

2D Bridge Modeling

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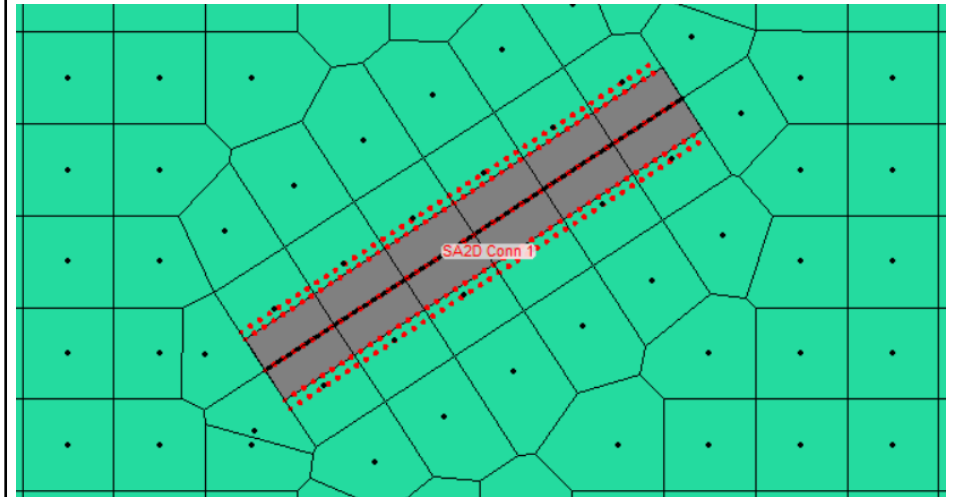


Approaches for Bridge Modeling



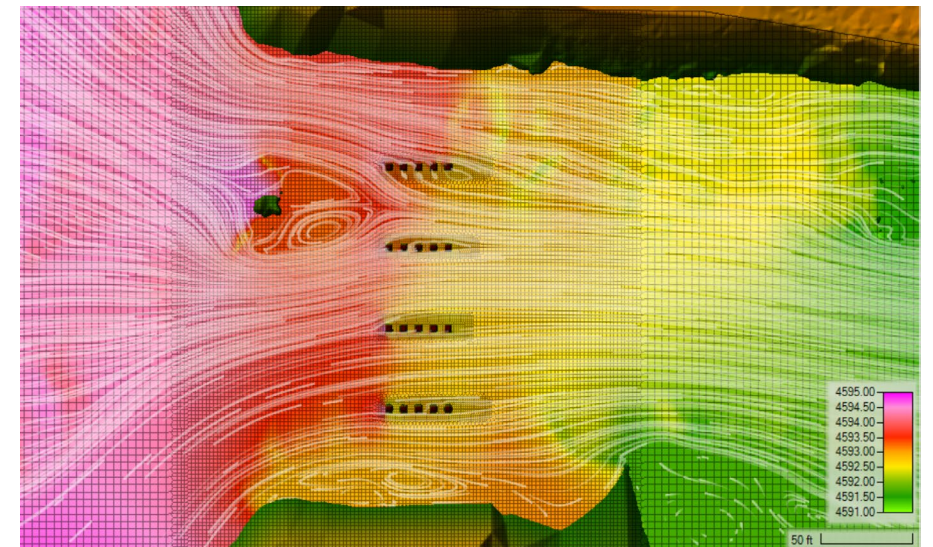
Simplified 2D Bridge Modeling (1D Family of Rating Curves)

