2D Bridge Modeling

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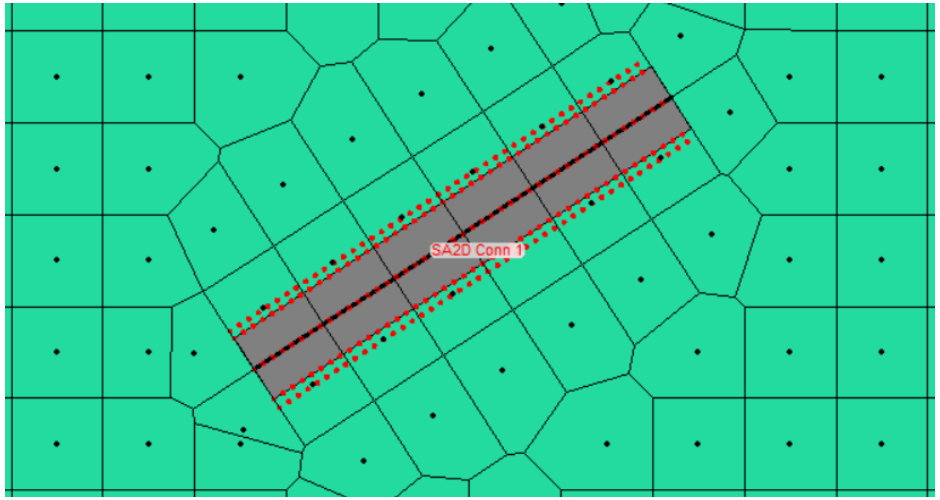
Approaches for Bridge Modeling

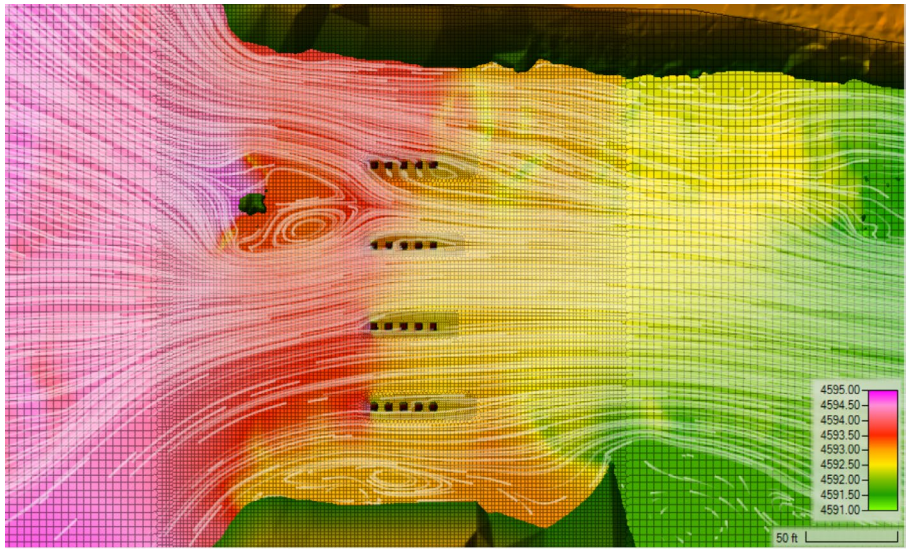
Simplified 2D Bridge Modeling (1D Family of Rating Curves)

- Enforces precomputed 1D bridge curves from a nested 1D bridge model
- Can handle any flow regime
- Cannot simulate detailed flow
- Terrain Modifications not necessary



Detailed 2D Bridge Modeling

- Handles pressure and overtopping
- Detailed Computational Mesh and Terrain Modifications
- Detailed flow through and over bridge

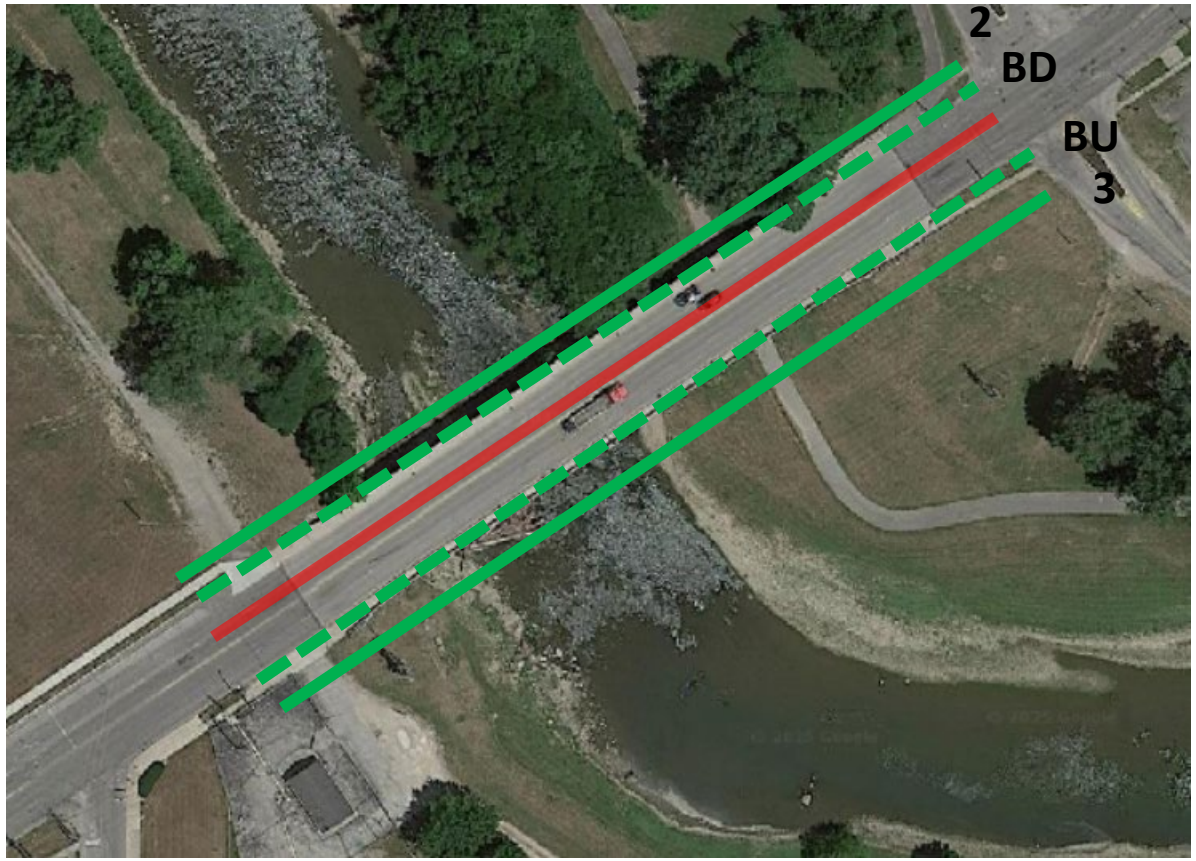


Simplified 2D Bridge Hydraulics

- Utilizing existing HEC-RAS 1D Bridge Hydraulics methods (Family of Rating Curves) inside of a 2D Flow Area

- Model complete range of Bridge Hydraulic flow regimes
  - Low flow
  - Pressure flow
  - Pressure flow and weir flow (road over-topping)
  - Low flow and weir flow

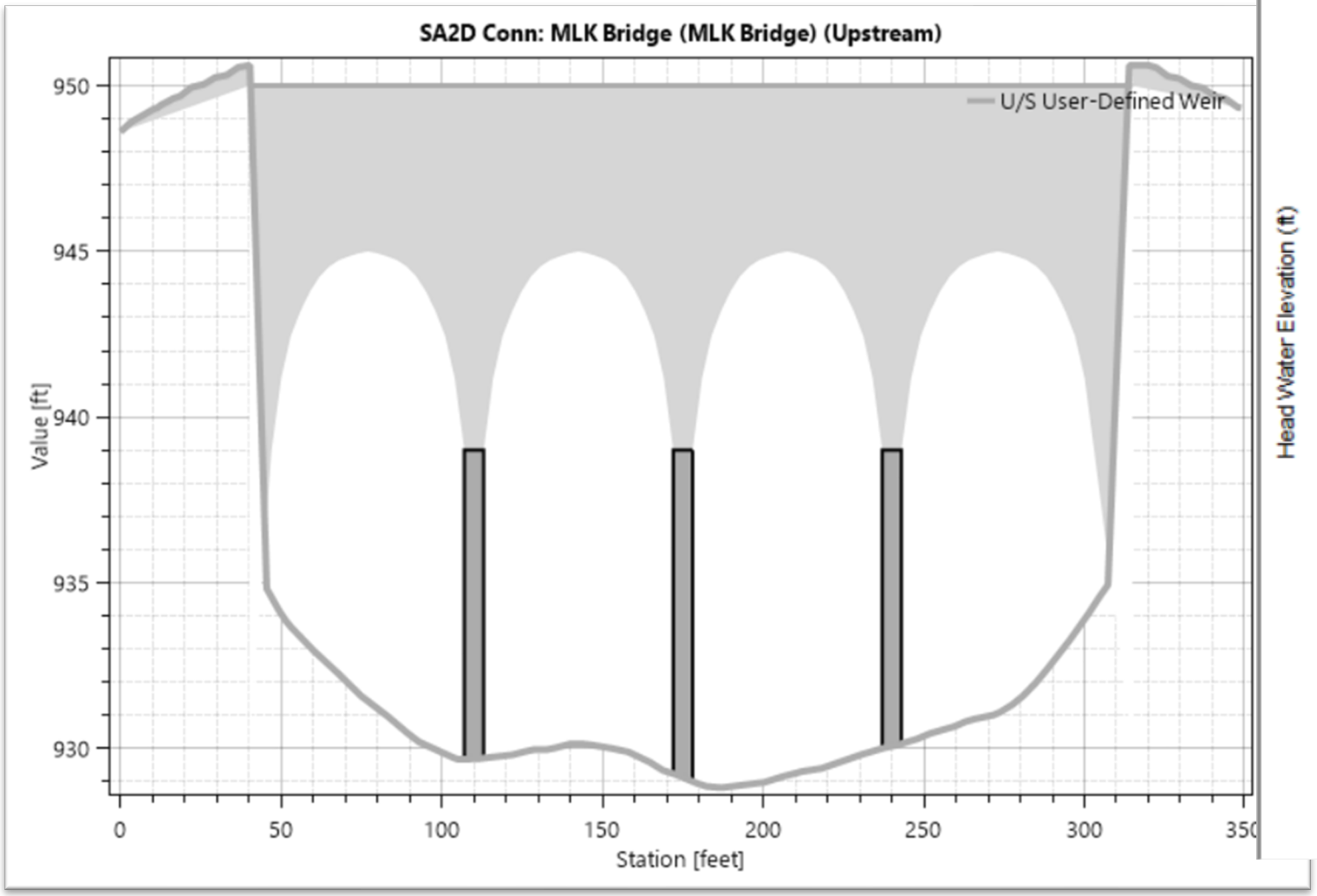
1D Bridge Hydraulics Layout

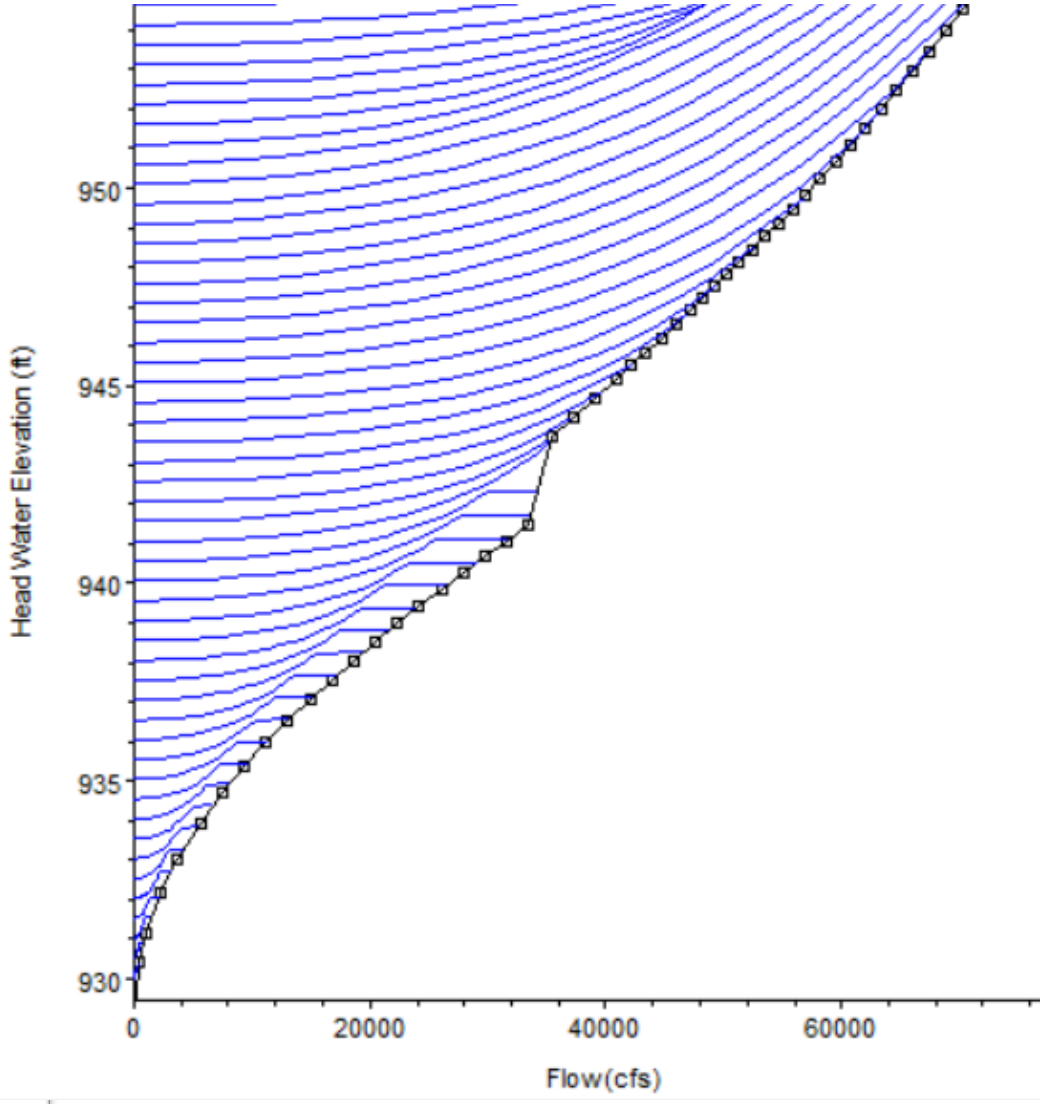


- XS2 - D/S away from embankment
- BD – D/S face of bridge
- BU – U/S face of bridge
- XS3 – U/S away from embankment

- Develop a HW/TW relationship for a given flow from XS2 to XS3 - “Family of Rating Curves”

