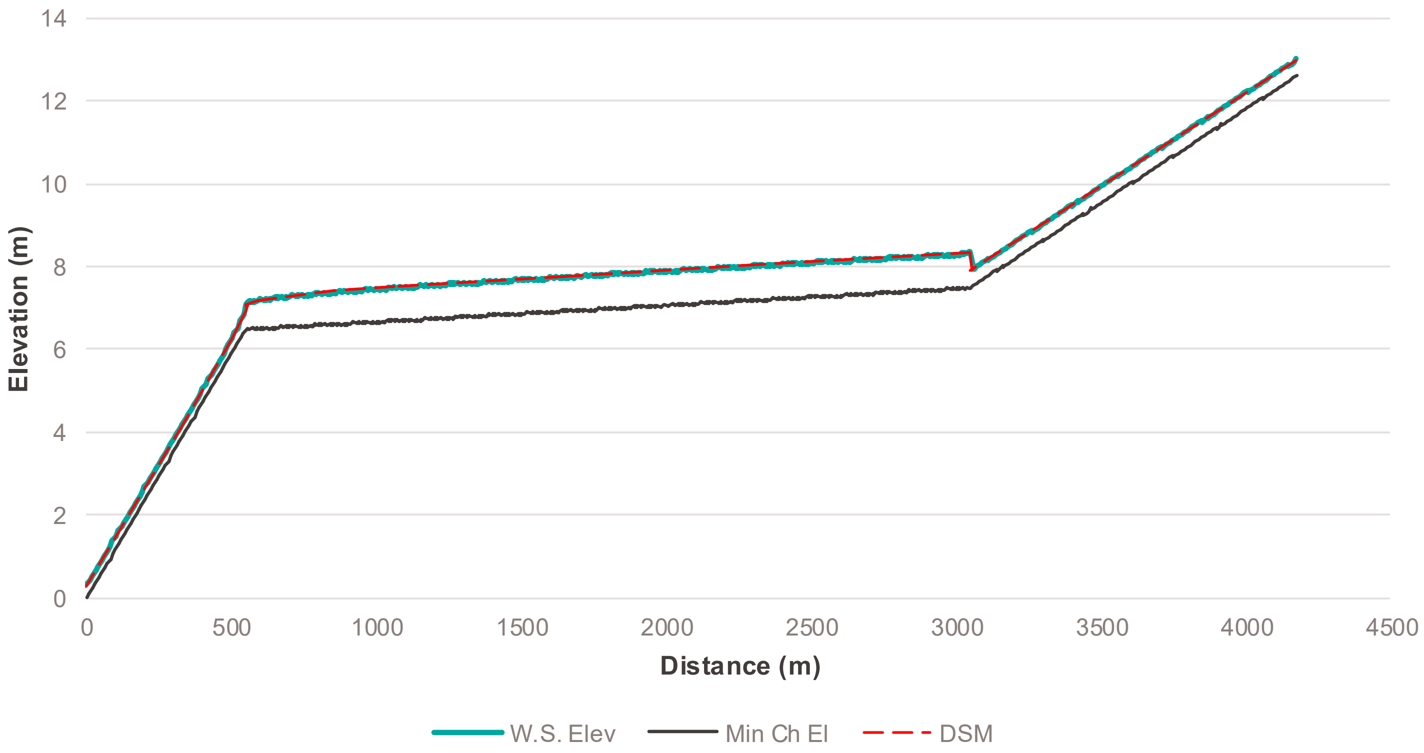
We can get results as table



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
Tutorial	3	PF 1	35.00	13.50	13.88	14.08	14.58	0.005302	3.72	9.41	25.00	1.94
Tutorial	2.9956*	PF 1	35.00	13.47	13.85	14.06	14.56	0.005315	3.72	9.40	25.00	1.94
Tutorial	2.9911*	PF 1	35.00	13.45	13.82	14.03	14.53	0.005315	3.72	9.40	25.00	1.94
Tutorial	2.9867*	PF 1	35.00	13.42	13.80	14.00	14.50	0.005304	3.72	9.41	25.00	1.94
Tutorial	2.9822*	PF 1	35.00	13.39	13.77	13.98	14.47	0.005277	3.72	9.42	25.00	1.93
Tutorial	2.9778*	PF 1	35.00	13.37	13.74	13.95	14.45	0.005277	3.72	9.42	25.00	1.93
Tutorial	2.9733*	PF 1	35.00	13.34	13.72	13.92	14.42	0.005243	3.71	9.44	25.00	1.93
Tutorial	2.9689*	PF 1	35.00	13.31	13.69	13.90	14.39	0.005219	3.70	9.45	25.00	1.92
Tutorial	2.9644*	PF 1	35.00	13.29	13.67	13.87	14.36	0.005219	3.70	9.45	25.00	1.92
Tutorial	2.9600*	PF 1	35.00	13.26	13.64	13.84	14.33	0.005172	3.69	9.48	25.00	1.92
Tutorial	2.9556*	PF 1	35.00	13.23	13.61	13.82	14.31	0.005208	3.70	9.46	25.00	1.92
Tutorial	2.9511*	PF 1	35.00	13.21	13.59	13.79	14.28	0.005208	3.70	9.46	25.00	1.92
Tutorial	2.9467*	PF 1	35.00	13.18	13.56	13.76	14.25	0.005159	3.69	9.48	25.00	1.91
Tutorial	2.9422*	PF 1	35.00	13.15	13.53	13.74	14.22	0.005119	3.68	9.51	25.00	1.91
Tutorial	2.9378*	PF 1	35.00	13.13	13.51	13.71	14.20	0.005110	3.68	9.51	25.00	1.90
Tutorial	2.9333*	PF 1	35.00	13.10	13.48	13.68	14.17	0.005156	3.69	9.49	25.00	1.91
Tutorial	2.9289*	PF 1	35.00	13.07	13.45	13.66	14.15	0.005195	3.70	9.46	25.00	1.92
Tutorial	2.9244*	PF 1	35.00	13.05	13.43	13.63	14.12	0.005194	3.70	9.47	25.00	1.92