- 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





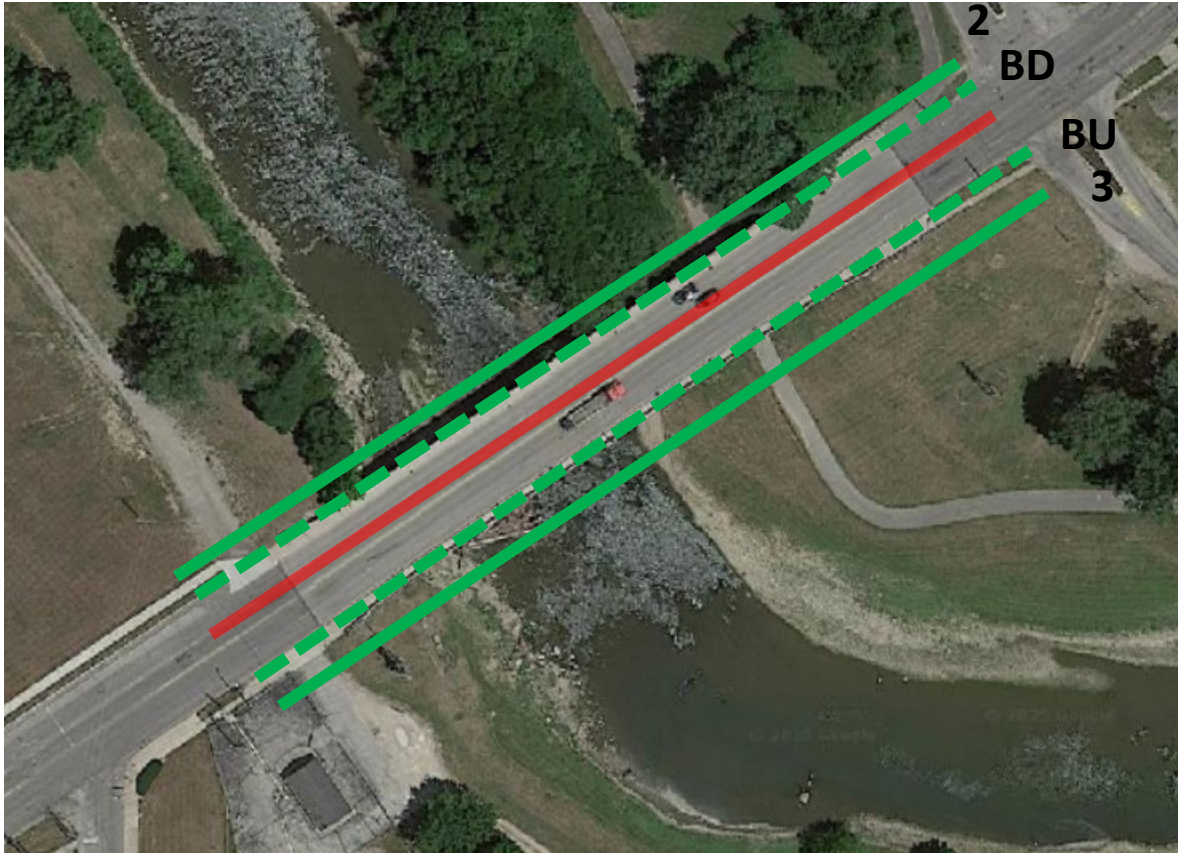
Simplified 2D Bridge Hydraulics



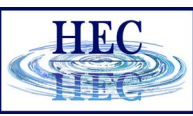
- Utilizing existing HEC-RAS **1D Bridge Hydraulics methods** (Family of Rating Curves) inside of a 2D Flow Area
- Model complete range of Bridge Hydraulic flow regimes
 - Low flow
 - Pressure flow
 - Pressure flow and weir flow (road over-topping)
 - Low flow and weir flow