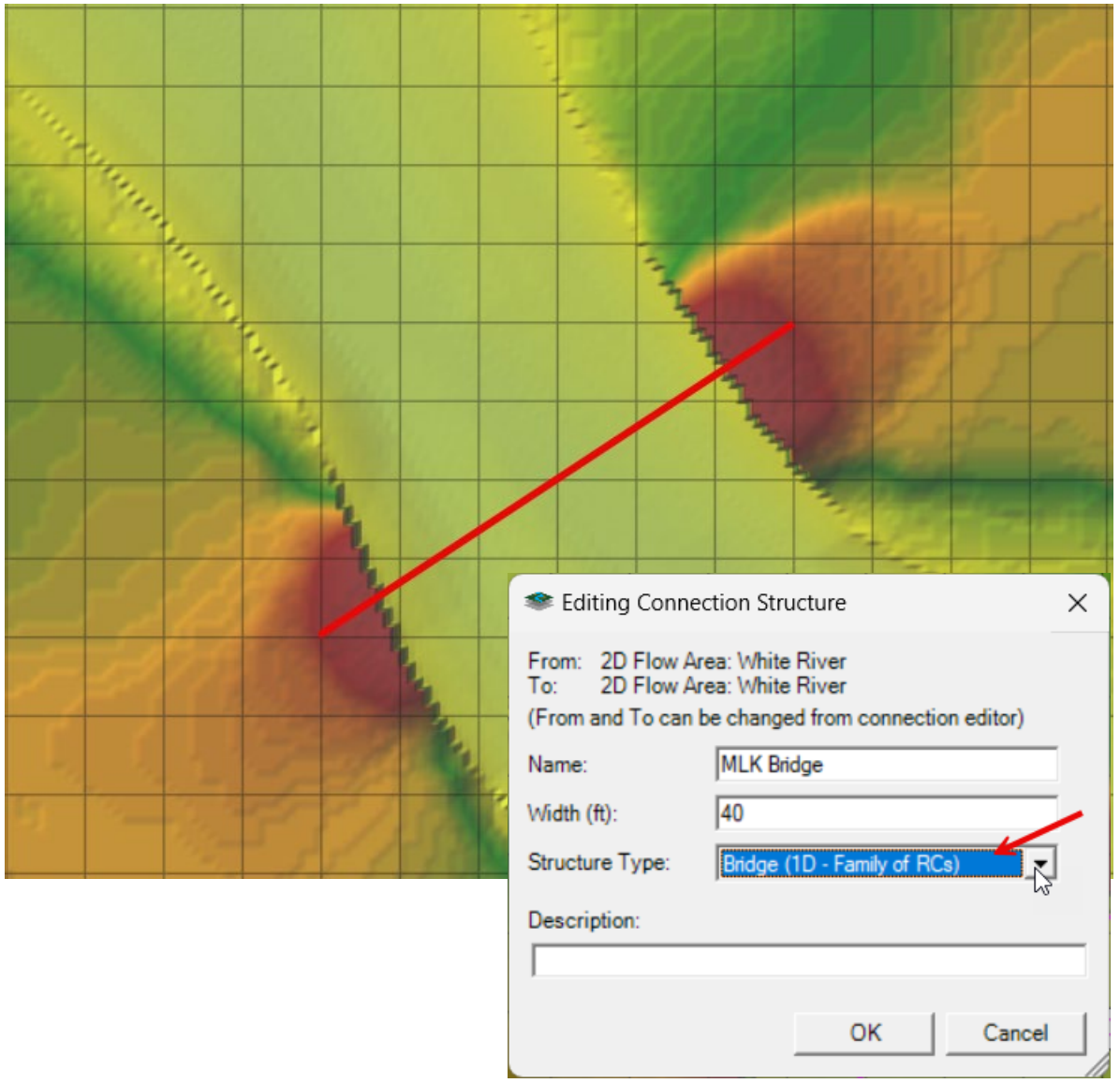
HTab – Family of Bridge Curves





2D Bridge Layout

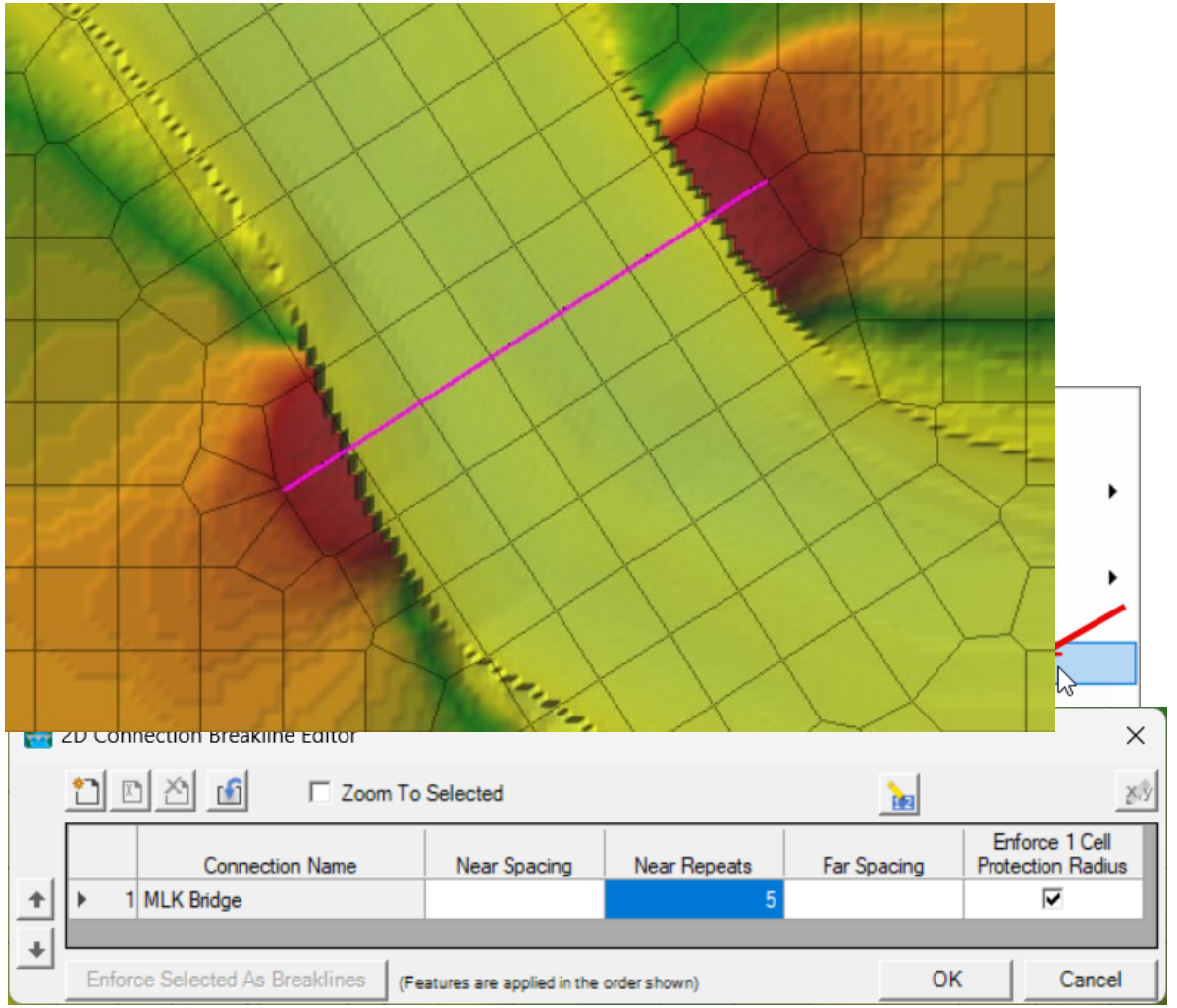
- Bridge is specified as a **SA/2D Connection**
- Choose **Bridge** structure type
- Only model **bridge opening** (if weir flow in overbanks add structure for that – or use 2D equations for non-weir flow)



2D Bridge Layout

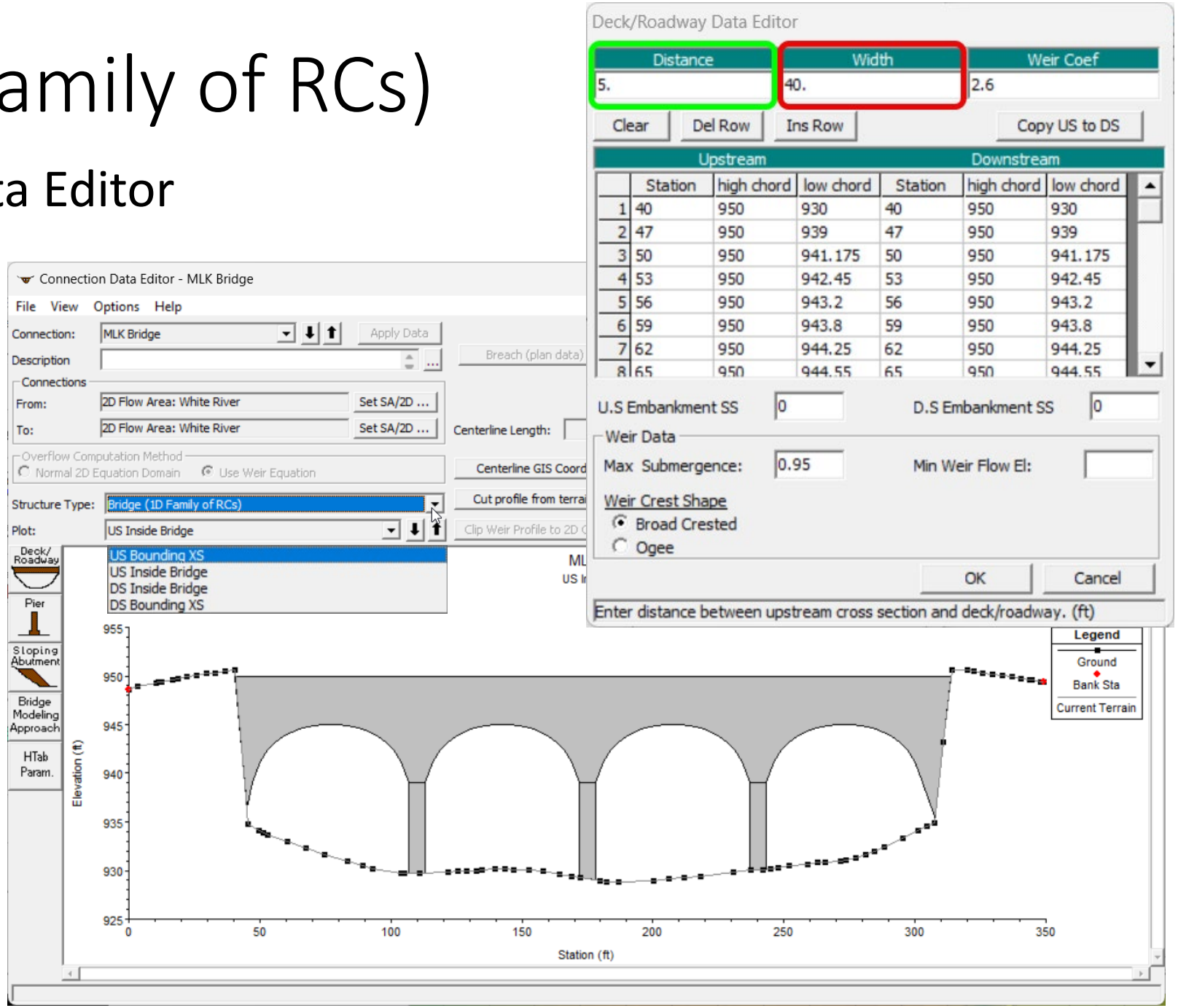
- Note that the mesh faces snap to bridge line

- Specify Breakline Near Repeats
- Enforce as Breakline
  - Bridge by bridge - or –
  - Regenerate Mesh with Breaklines



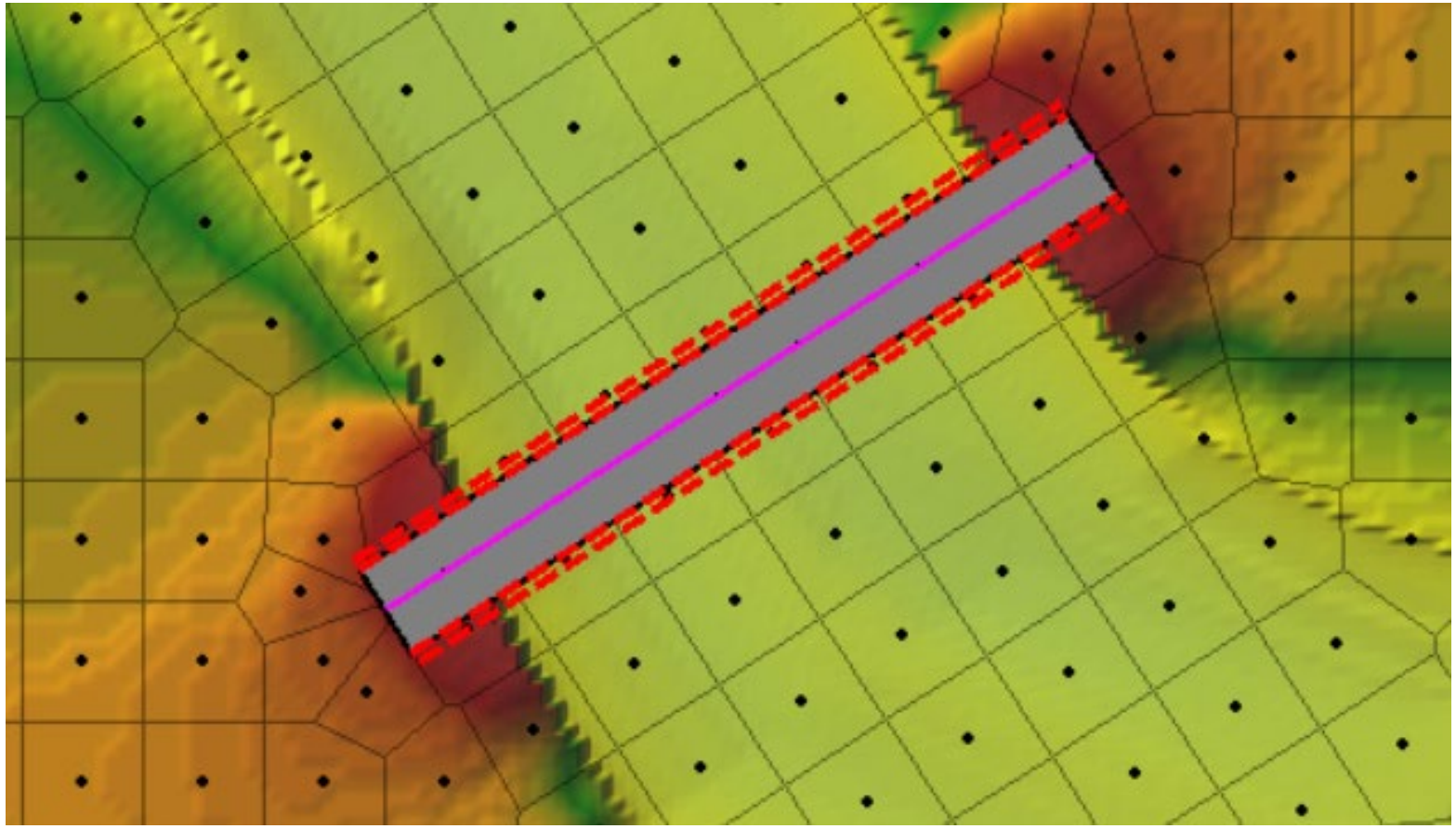
2D Bridge (1D Family of RCs)

- Open in Geometric Data Editor
- Structure Type: Bridge
- Add Deck/Roadway
- XS3 – US Bounding XS
- BU – US Inside Bridge
- BD – DS Inside Bridge
- XS2 – DS Bounding XS



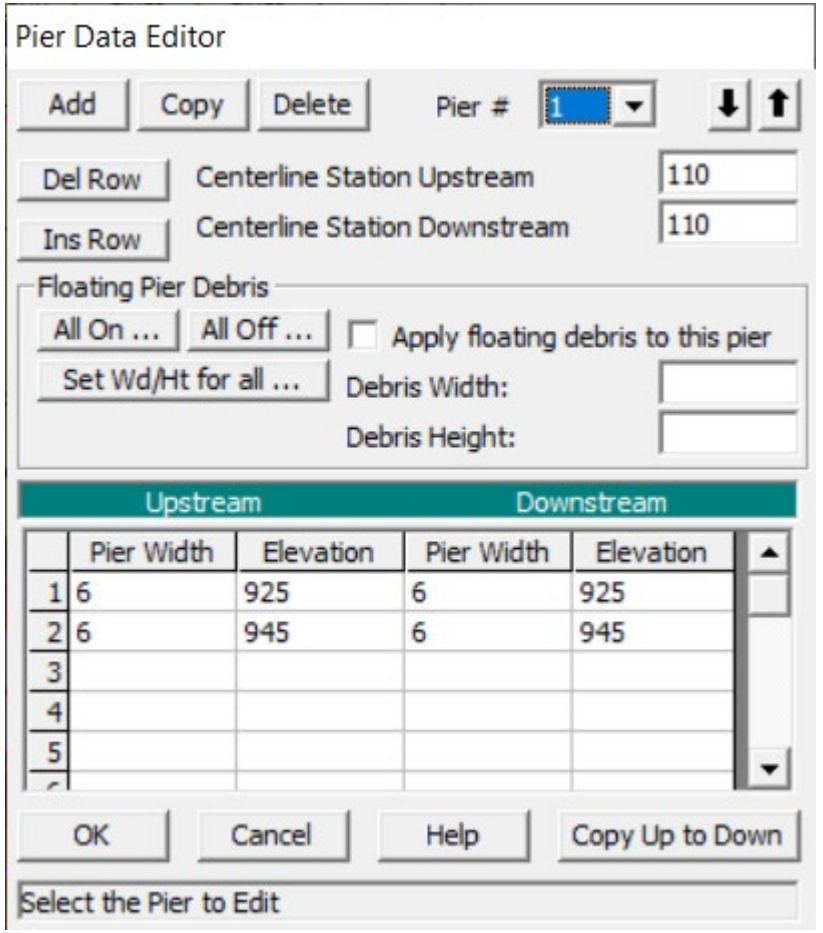
2D Bridge Layout

- RAS automatically computes a set of cross sections (XS2, BD, BU, XS3)
- **Width** – BD and BU are at the bridge face
- **Distance** - XS2 and XS3 are outside of bridge face



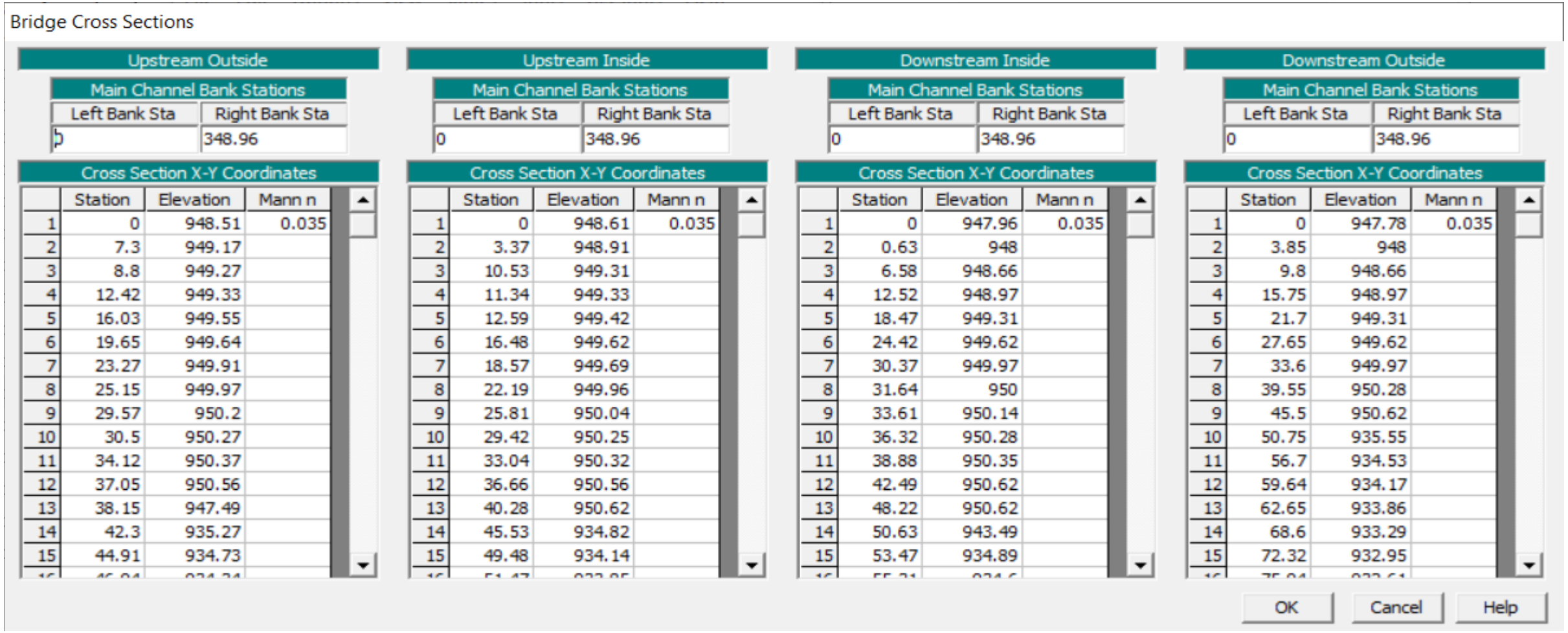
Piers and Abutments

- Enter Piers and Abutments to be included in Hydraulic Tables
- This information is NOT included in the mesh cell property tables.
- Therefore, computed velocities will not be accurate.
- Good practice to include piers and abutments in bridge and terrain.