Tutorial	2.9200*	PF 1	35.00	13.02	13.40	13.60	14.09	0.005156	3.69	9.49	25.00	1.91
Tutorial	2.9156*	PF 1	35.00	12.99	13.37	13.58	14.07	0.005194	3.70	9.47	25.00	1.92
Tutorial	2.9111*	PF 1	35.00	12.97	13.35	13.55	14.04	0.005193	3.70	9.47	25.00	1.92
Tutorial	2.9067*	PF 1	35.00	12.94	13.32	13.52	14.02	0.005226	3.70	9.45	25.00	1.92
Tutorial	2.9022*	PF 1	35.00	12.91	13.29	13.50	13.99	0.005177	3.69	9.47	25.00	1.92
Tutorial	2.8978*	PF 1	35.00	12.89	13.27	13.47	13.96	0.005177	3.69	9.47	25.00	1.92
Tutorial	2.8933*	PF 1	35.00	12.86	13.24	13.44	13.93	0.005135	3.68	9.50	25.00	1.91
Tutorial	2.8889*	PF 1	35.00	12.83	13.21	13.42	13.91	0.005177	3.69	9.47	25.00	1.92
Tutorial	2.8844*	PF 1	35.00	12.81	13.19	13.39	13.88	0.005171	3.69	9.48	25.00	1.92
Tutorial	2.8800*	PF 1	35.00	12.78	13.16	13.36	13.86	0.005208	3.70	9.46	25.00	1.92
Tutorial	2.8756*	PF 1	35.00	12.75	13.13	13.34	13.83	0.005168	3.69	9.48	25.00	1.91
Tutorial	2.8711*	PF 1	35.00	12.73	13.11	13.31	13.80	0.005156	3.69	9.49	25.00	1.91
Tutorial	2.8667*	PF 1	35.00	12.70	13.08	13.28	13.77	0.005111	3.68	9.51	25.00	1.90
Tutorial	2.8622*	PF 1	35.00	12.67	13.05	13.26	13.75	0.005157	3.69	9.49	25.00	1.91
Tutorial	2.8578*	PF 1	35.00	12.65	13.03	13.23	13.72	0.005146	3.69	9.49	25.00	1.91
Tutorial	2.8533*	PF 1	35.00	12.62	13.00	13.20	13.70	0.005186	3.70	9.47	25.00	1.92

HEC-RAS: Results

And compare with our Direct-Step Method results:



Exercise

Model the following situation. Which Boundary Conditions do you think are more appropriate for this case? If you double the discharge, how does the Hydraulic Profile change? How would you solve this problem with the Direct-Step Method?