1D Bridge Hydraulics Layout

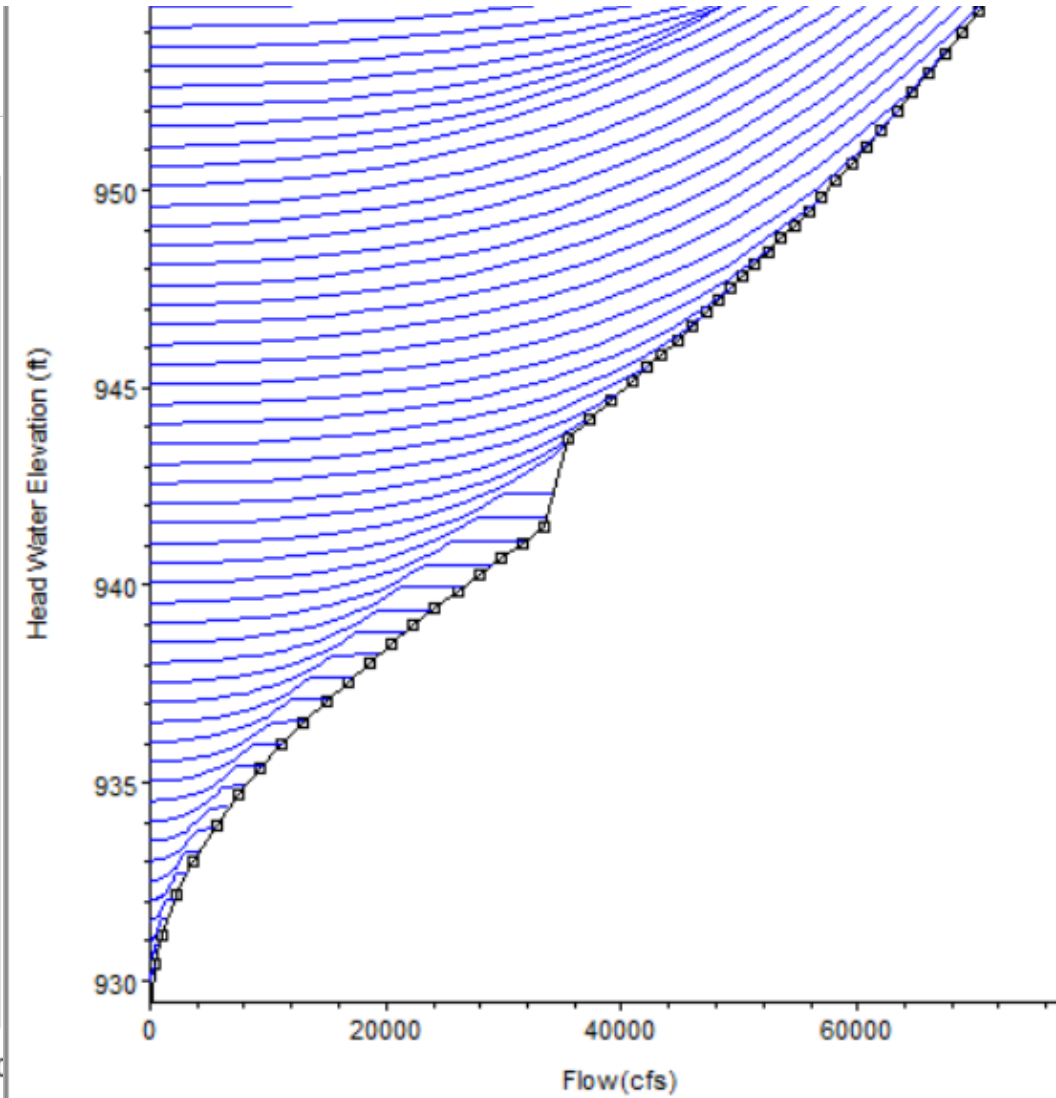
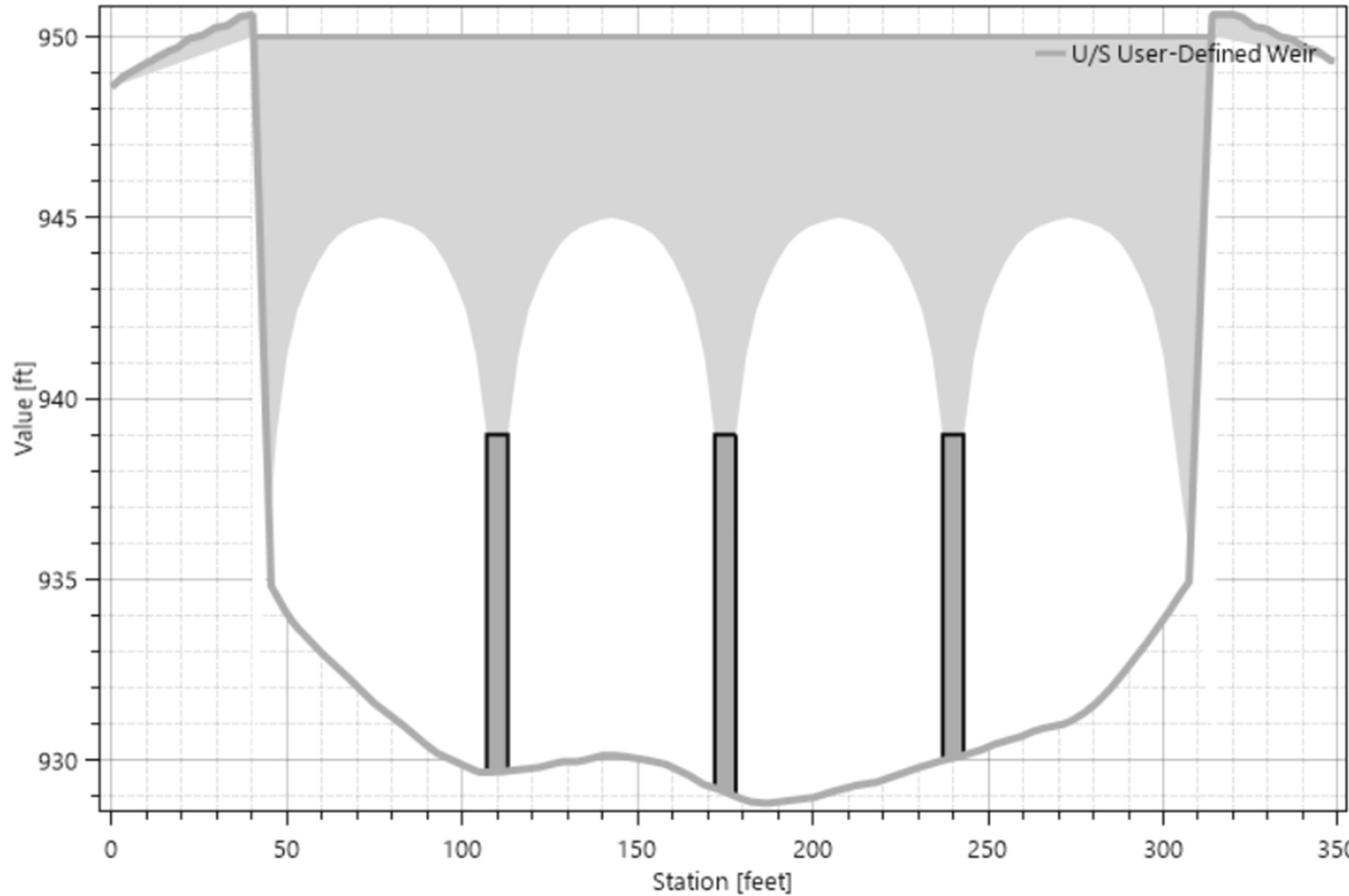