Manning's n Data for the XS's

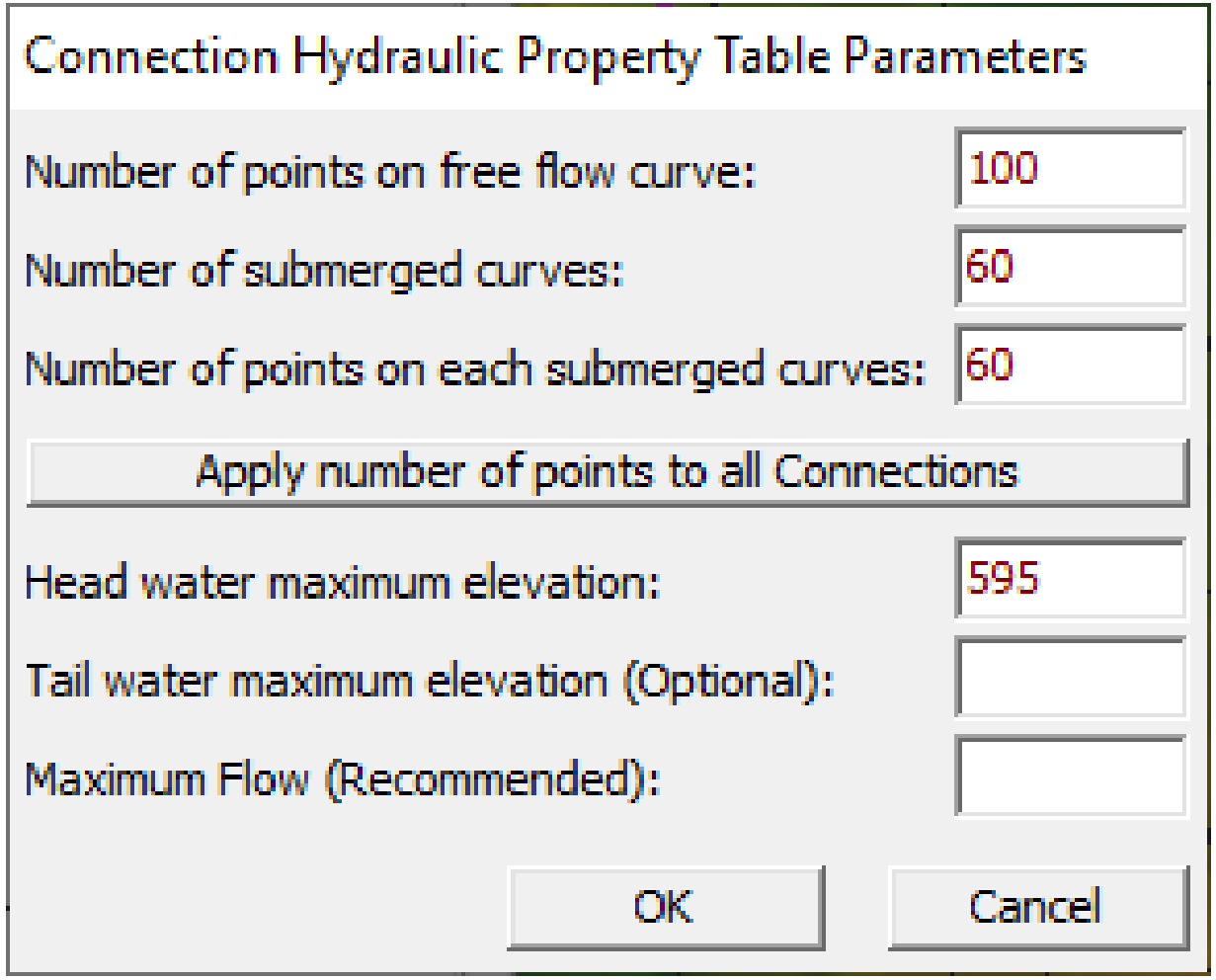
- Options | External and Internal Bridge Cross Sections…



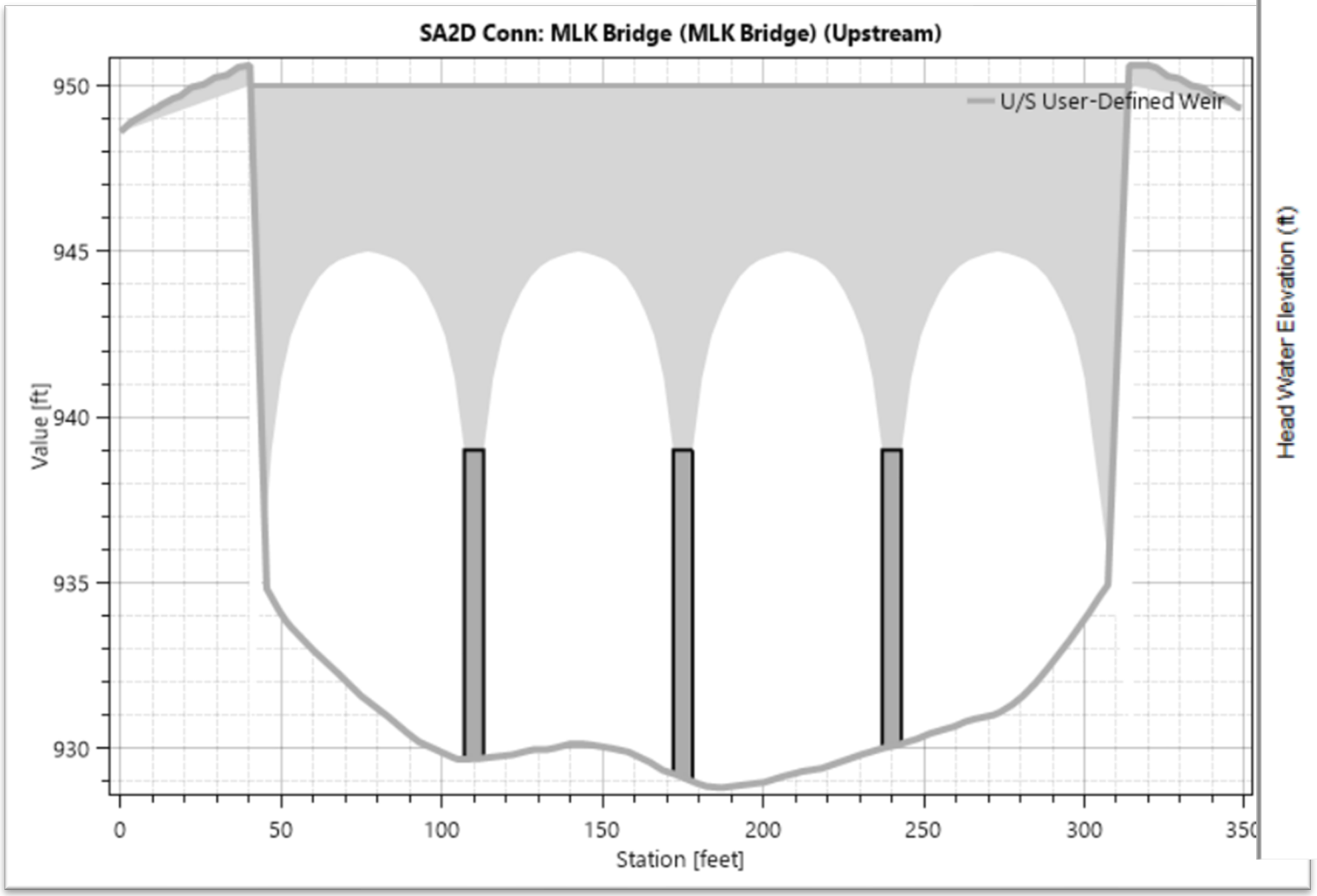
Hydraulic Table Parameters

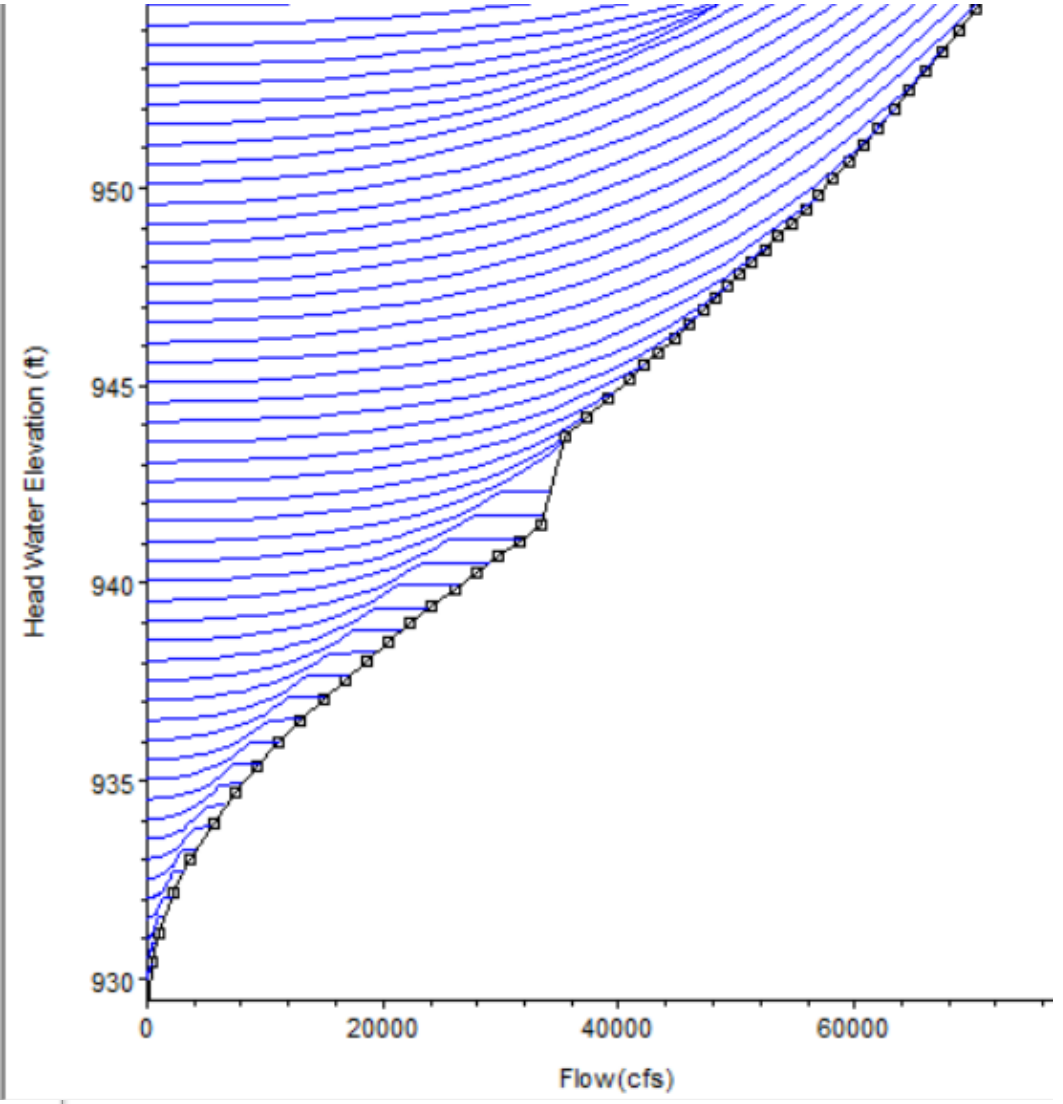
HTab Param.

- **Number of points on free flow curve** (maximum is 100)
- **Number of submerged curves** (maximum is 60)
- **Number of points on each submerged curve** (maximum is 60)
- **Head water maximum elevation**.
- Tail water maximum **elevation** is optional, as is the Maximum Flow.



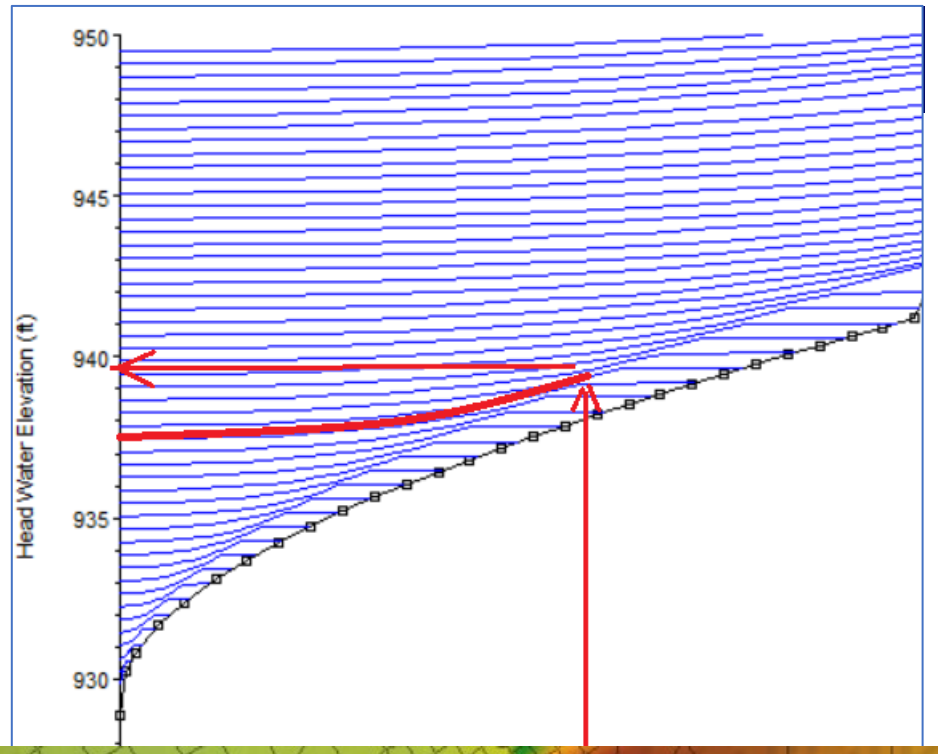
HTab – Family of Bridge Curves

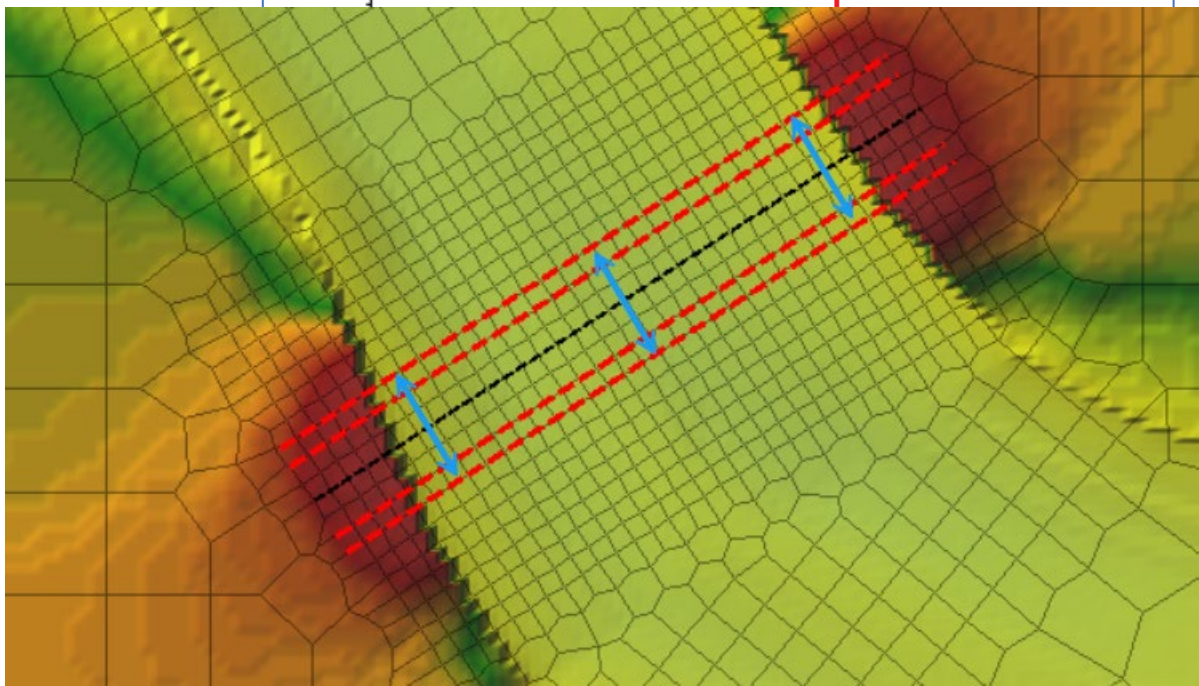




Computational Procedure

- Headloss from XS2 to XS3 by increasing bottom friction using a drag factor on faces under the bridge
- Adjust bridge drag factor to match bridge curves (iterates if error is large)
- Drag factor is constant across all faces though the bridge



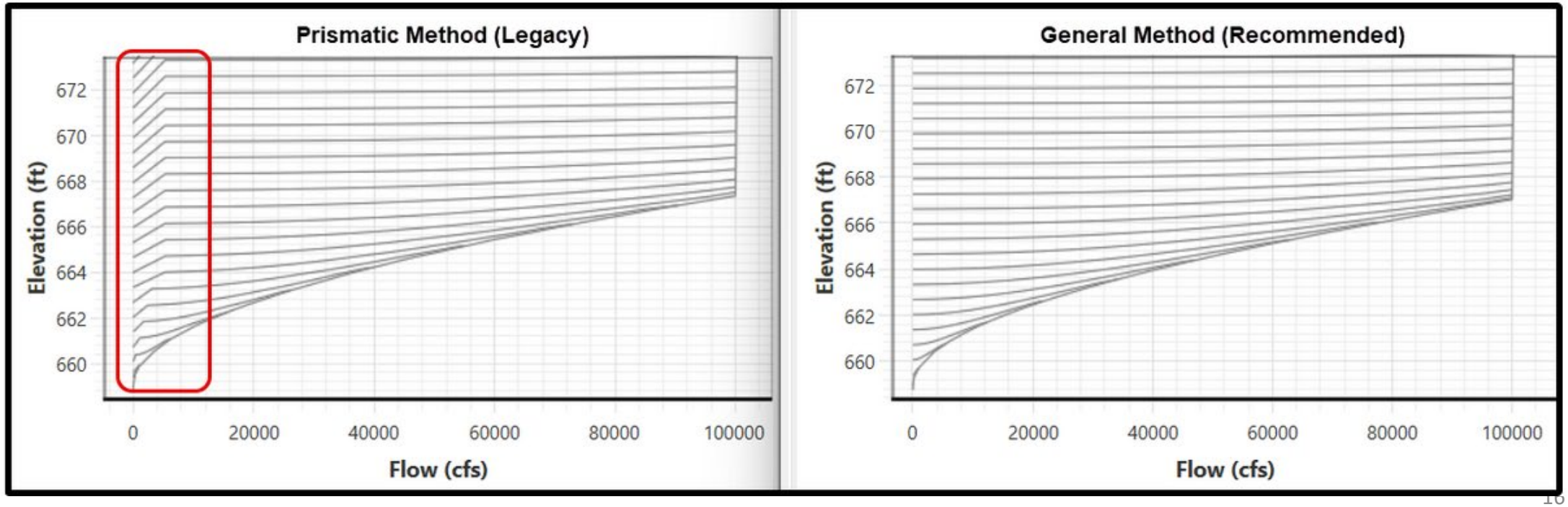


Version 6.5 Computational Improvement

- 6.4.1 and Earlier
  - Flow computed from Headwater and Tailwater
  - Friction loss terms are adjusted so that compute 2D flows match expected 1D Flow just on *centerline cell faces*
- 6.5 and Later
  - Headwater computed from Tailwater and Flow
  - Drag loss is applied to *all cell faces* under the bridge deck

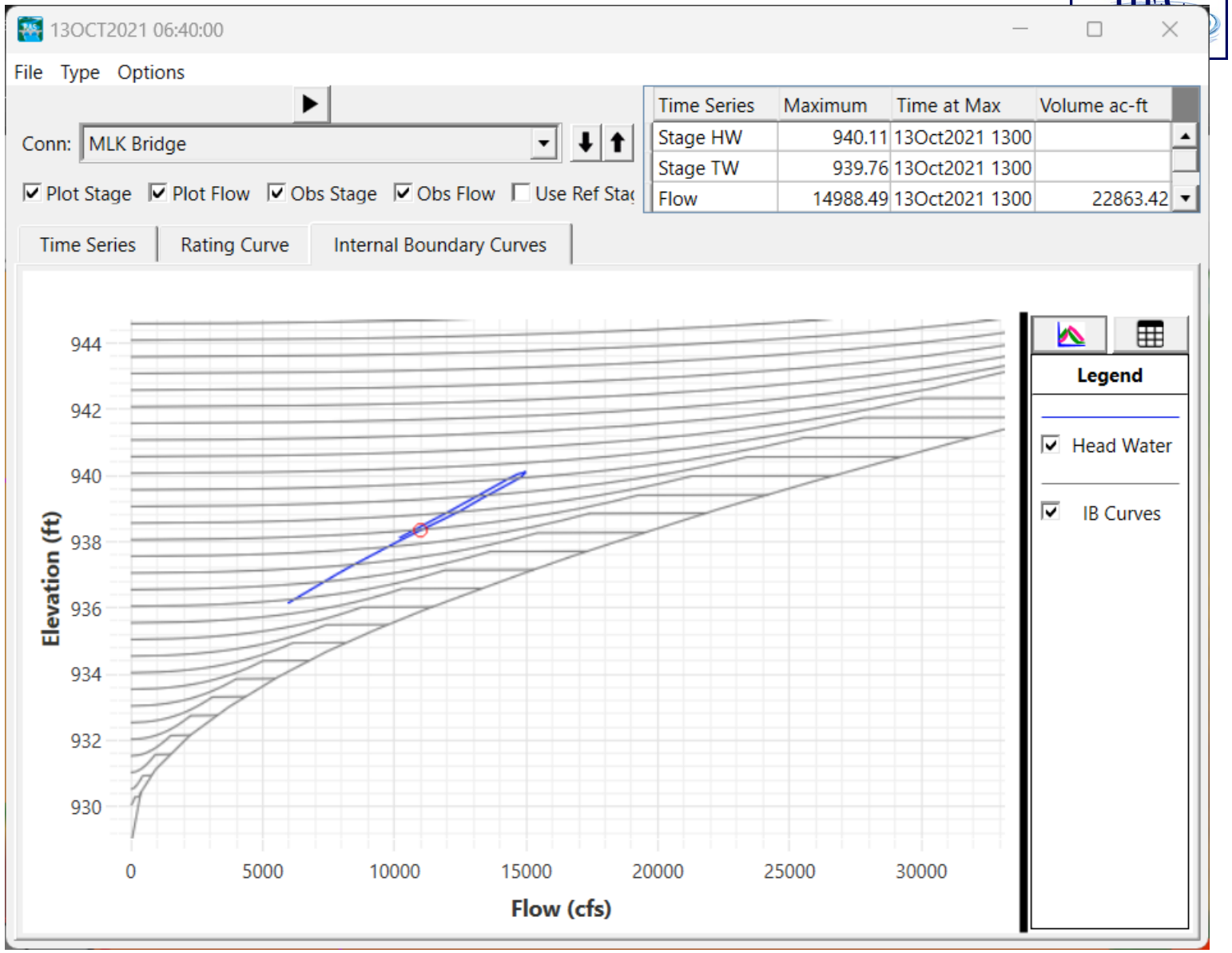
Version 6.7 Computational Improvement

- Added Momentum (General) method implemented computes the losses using the general 1D momentum approach and works on both natural and prismatic channels.
- The Prismatic (Legacy) method overly sensitive to cross-section shape and bed slope.

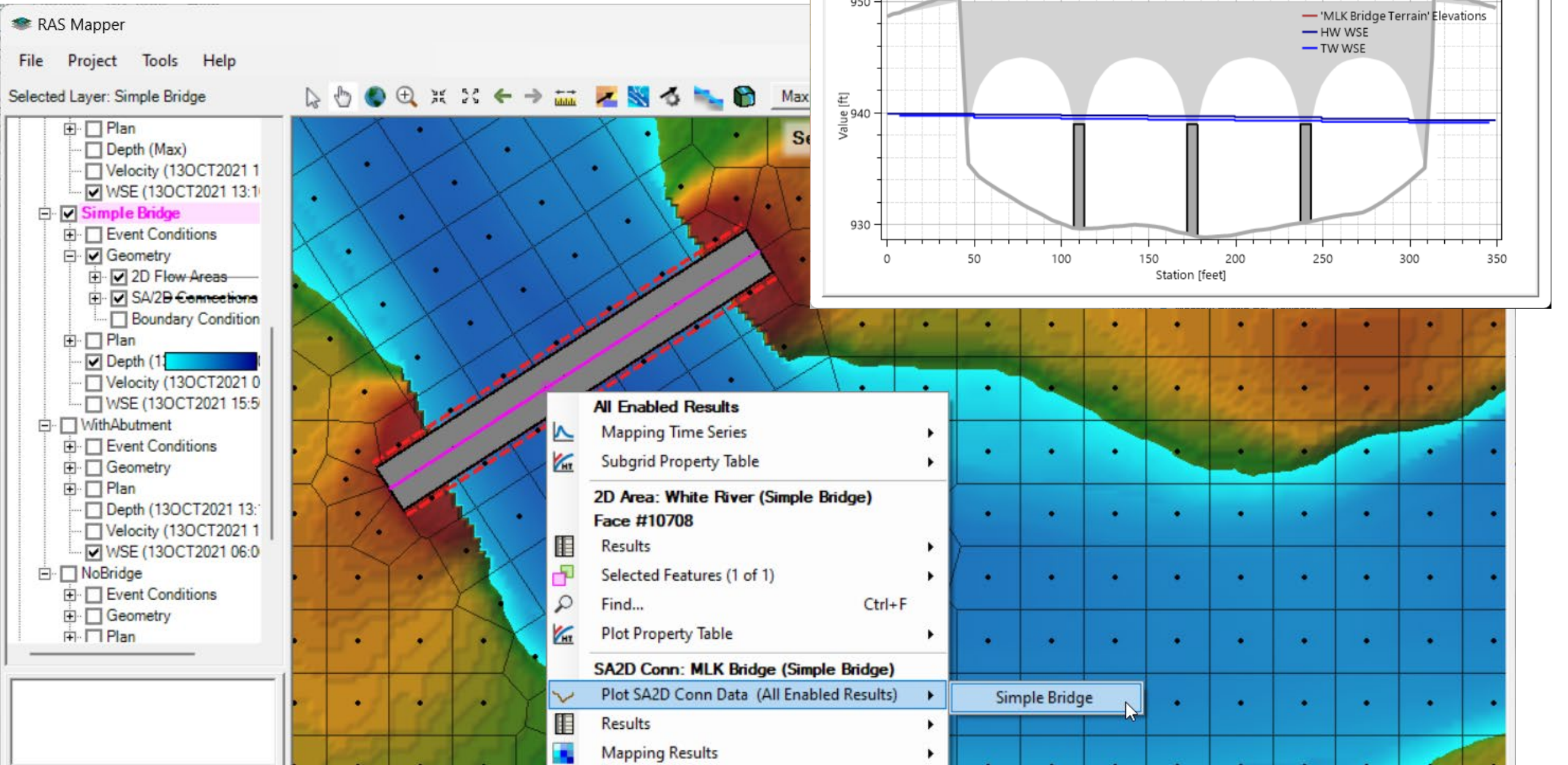


Bridge Output

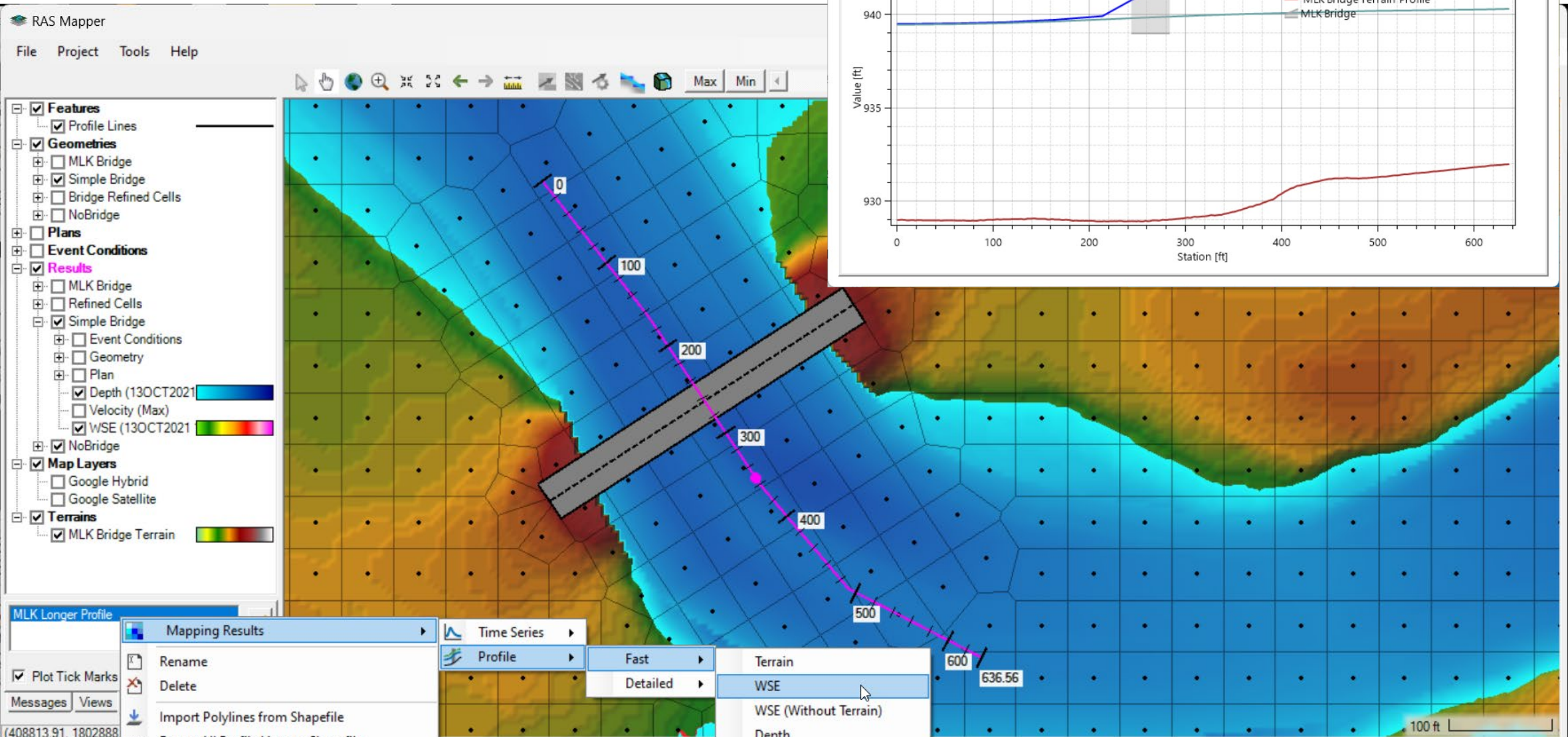
- Blue line represents actual flows and stages during simulation
- Animation time step shows solution with red circle



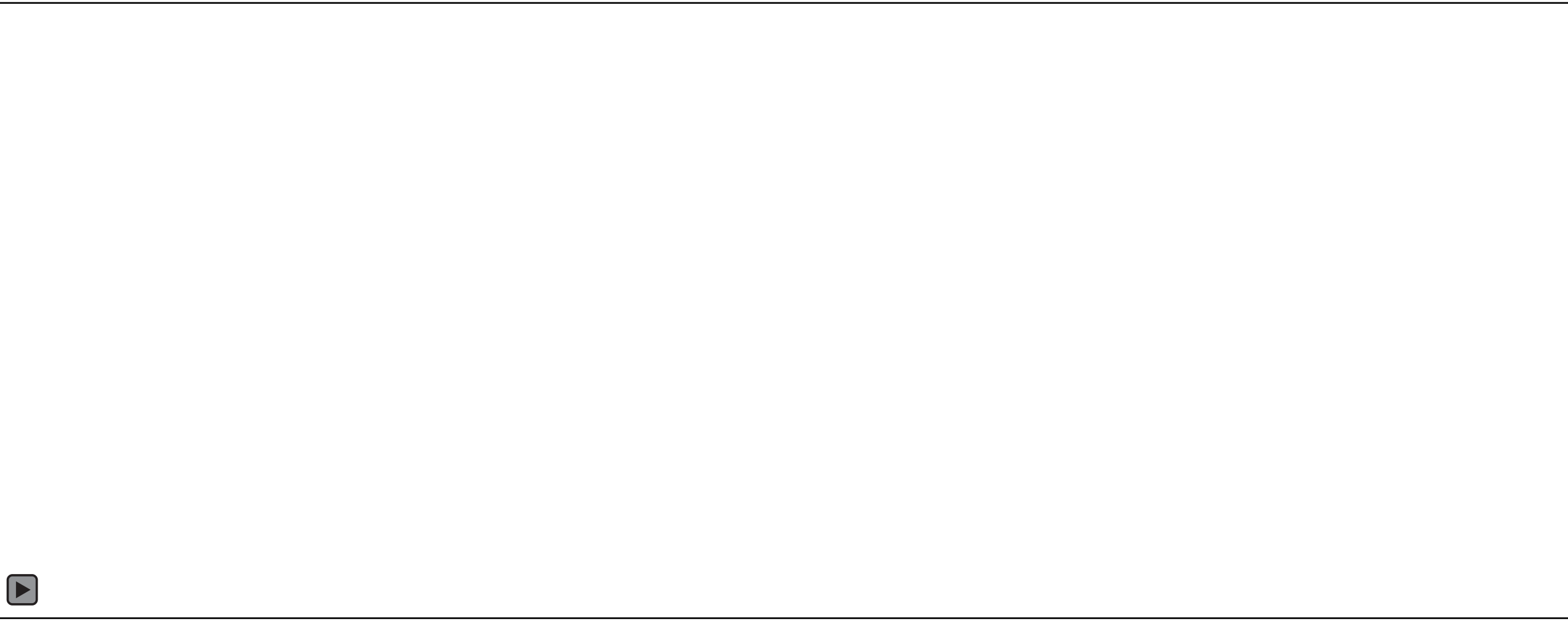
Bridge Output



Bridge Output



Bridge Animation



Bridge Output

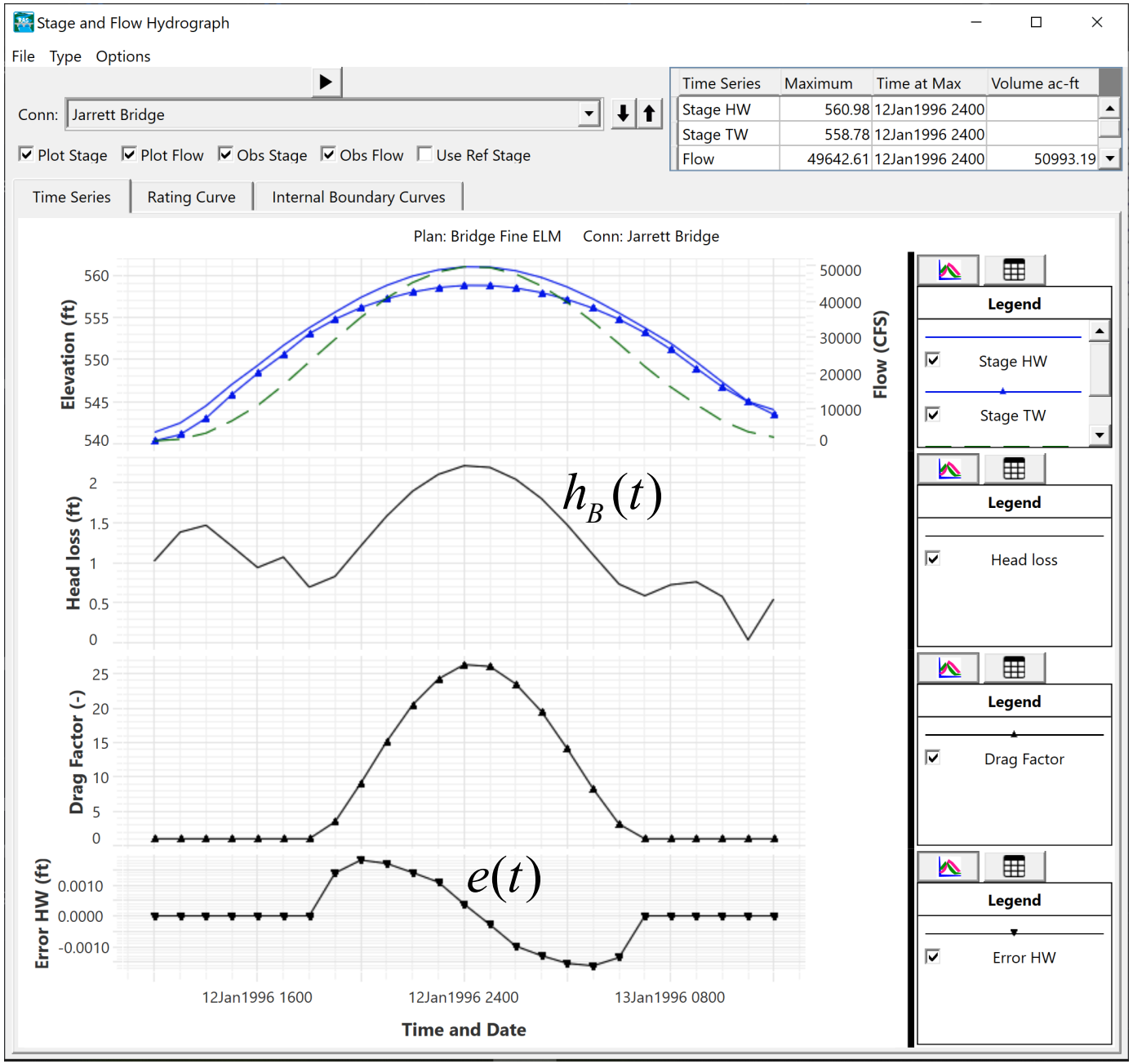
- Head loss through bridge

$$h_B = \overline{z}_{s,H} - \overline{z}_{s,T}$$

- Drag factor
  - Limited to 1
  - Constant under bridge
- Error

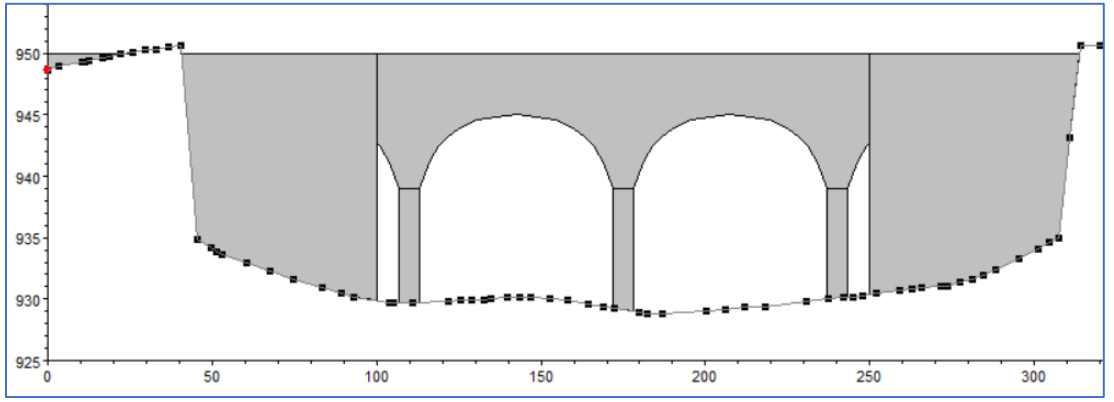
$$e(t) = z_{s,H} - \overline{z}_{s,H}$$

  - Usually small but can be increase if controller has trouble especially during flow transitions