- XS2 - D/S away from embankment
 - BD – D/S face of bridge
 - BU – U/S face of bridge
 - XS3 – U/S away from embankment
-
- Develop a HW/TW relationship for a given flow from XS2 to XS3 - “Family of Rating Curves”



HTab – Family of Bridge Curves

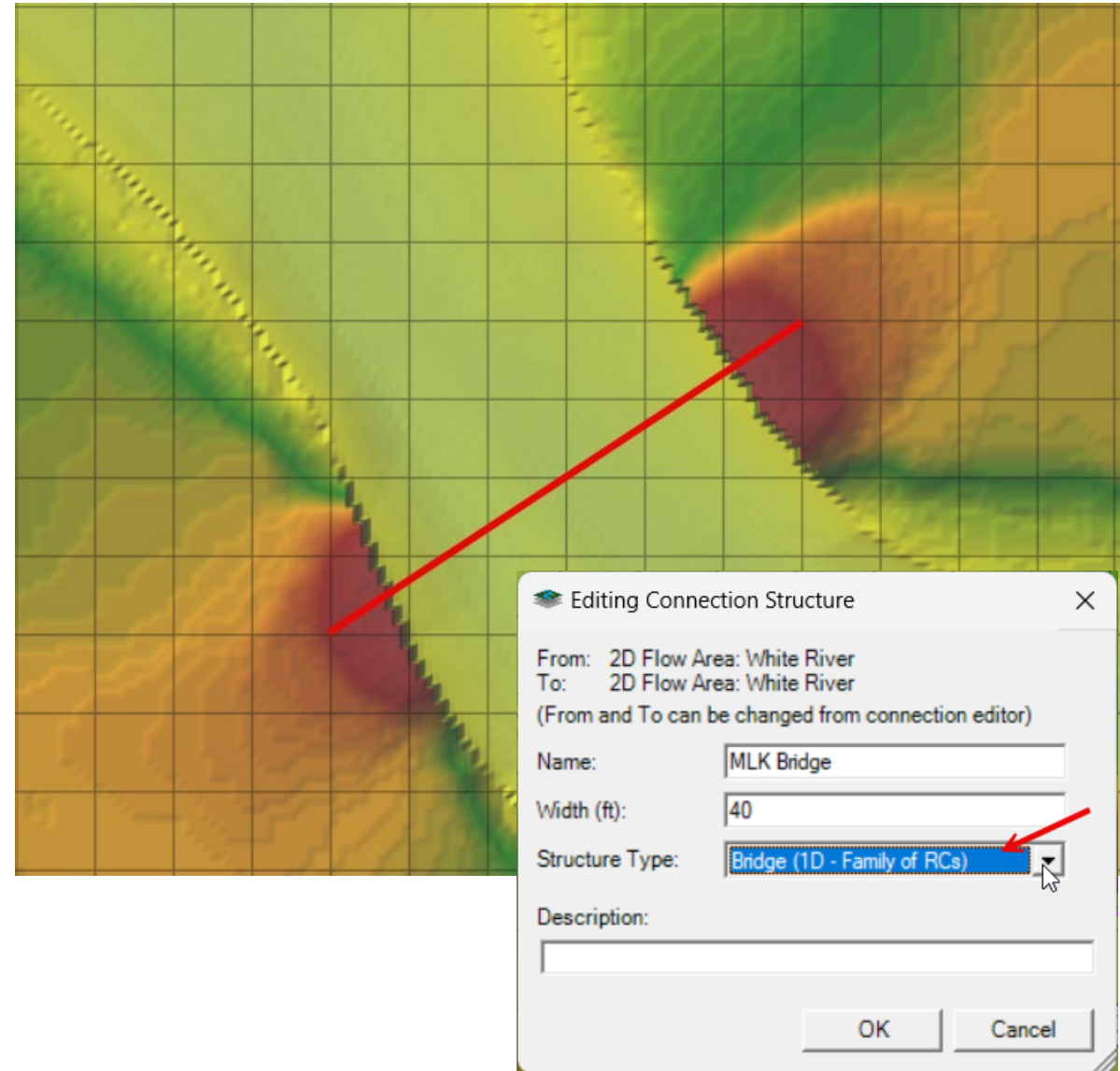
SA2D Conn: MLK Bridge (MLK Bridge) (Upstream)