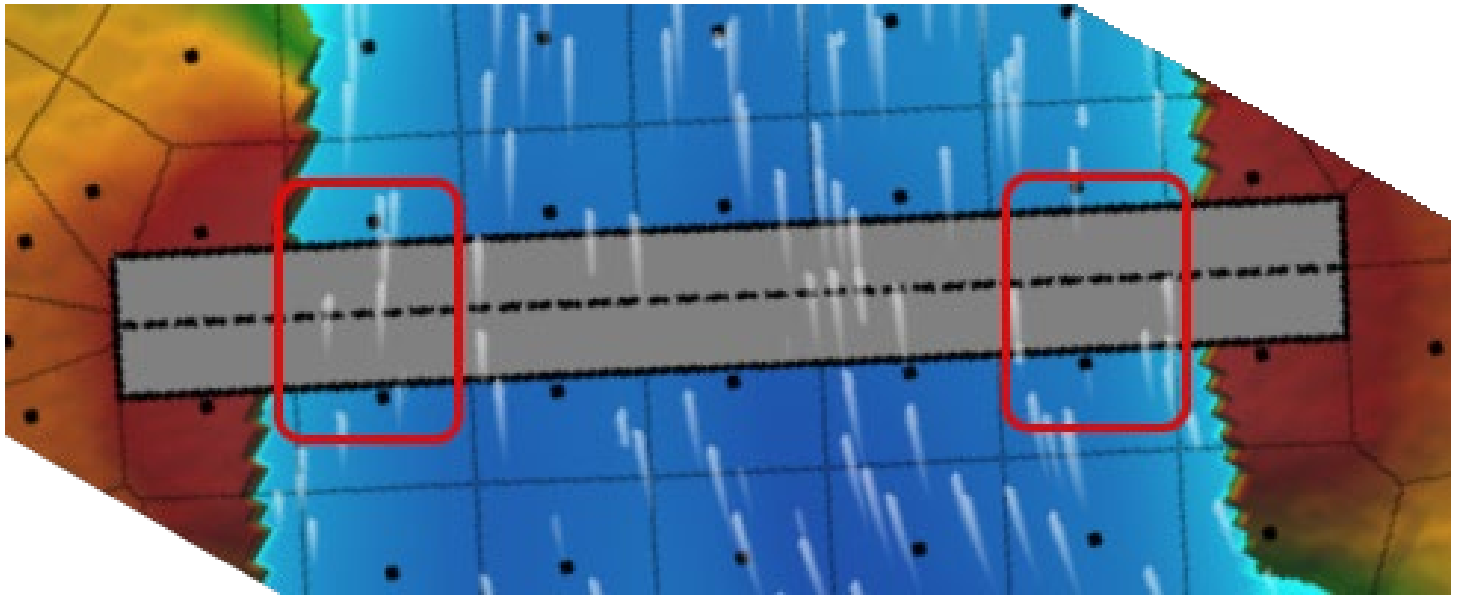


Limitations – Simplified 2D Bridge Modeling

- Detailed velocities will not be correct. Appropriate solution for computing WSE.
  - Bridge geometry is included in HTab Curves but not Cell Property Tables

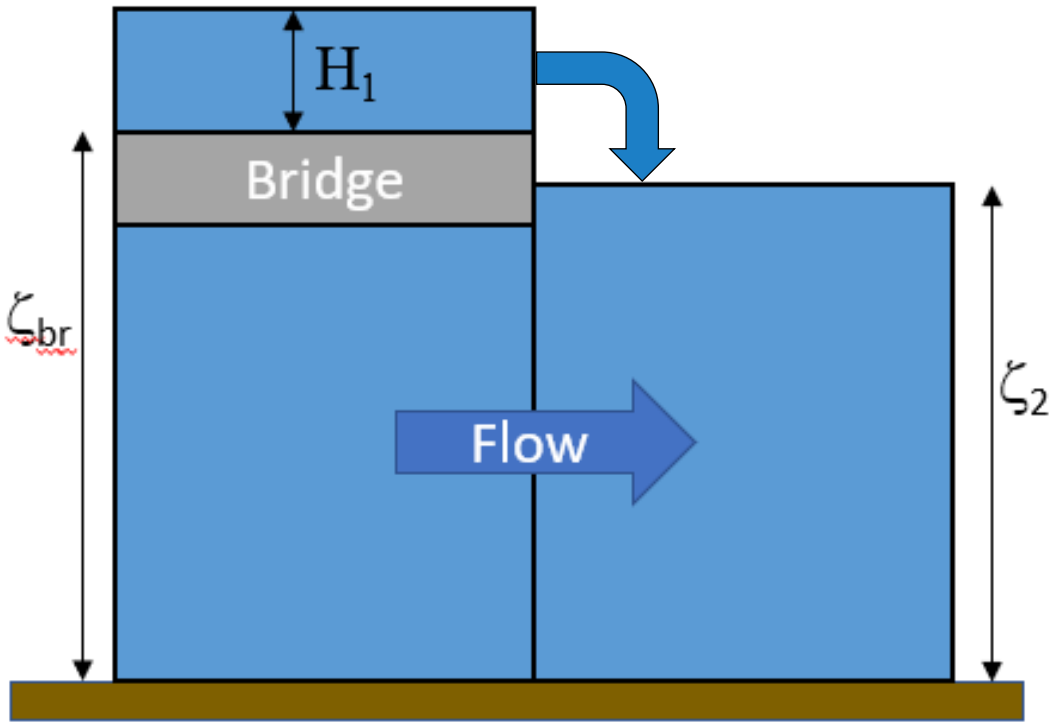


- Velocity traces through the abutments and piers, if not included in the terrain



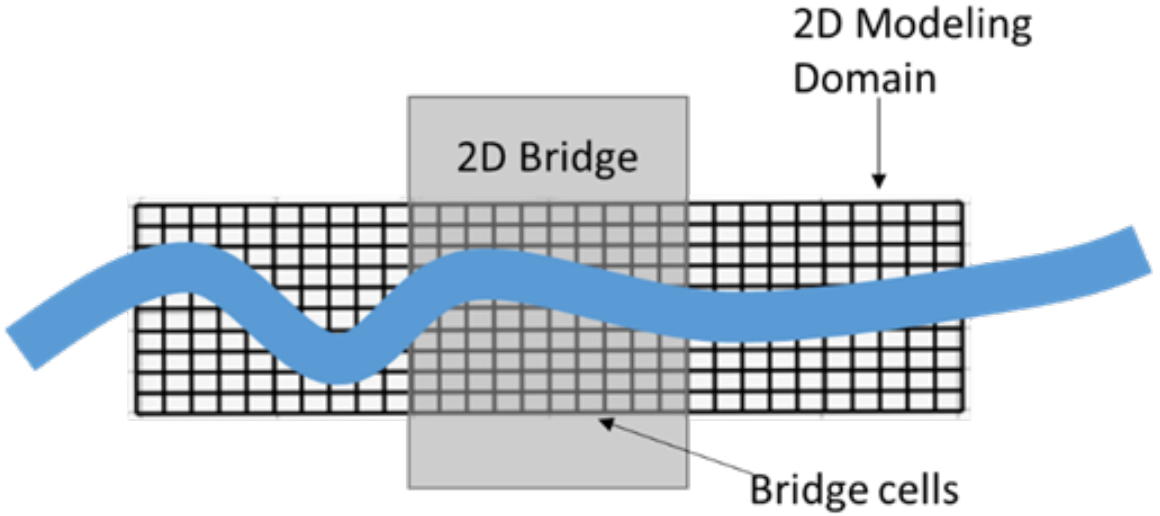
Detailed Bridge Modeling

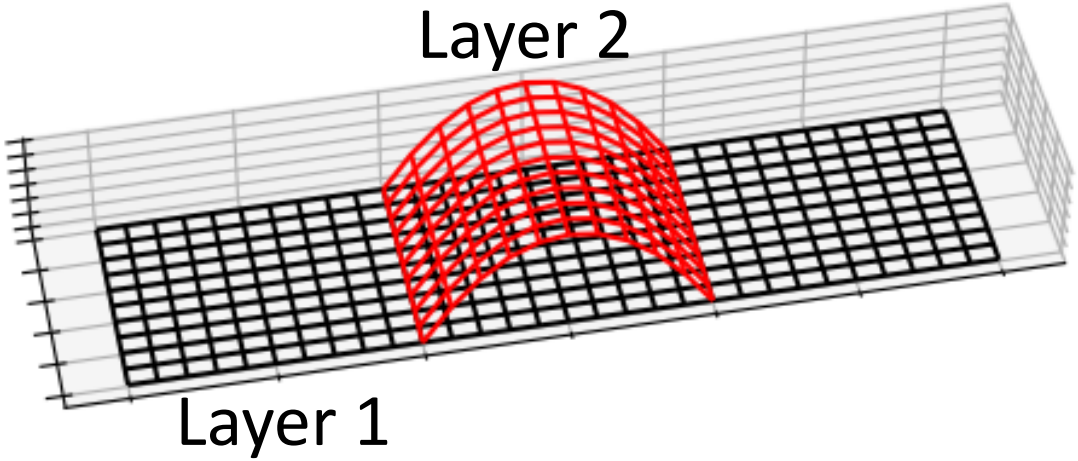
- Regular 2D Approach (2D)
  - Low flow conditions only (water below deck)
- Pressure/Overtopping (2Dx2)
  - Version 6.7 Betas (Official Release at end of FY)
  - Two-layer (2Dx2) mesh for bridges
  - Additional mesh above each bridge
  - Requires bridge deck geometry
  - All flow conditions
  - Minor Losses
- Simplified 1D/2D and Pressure/Overtopping can be used at different bridges within the same project



Introduction to 2Dx2 Approach

- Cells and faces under deck cloned/copied above the deck
- Effectively a 2-layer mesh
- Shallow-water equations solved on each layer
- Layers only connected at the deck boundaries
- 1st layer under deck can pressurize
- 2nd layer above deck but mesh is created at runtime

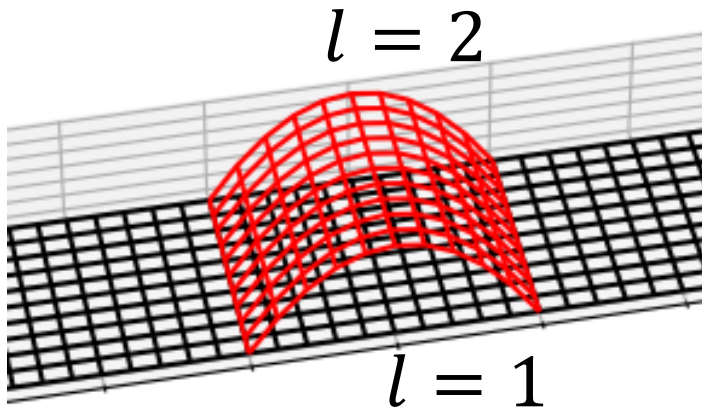




2Dx2 Flow Theory

- Continuity

$$\frac{\partial h_l}{\partial t} + \nabla \cdot (h_l \boldsymbol{V}_l) = S_l$$



- Momentum

$$\frac{\partial \boldsymbol{V}_l}{\partial t} + (\boldsymbol{V}_l \cdot \nabla)\boldsymbol{V}_l = -g\nabla H_l - \frac{K_{L,l}}{2W}|\boldsymbol{V}_l|\boldsymbol{V}_l + \cdots$$

Hydraulic Head

$$H_1 = z_{s,1} + \frac{P_1}{\rho g} \qquad H_2 = z_{s,2}$$

z_s: Water surface elevation

$\boldsymbol{V}$: Velocity

h: Depth

K_L: Minor loss coefficient

g: Gravity

H: Hydraulic head

P: Pressure

ρ: Water density

W: Bridge width

l: layer [1,2]

Plunging Flow

- Energy Balance

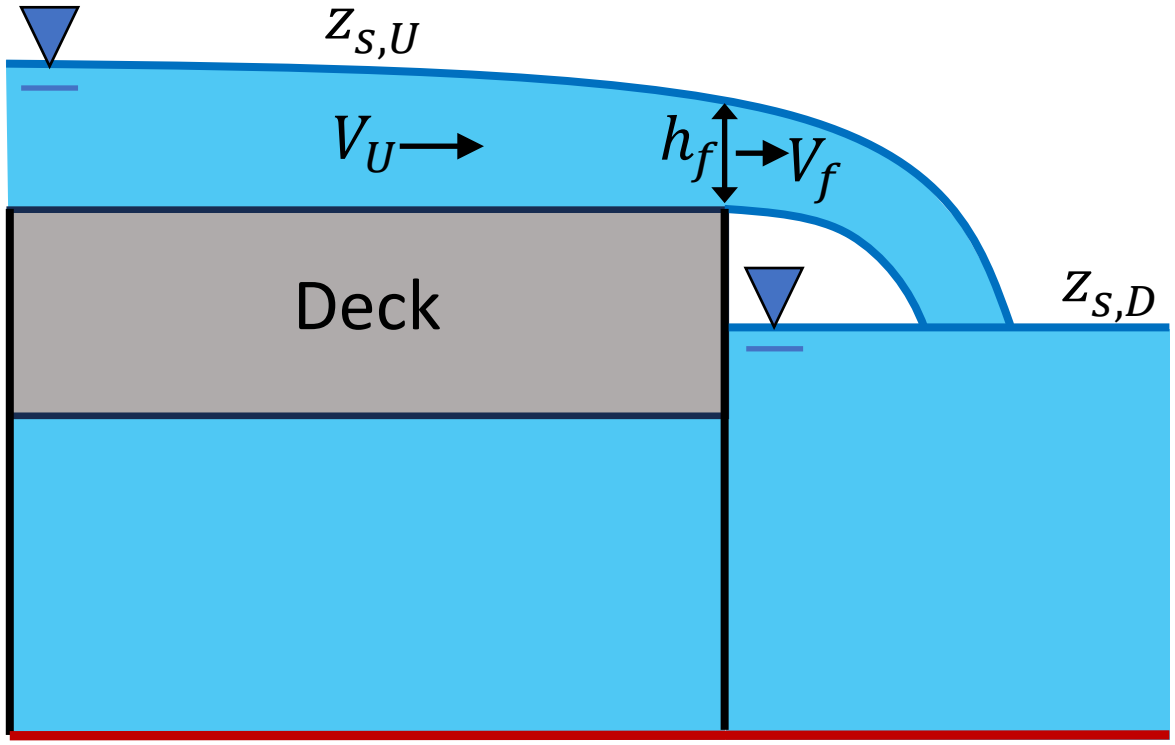
$$\frac{V_U^2}{2g} + z_{s,U} = \frac{V_f^2}{2g} + z_{b,f} + h_f$$

Water depth at edge of bridge

$$h_f = \frac{2}{3} E_f$$

Energy head above deck

$$E_f = z_{s,U} - z_{b,f} + \frac{V_U^2}{2g}$$



- Plunging occurs when

$z_{s,D} < z_{b,f}$, $\quad h_f > 0$

Minor Losses

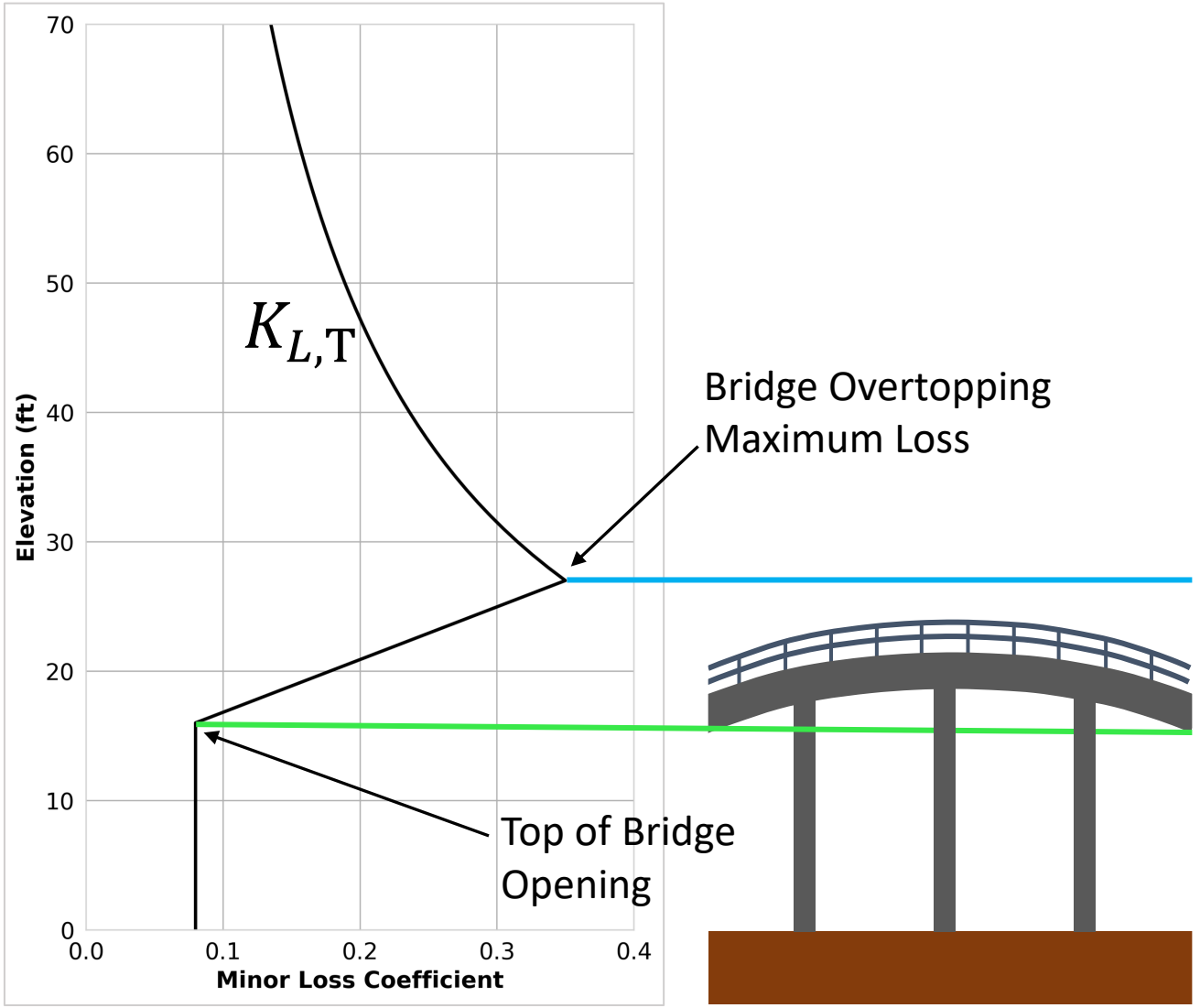
- For Pressure/Overtopping
- Minor Head Loss

$$H_L = K_L \frac{\bar{V}^2}{2g}$$

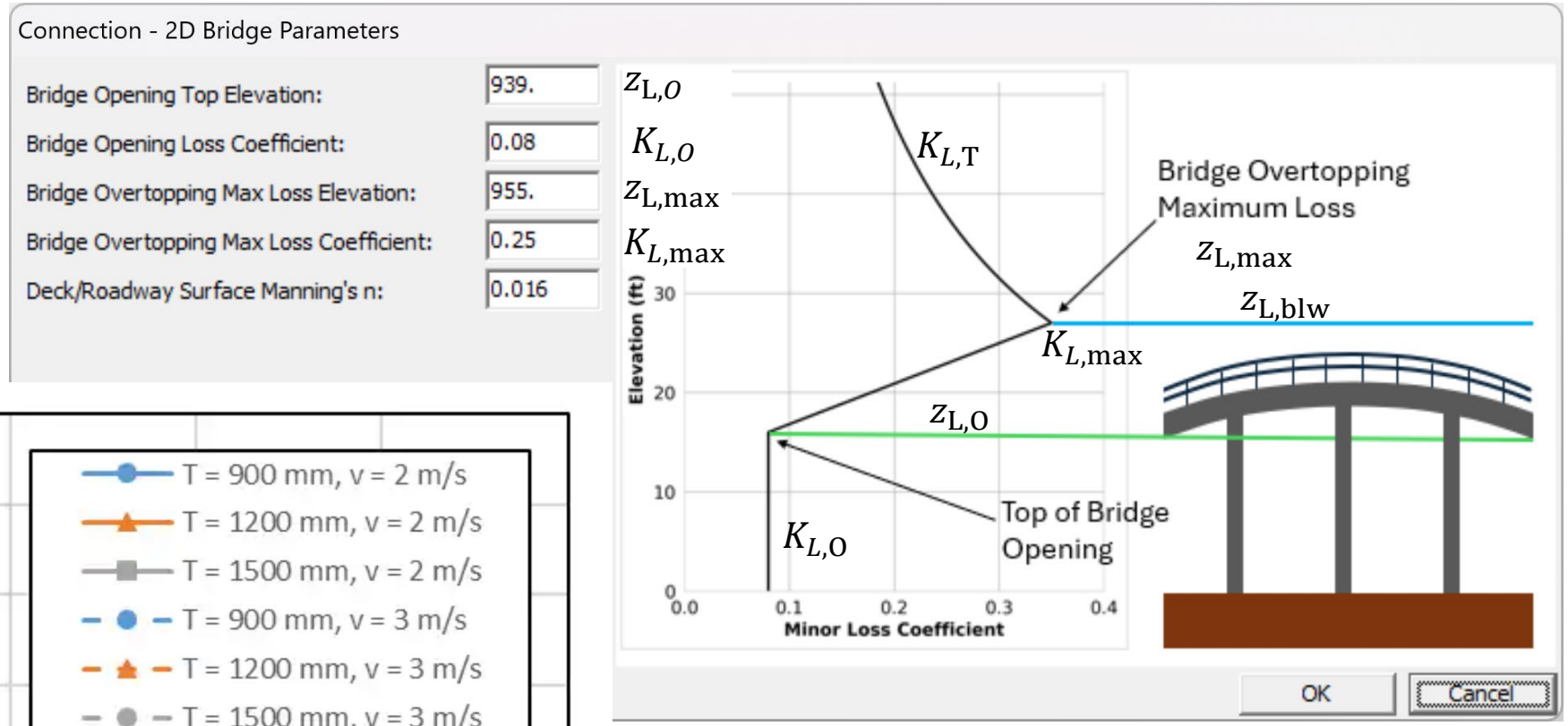
- Apportioning Minor Losses

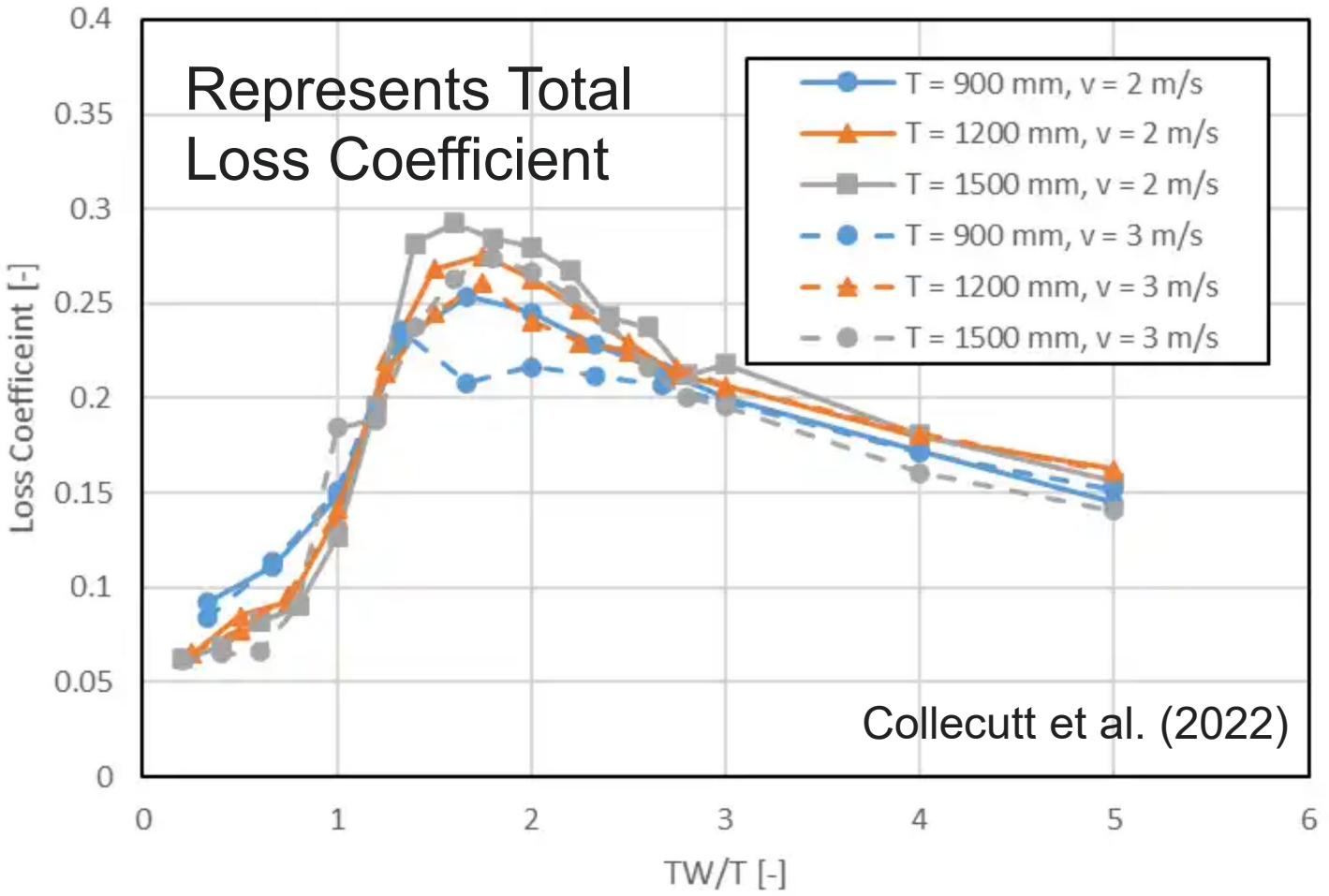
$$K_{L,\mathrm{T}} \frac{\bar{V}^2}{2g} = K_{L,\mathrm{blw}} \frac{\bar{V}_{\mathrm{blw}}^2}{2g} + K_{L,\mathrm{abv}} \frac{\bar{V}_{\mathrm{abv}}^2}{2g}$$

  - Note: Velocities area-averaged over bridge centerline



Minor Losses

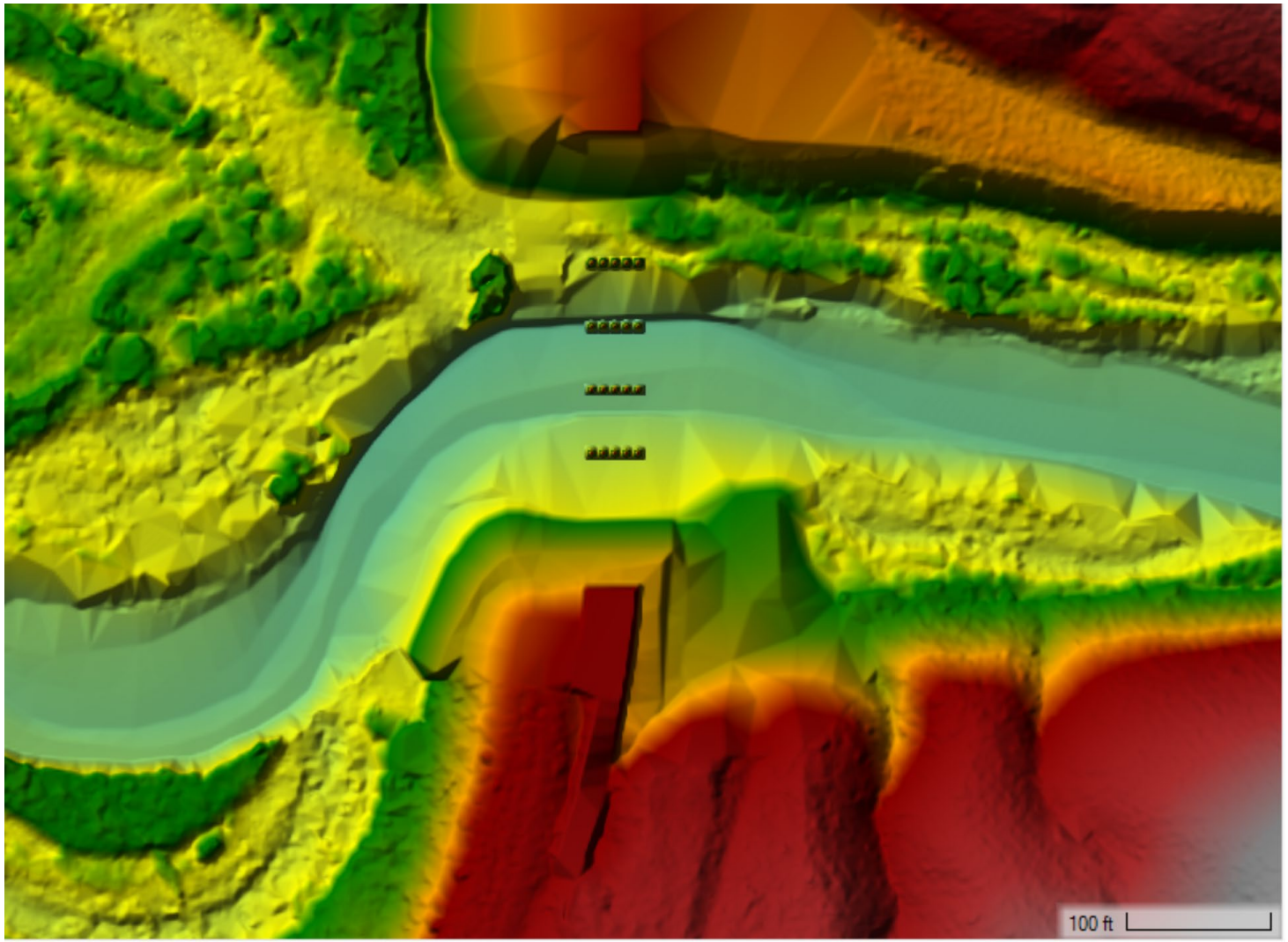




- Based on average water surface and velocities
- Minor Loss coefficient applied uniformly over and under bridge

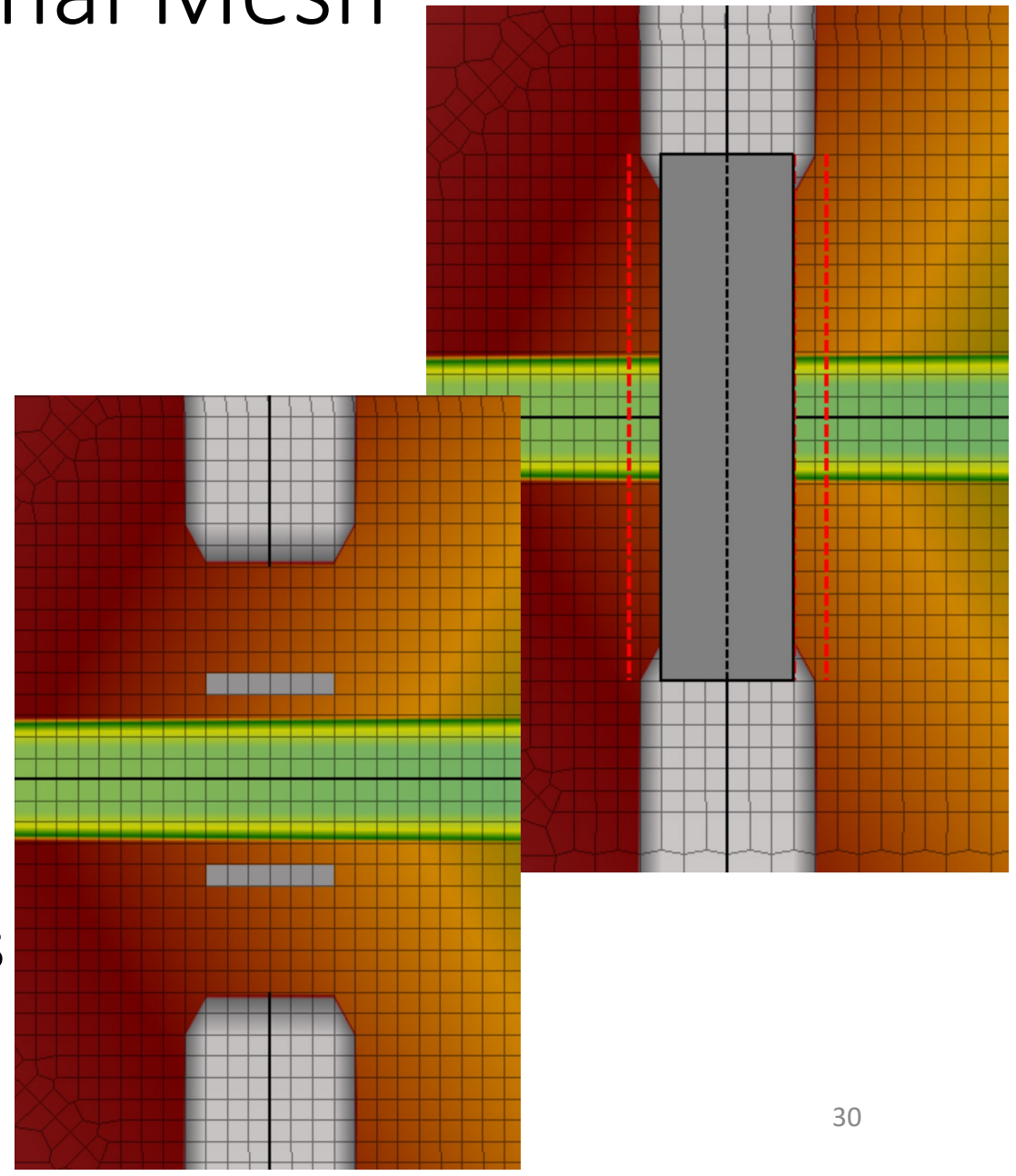
Model Setup: Terrain

- Terrain MUST include
  - Piers
  - Embankments
- Only the deck is not included in the terrain



Model Setup: Computational Mesh

- User's responsibility to line up bridge deck with faces
- Careful adding refinement at piers
  - Cells get cloned above deck
  - Small timesteps and instabilities
- XS's 2 and 3 only used for output
  - Not important for actual calculations
- Center XS used to compute average velocities and bridge output variables



Model Setup: Computational Mesh

- Timestep is related to cell volume
- Bridge deck can cause small cells with tiny volumes which cause issues
- Be careful where you place faces
- HEC-RAS automatically removed cells with zero or “small” volumes

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Performing Unsteady Flow Simulation  HEC-RAS 6.7 Beta3 April 2025
Removing below bridge deck cell 3135 from computations because of small volume
Removing below bridge deck cell 3136 from computations because of small volume
Removing below bridge deck cell 3137 from computations because of small volume
Removing below bridge deck cell 3138 from computations because of small volume
Removing below bridge deck cell 3139 from computations because of small volume
Removing below bridge deck cell 3140 from computations because of small volume
Removing below bridge deck cell 3768 from computations because of zero volume
Removing below bridge deck cell 3769 from computations because of zero volume
Removing below bridge deck cell 3770 from computations because of zero volume
Removing below bridge deck cell 3771 from computations because of zero volume
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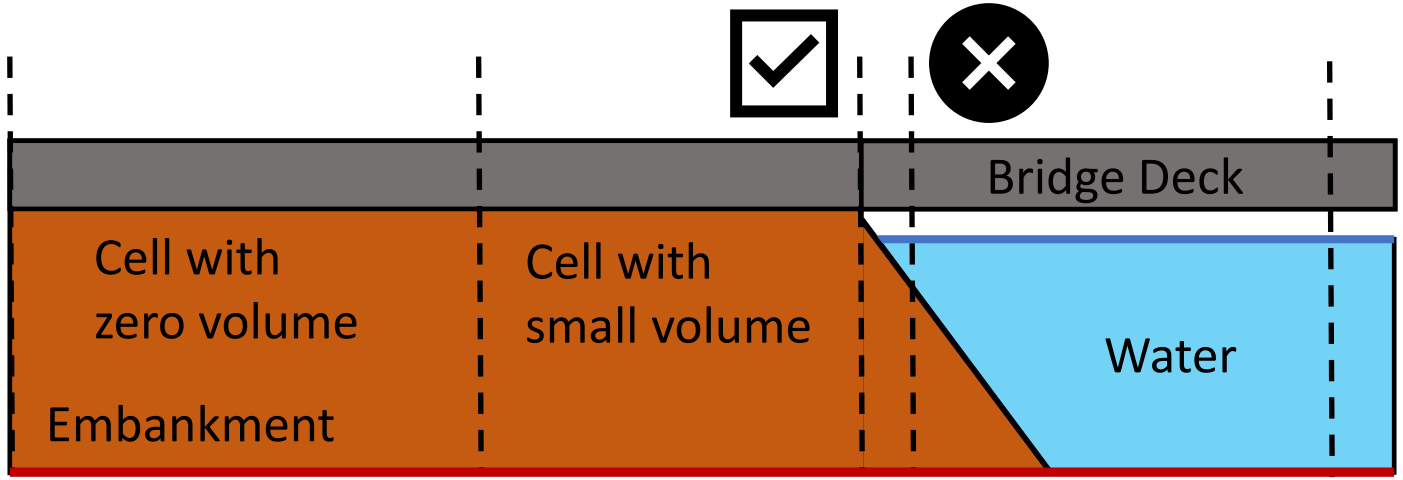
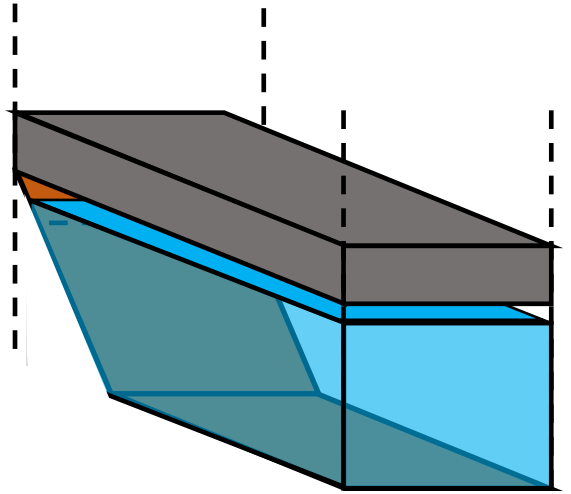
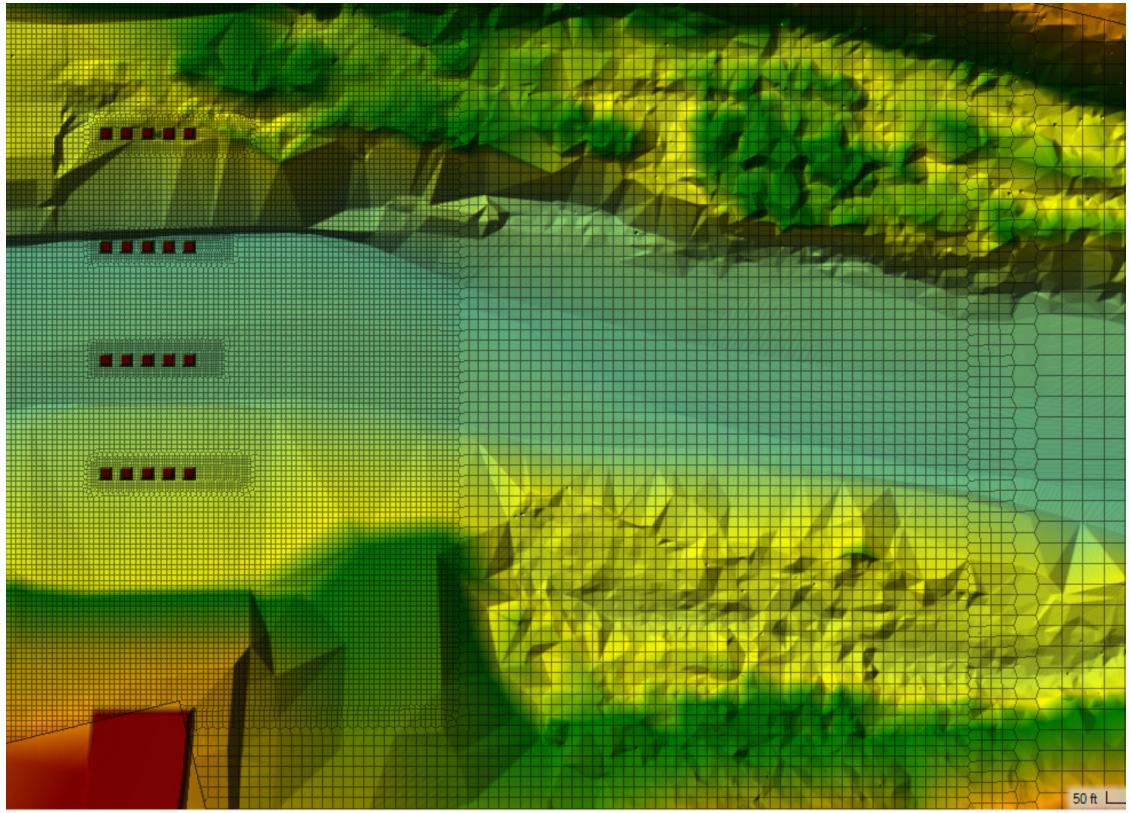