2D Bridge Layout

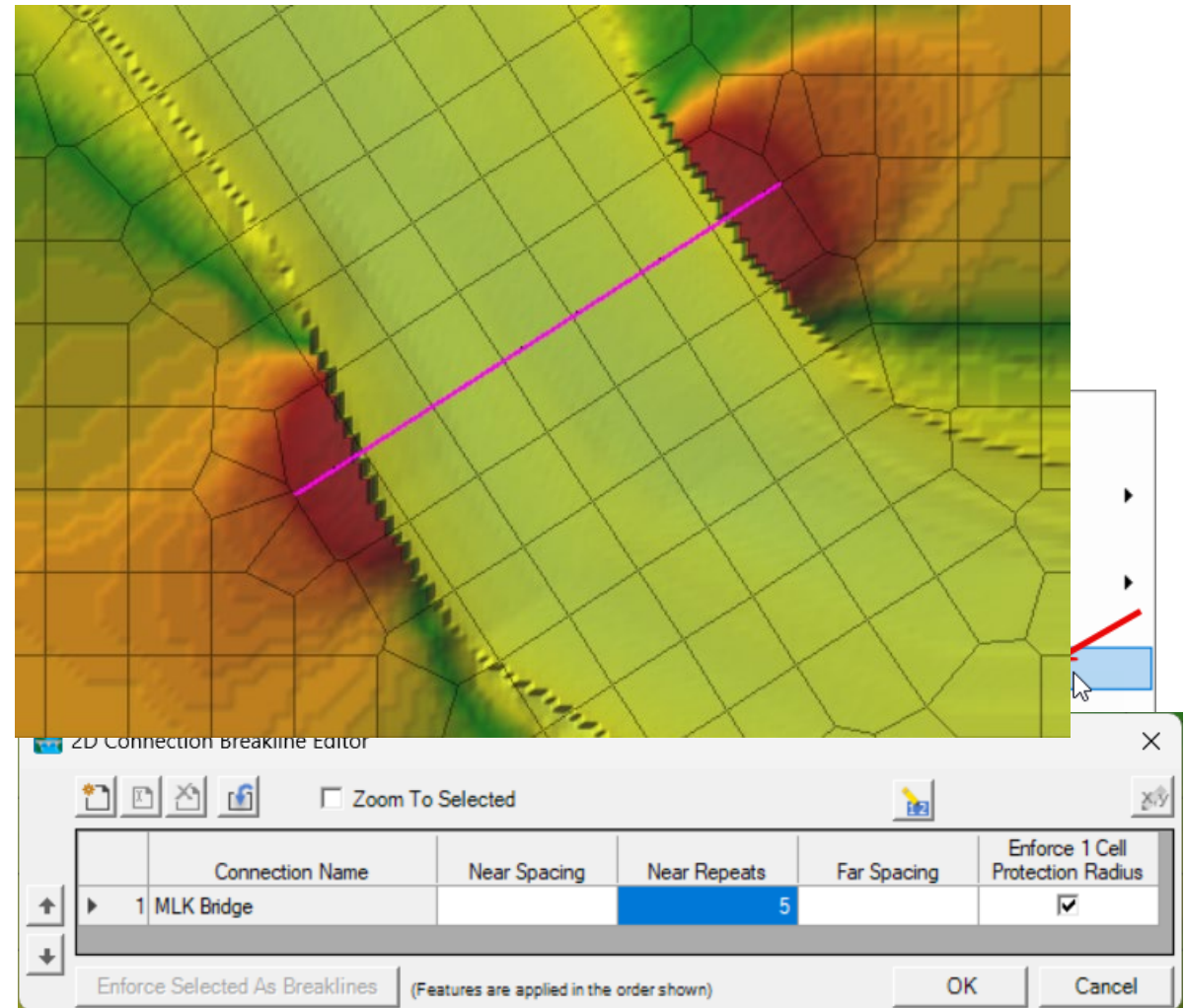
- Bridge is specified as a **SA/2D Connection**
- Choose **Bridge** structure type
- Only model **bridge opening** (if weir flow in overbanks add structure for that – or use 2D equations for non-weir flow)





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

Deck/Roadway Data Editor

Distance	Width	Weir Coef
5.	40.	2.6

Upstream				Downstream		
	Station	high chord	low chord	Station	high chord	low chord
1	40	950	930	40	950	930
2	47	950	939	47	950	939
3	50	950	941.175	50	950	941.175
4	53	950	942.45	53	950	942.45
5	56	950	943.2	56	950	943.2
6	59	950	943.8	59	950	943.8
7	62	950	944.25	62	950	944.25
8	65	950	944.55	65	950	944.55

U.S Embankment SS: D.S Embankment SS:

Weir Data
 Max Submergence: Min Weir Flow El:

Weir Crest Shape
 Broad Crested
 Ogee

Enter distance between upstream cross section and deck/roadway. (ft)

Connection Data Editor - MLK Bridge

File View Options Help

Connection: MLK Bridge

Description:

From: 2D Flow Area: White River

To: 2D Flow Area: White River

Structure Type: **Bridge (1D Family of RCs)**

Plot: US Inside Bridge

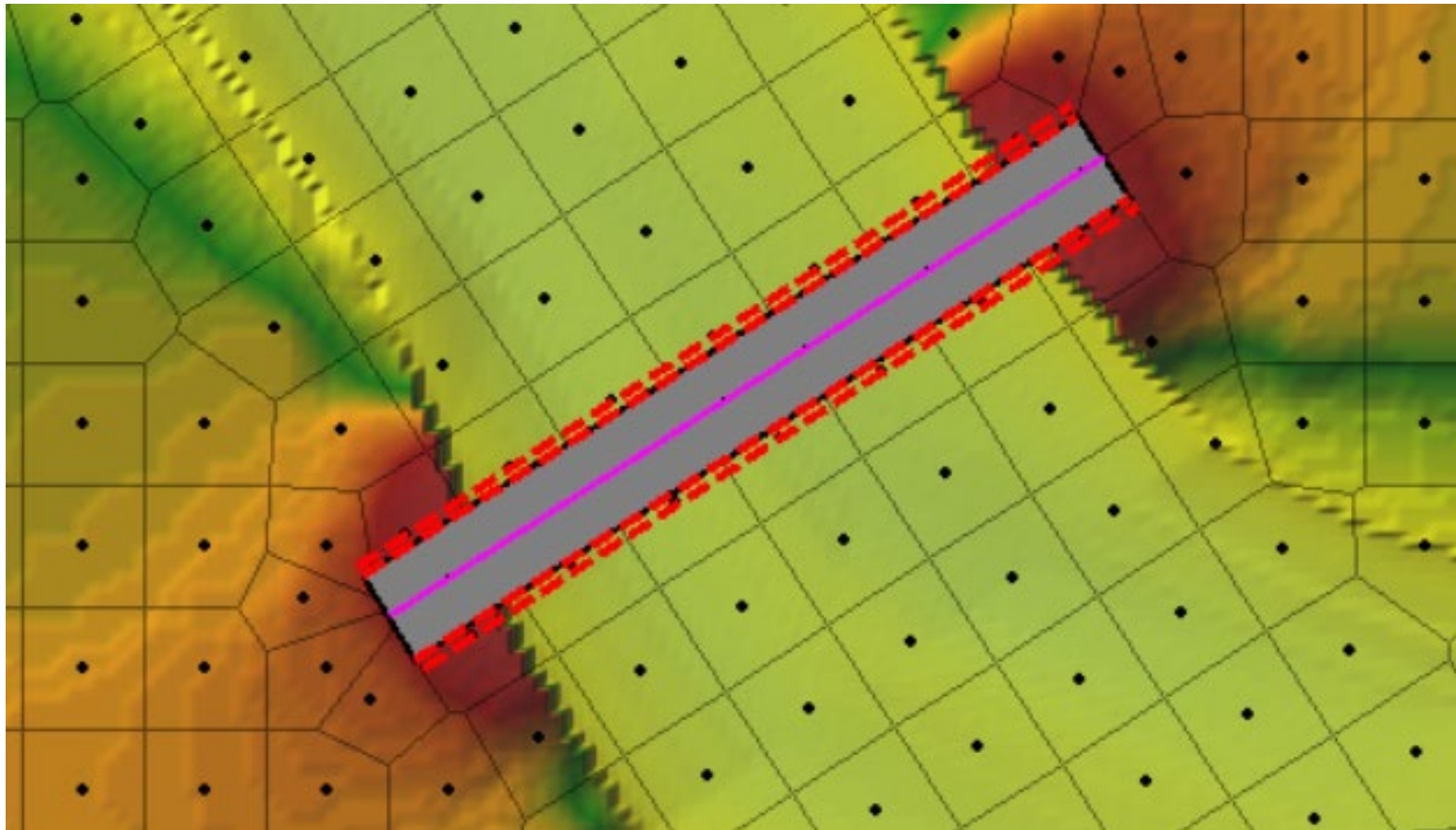
Deck/Roadway
 US Bounding XS
 US Inside Bridge
 DS Inside Bridge
 DS Bounding XS

Elevation (ft) vs Station (ft) graph showing bridge profile and ground terrain.



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.

Pier Data Editor

Add Copy Delete Pier # 1 ↓ ↑

Del Row Centerline Station Upstream 110

Ins Row Centerline Station Downstream 110

Floating Pier Debris

All On ... All Off ... Apply floating debris to this pier

Set Wd/Ht for all ... Debris Width:

Debris Height:

	Upstream		Downstream		
	Pier Width	Elevation	Pier Width	Elevation	
1	6	925	6	925	▲
2	6	945	6	945	
3					
4					
5					
6					▼

OK Cancel Help Copy Up to Down

Select the Pier to Edit



Manning's n Data for the XS's

- Options | External and Internal Bridge Cross Sections...