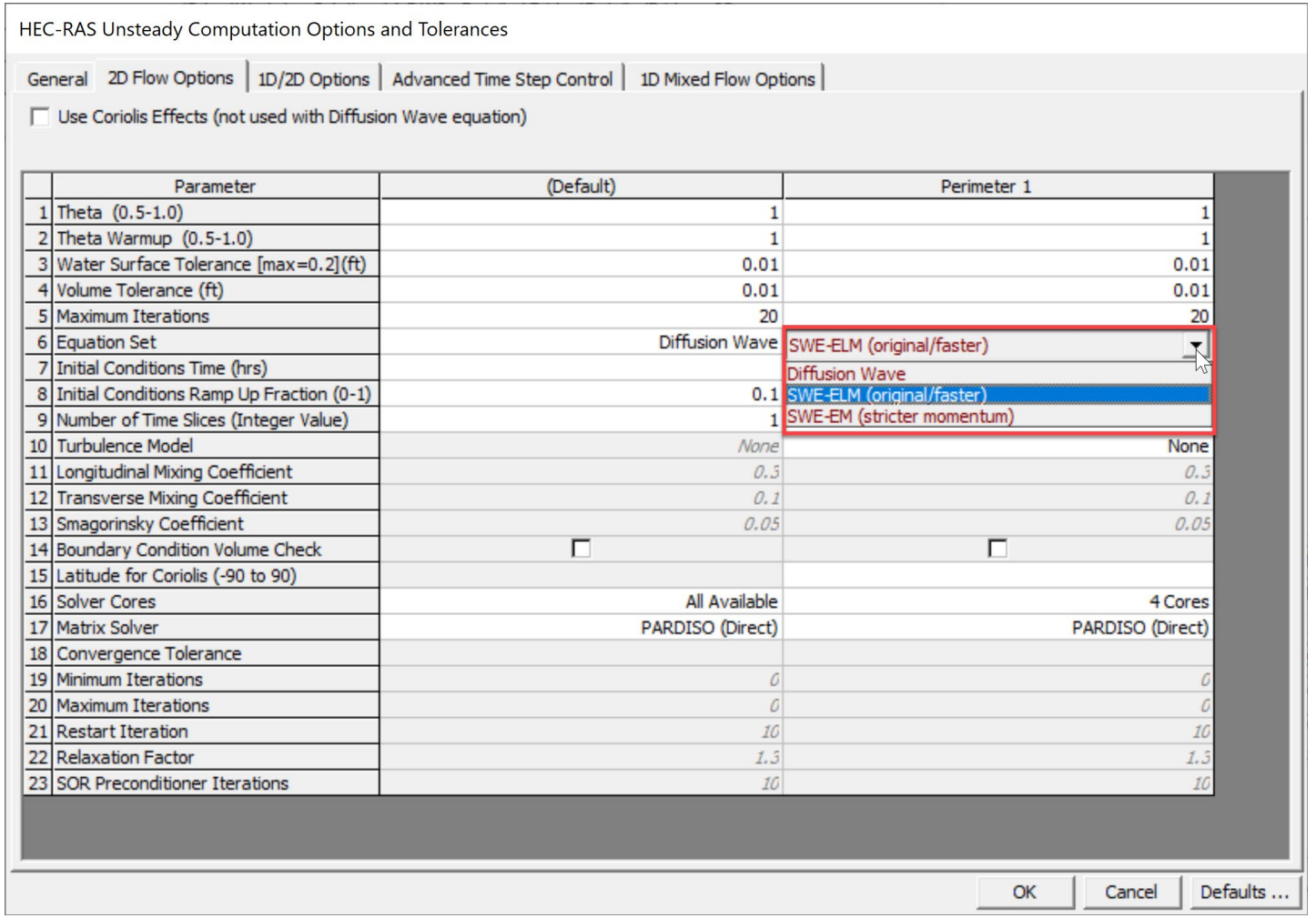
Model Setup: Computational Mesh

- Start coarse and refine as needed
- Grid convergence
- Use breaklines and refinement regions
- Minimum cell size will drive time step
- Too fine resolution will lead to small timesteps and potentially instabilities
- Nest smaller mesh within larger model to reduce domain size if possible



Model Setup: Equation Set

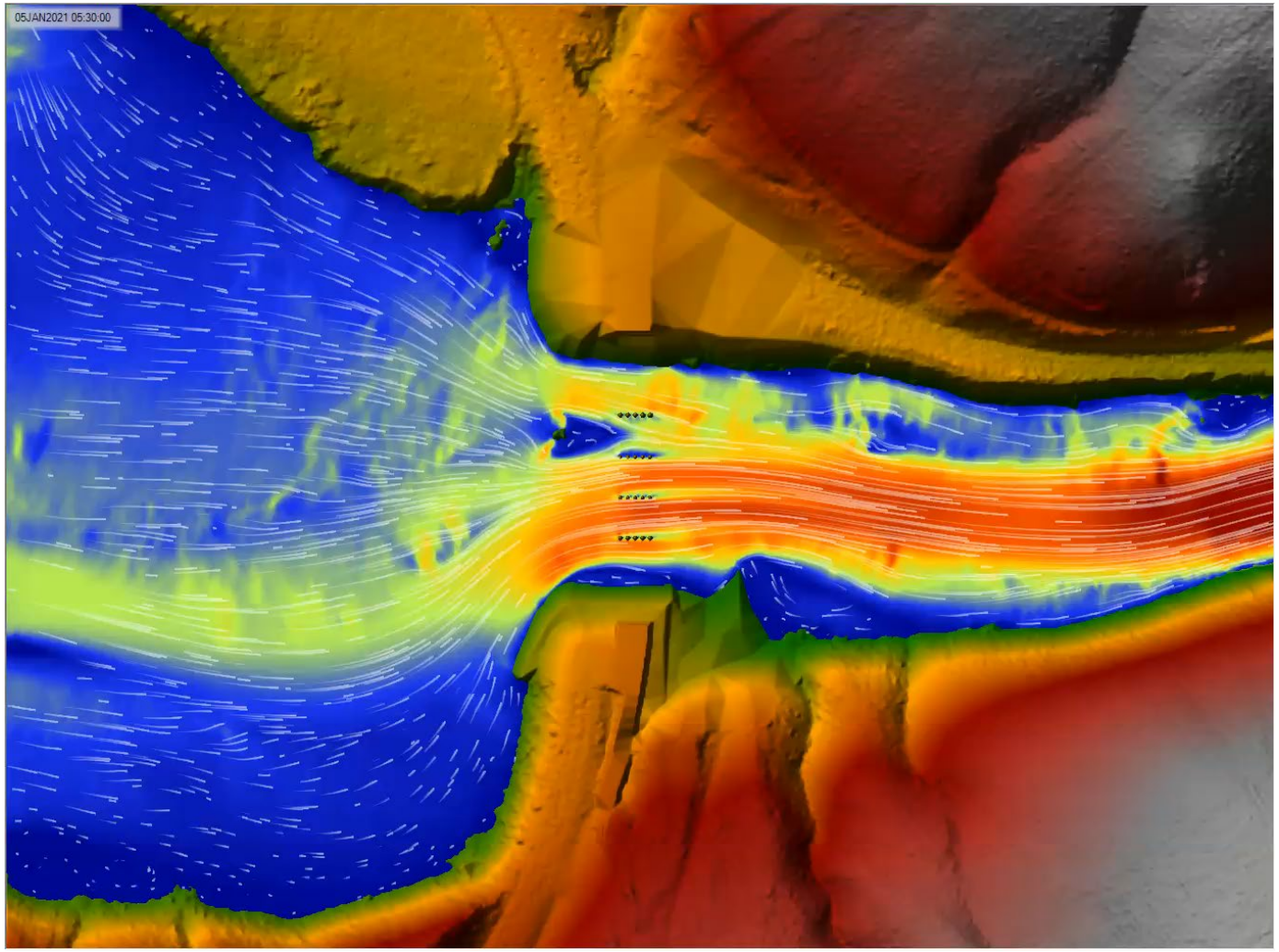
- Diffusion Wave Equation
  - Not supported by 2Dx2 approach
  - Preliminary runs and/or initialization
- Shallow Water Equations
  - Production runs
  - Include turbulence
  - SWE-EM recommended



Model Setup: Turbulence

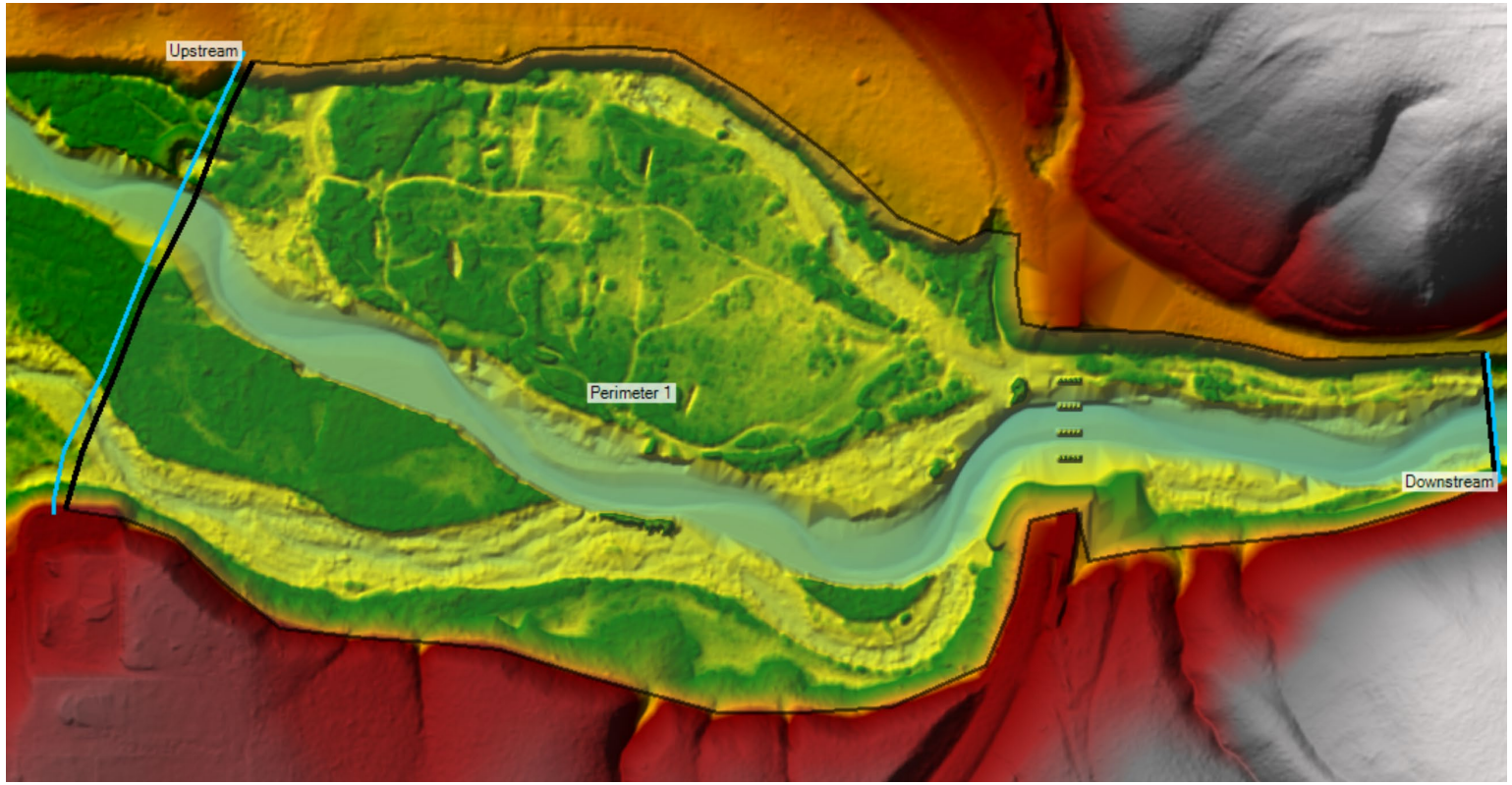
- Important for high-resolution production runs
- Use **Conservative** method!
- Eddy Viscosity Model
  - Use Parabolic-Smagorisnky
  - Calibrate if possible
  - In lieu of calibration, perform sensitivity analysis

	Turbulence	
1	Turbulence Method	Conservative
2	Longitudinal Mixing Coefficient	0.3
3	Transverse Mixing Coefficient	0.1
4	Smagorinsky Coefficient	0.05



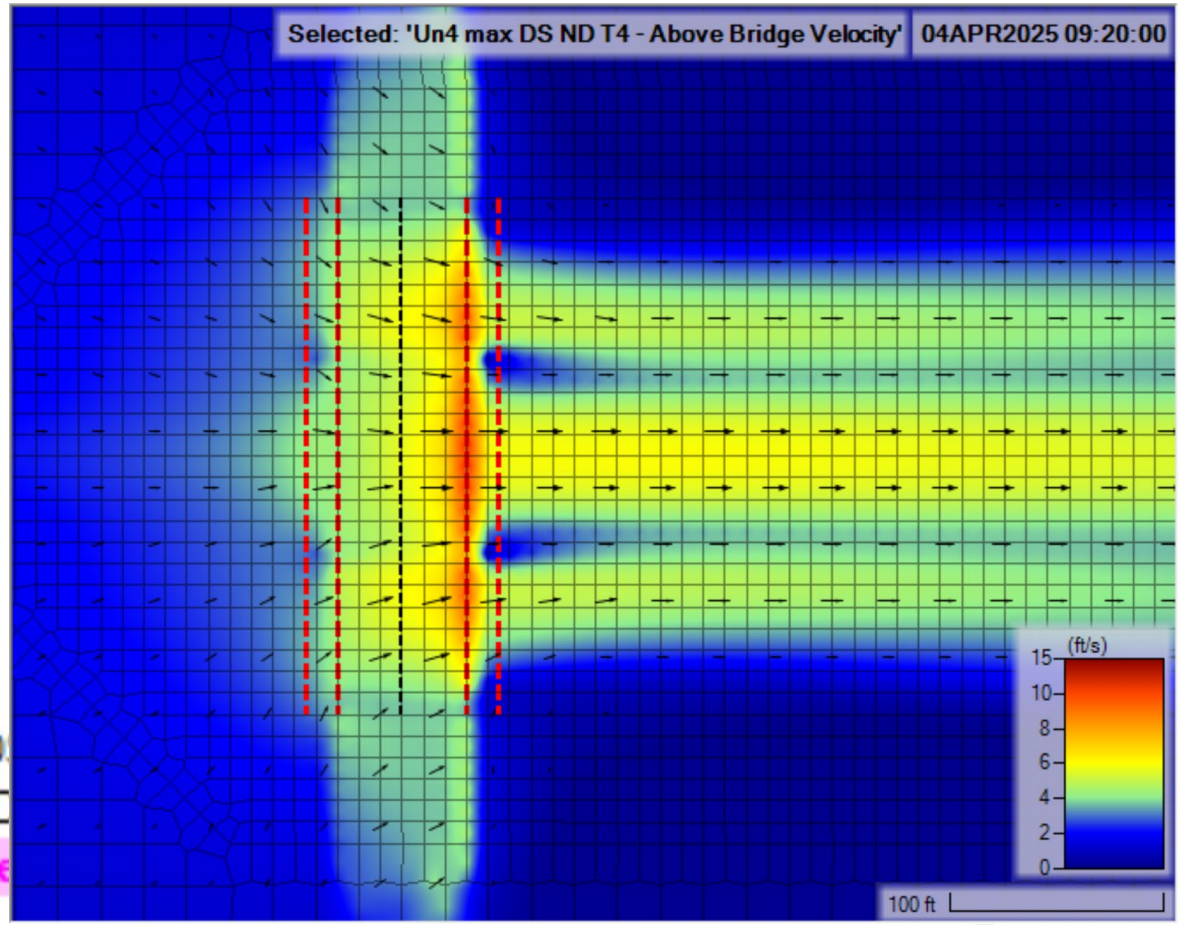
Boundary Conditions

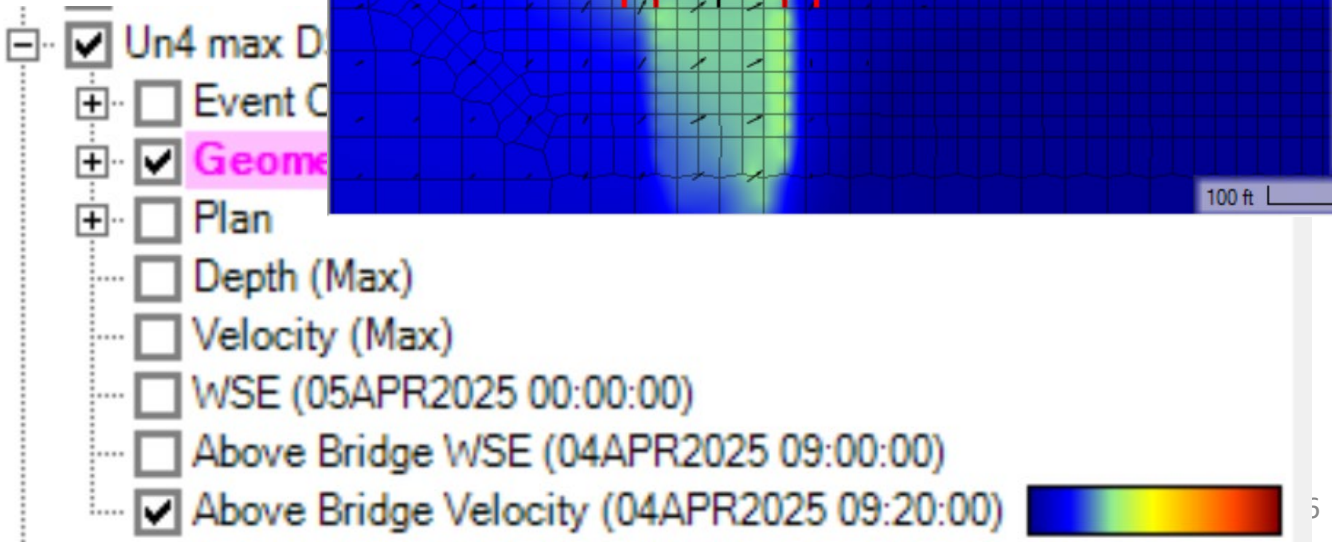
- Tempting to place them very close to the bridge but don’t
- Perform sensitivity on boundary placement and boundary values (such as friction slope)
- Place boundaries in areas with 1D flow (i.e. no recirculation, or sharp contracts and expansions)



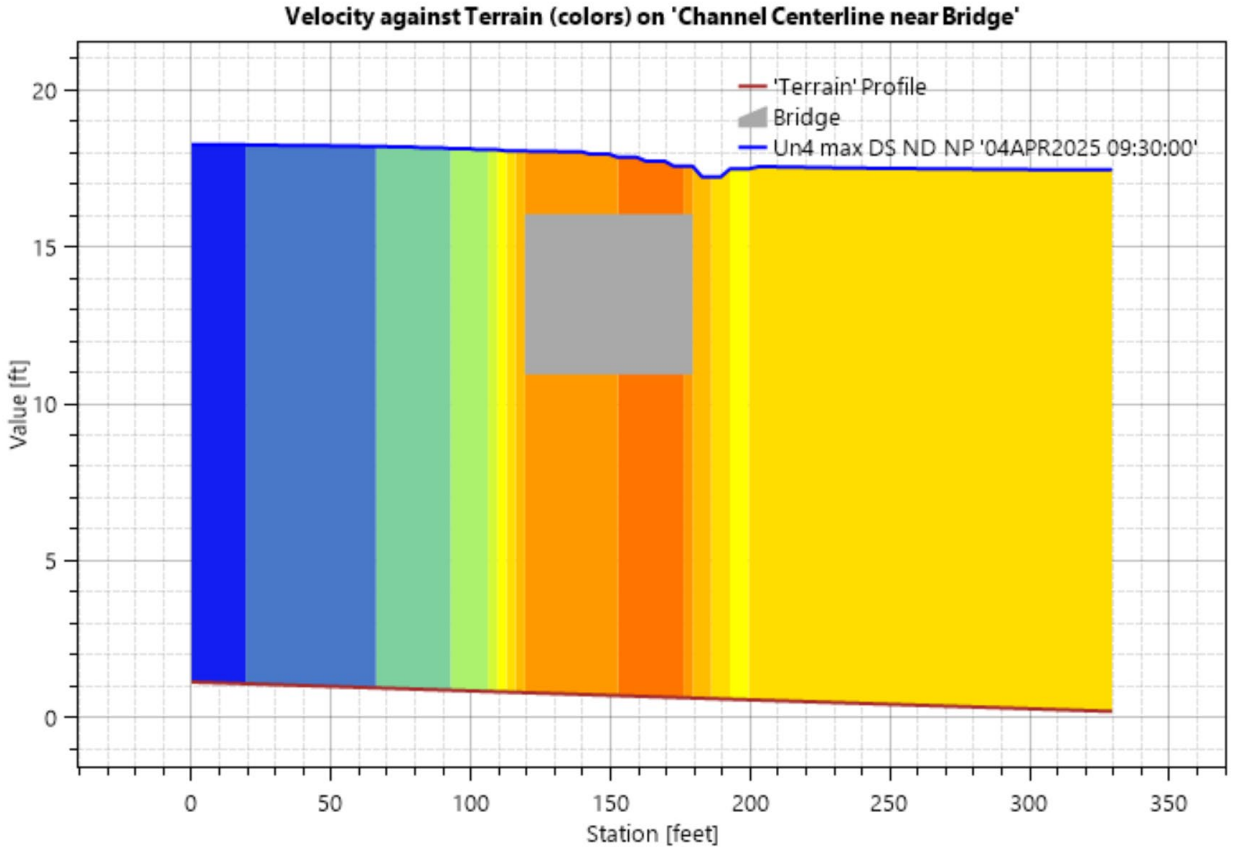
Mapping Output

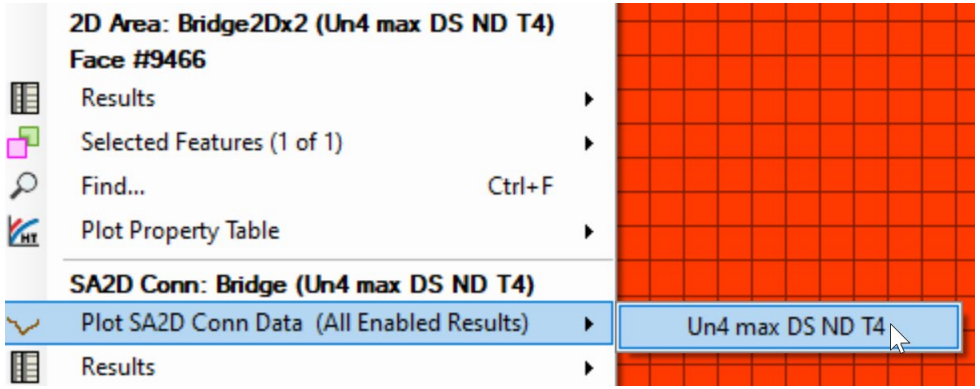
- Default **WSE**
  - Corresponds to max of the 1st and 2nd layers unless the flow is not pressurized
- Additional default Mapping layers
  - **Above Bridge WSE**
  - **Above Bridge Velocity**
  - 2nd layer output overrides 1st layer (not possible to view 2nd layer)

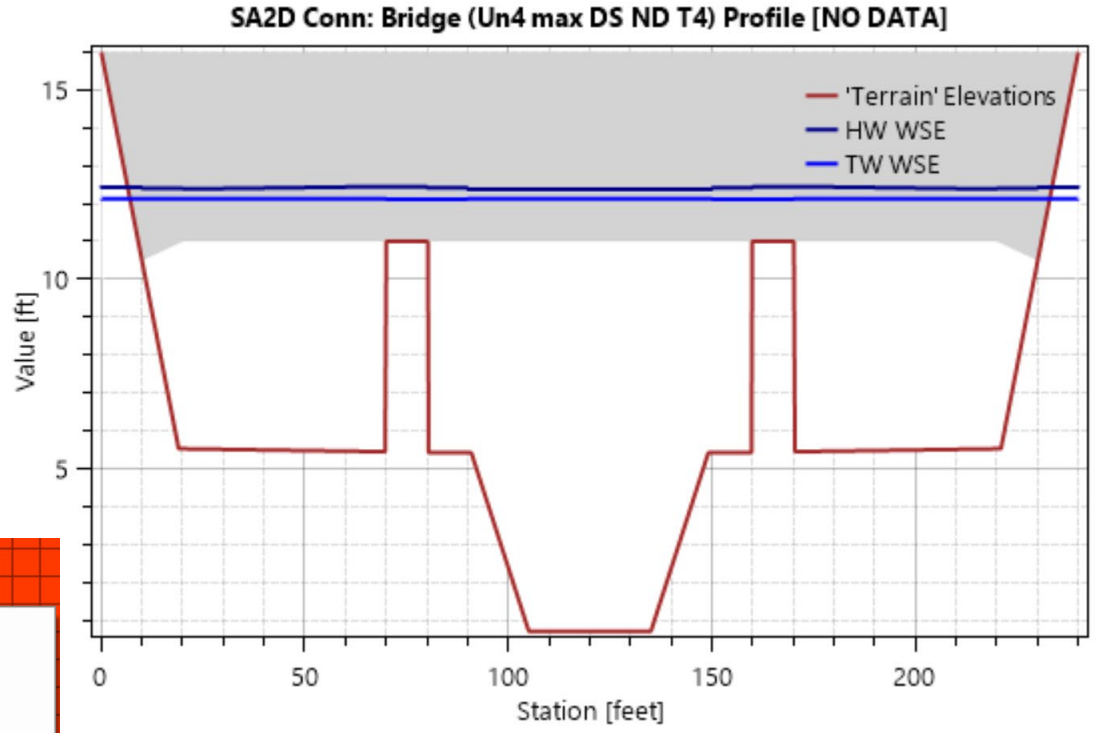


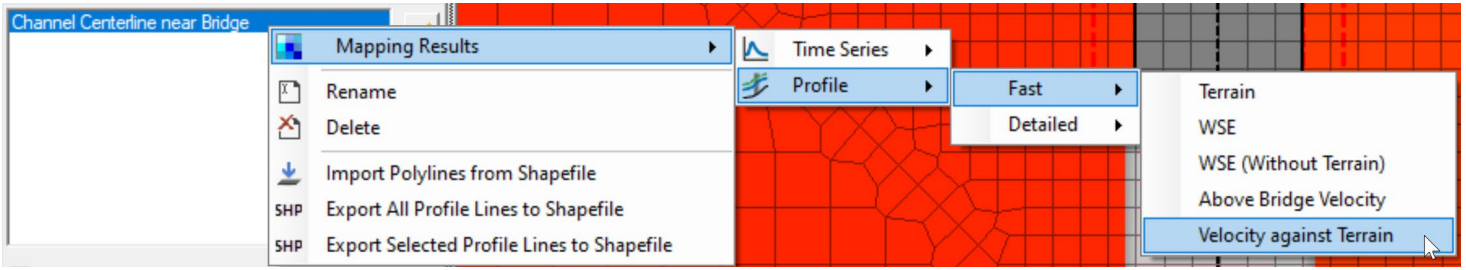


Profile Plots

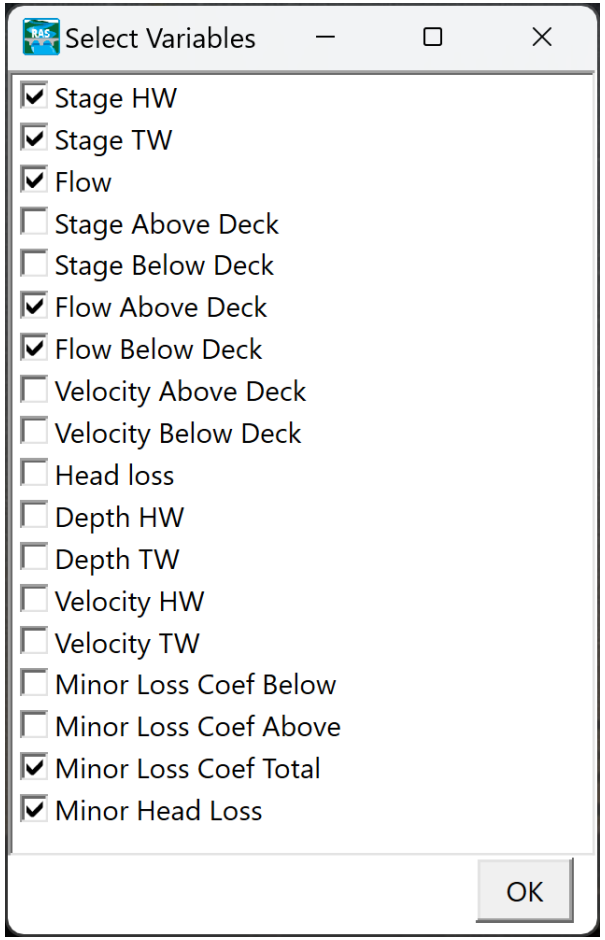


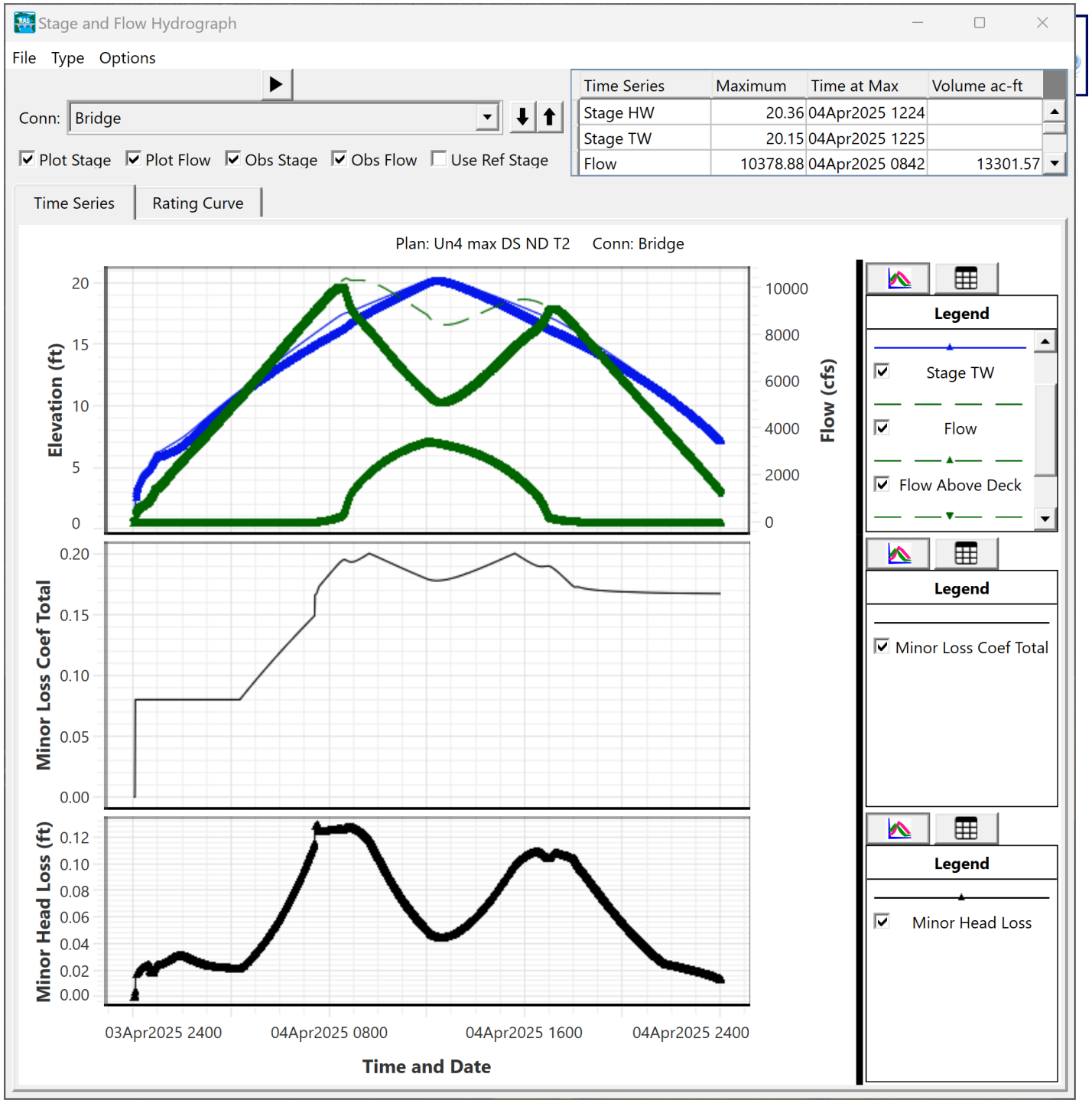






Time Series Plots





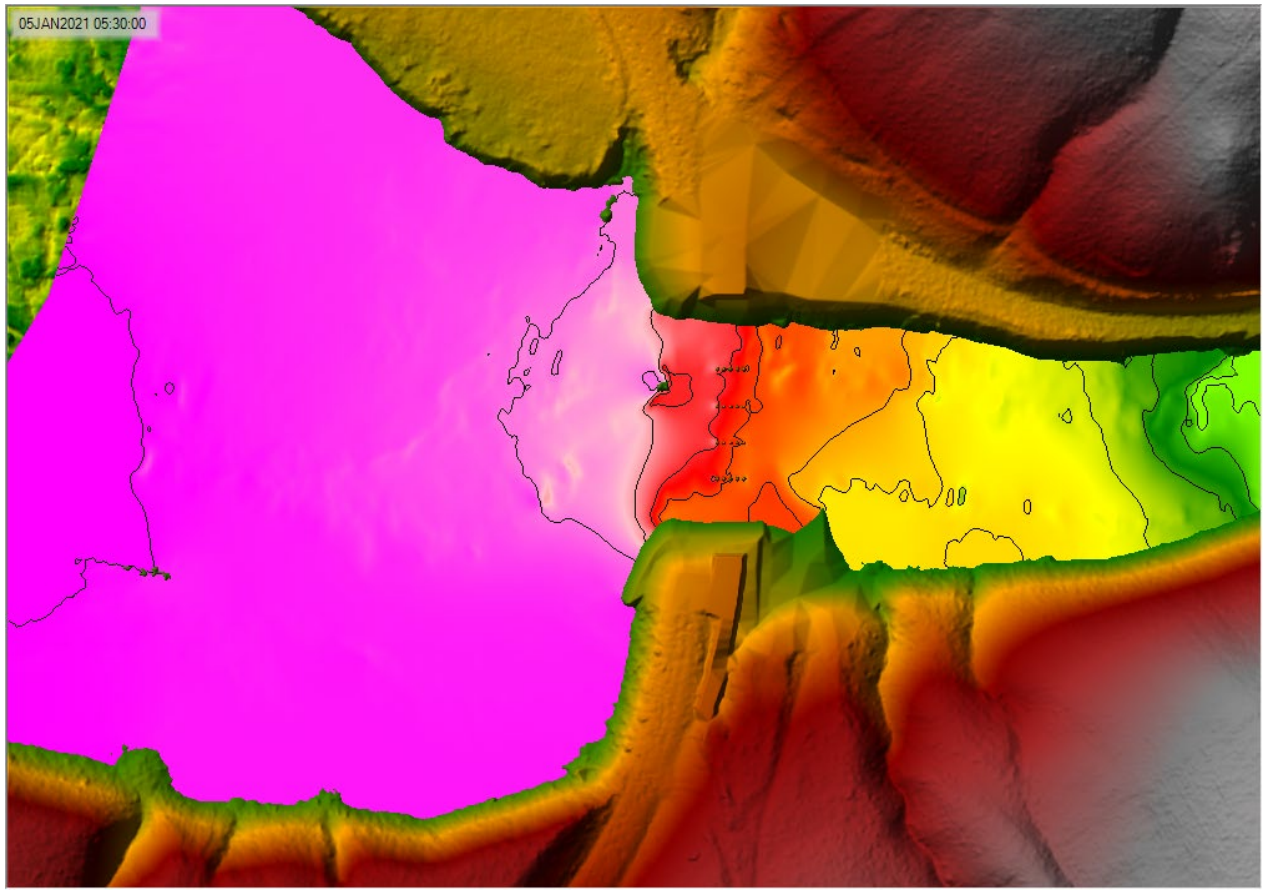
Limitations and 6.7 Release

- 2D Depth-averaged flow
- Hydrostatic Pressure
- Low and high chords approximated with a constant elevation
- Cannot view or interact with cloned bridge mesh
- Supported in 6.7 Release
  - Precip, evap, infiltration, wind, atmospheric pressure, and waves
- Not support in 6.7 Release
  - Bridge openings such as culverts
  - 2D sediment, secondary flow, debris flow, and others

https://www.northescambia.com/wp-content/uploads/2025/04/Flood-4004.jpg

When to Use What?

- Simplified 1D/2D Bridges
  - Head loss through the bridge
  - No detailed hydraulics
  - Coarse meshes
- Pressure/Overtopping
  - Detailed bridge hydraulics
  - Pressurized and high flow
  - Requires fine resolution mesh
  - Most physics-based



Questions?