Bridge Cross Sections

Upstream Outside				Upstream Inside				Downstream Inside				Downstream Outside			
Main Channel Bank Stations				Main Channel Bank Stations				Main Channel Bank Stations				Main Channel Bank Stations			
Left Bank Sta		Right Bank Sta		Left Bank Sta		Right Bank Sta		Left Bank Sta		Right Bank Sta		Left Bank Sta		Right Bank Sta	
0		348.96		0		348.96		0		348.96		0		348.96	
Cross Section X-Y Coordinates				Cross Section X-Y Coordinates				Cross Section X-Y Coordinates				Cross Section X-Y Coordinates			
Station	Elevation	Mann n		Station	Elevation	Mann n		Station	Elevation	Mann n		Station	Elevation	Mann n	
1	0	948.51	0.035	1	0	948.61	0.035	1	0	947.96	0.035	1	0	947.78	0.035
2	7.3	949.17		2	3.37	948.91		2	0.63	948		2	3.85	948	
3	8.8	949.27		3	10.53	949.31		3	6.58	948.66		3	9.8	948.66	
4	12.42	949.33		4	11.34	949.33		4	12.52	948.97		4	15.75	948.97	
5	16.03	949.55		5	12.59	949.42		5	18.47	949.31		5	21.7	949.31	
6	19.65	949.64		6	16.48	949.62		6	24.42	949.62		6	27.65	949.62	
7	23.27	949.91		7	18.57	949.69		7	30.37	949.97		7	33.6	949.97	
8	25.15	949.97		8	22.19	949.96		8	31.64	950		8	39.55	950.28	
9	29.57	950.2		9	25.81	950.04		9	33.61	950.14		9	45.5	950.62	
10	30.5	950.27		10	29.42	950.25		10	36.32	950.28		10	50.75	935.55	
11	34.12	950.37		11	33.04	950.32		11	38.88	950.35		11	56.7	934.53	
12	37.05	950.56		12	36.66	950.56		12	42.49	950.62		12	59.64	934.17	
13	38.15	947.49		13	40.28	950.62		13	48.22	950.62		13	62.65	933.86	
14	42.3	935.27		14	45.53	934.82		14	50.63	943.49		14	68.6	933.29	
15	44.91	934.73		15	49.48	934.14		15	53.47	934.89		15	72.32	932.95	

OK Cancel Help



Hydraulic Table Parameters

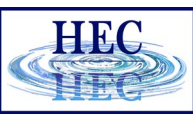
HTab
Param.



- **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.

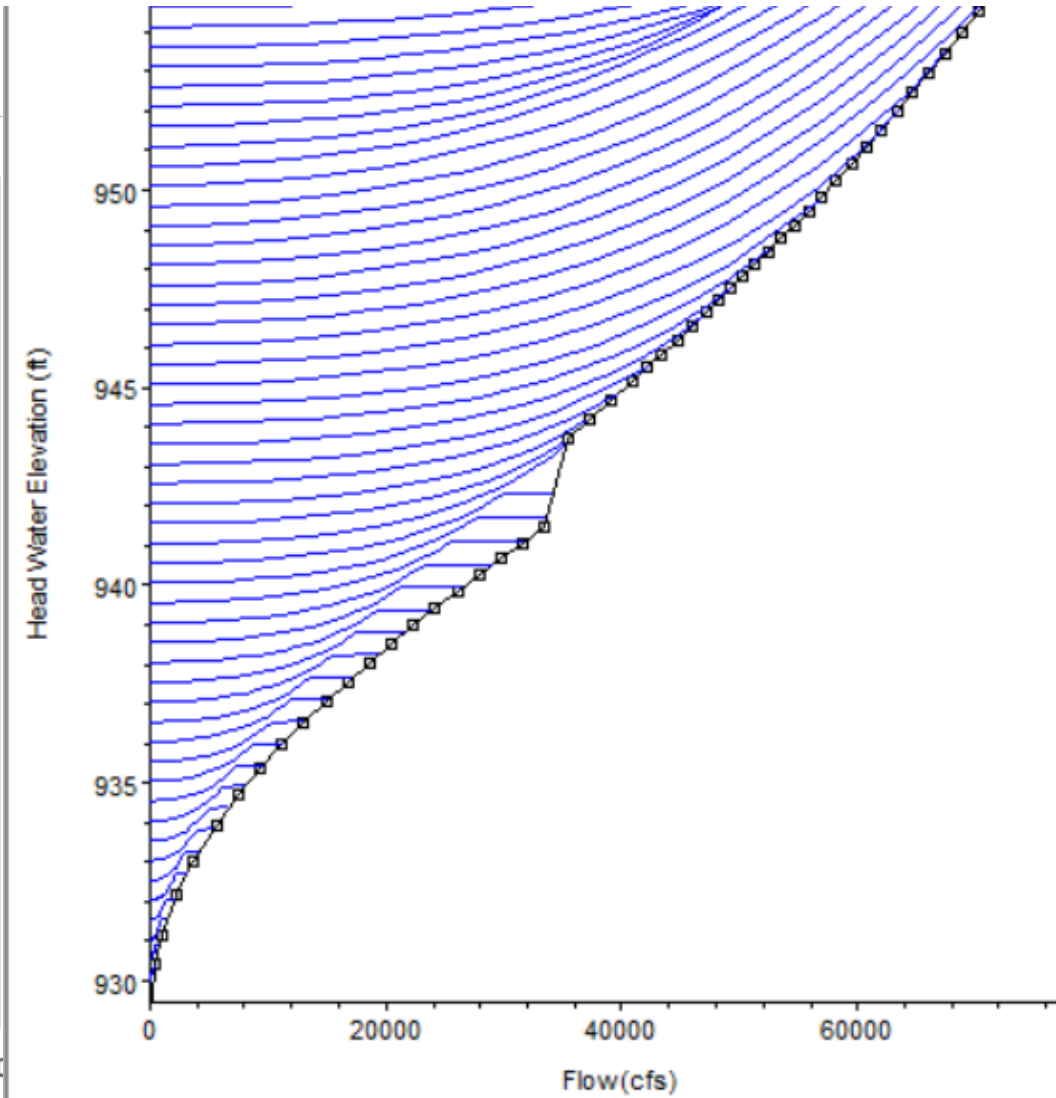
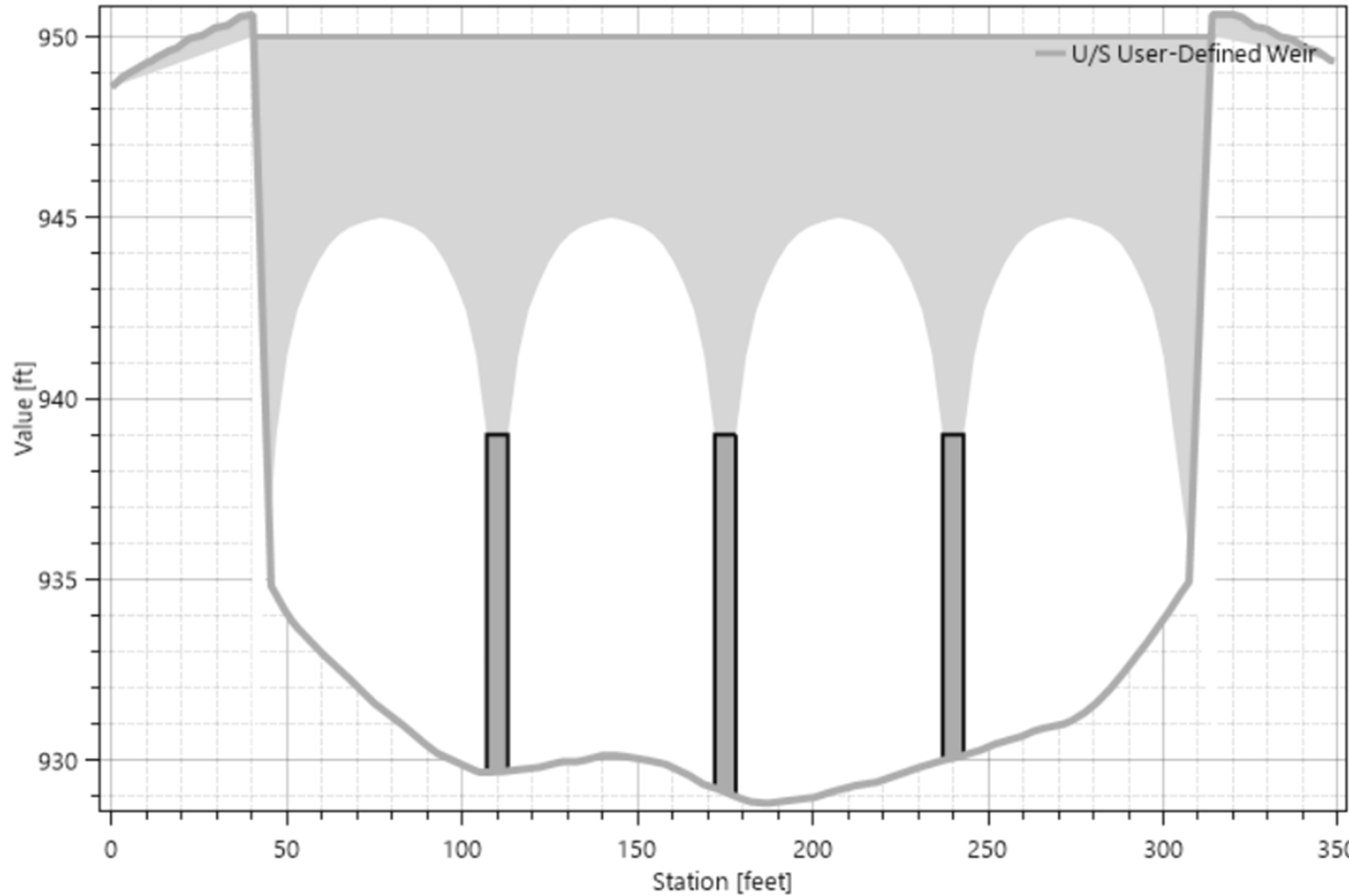
Connection Hydraulic Property Table Parameters

Number of points on free flow curve:	<input type="text" value="100"/>
Number of submerged curves:	<input type="text" value="60"/>
Number of points on each submerged curves:	<input type="text" value="60"/>
<input type="button" value="Apply number of points to all Connections"/>	
Head water maximum elevation:	<input type="text" value="595"/>
Tail water maximum elevation (Optional):	<input type="text"/>
Maximum Flow (Recommended):	<input type="text"/>
<input type="button" value="OK"/> <input type="button" value="Cancel"/>	



HTab – Family of Bridge Curves

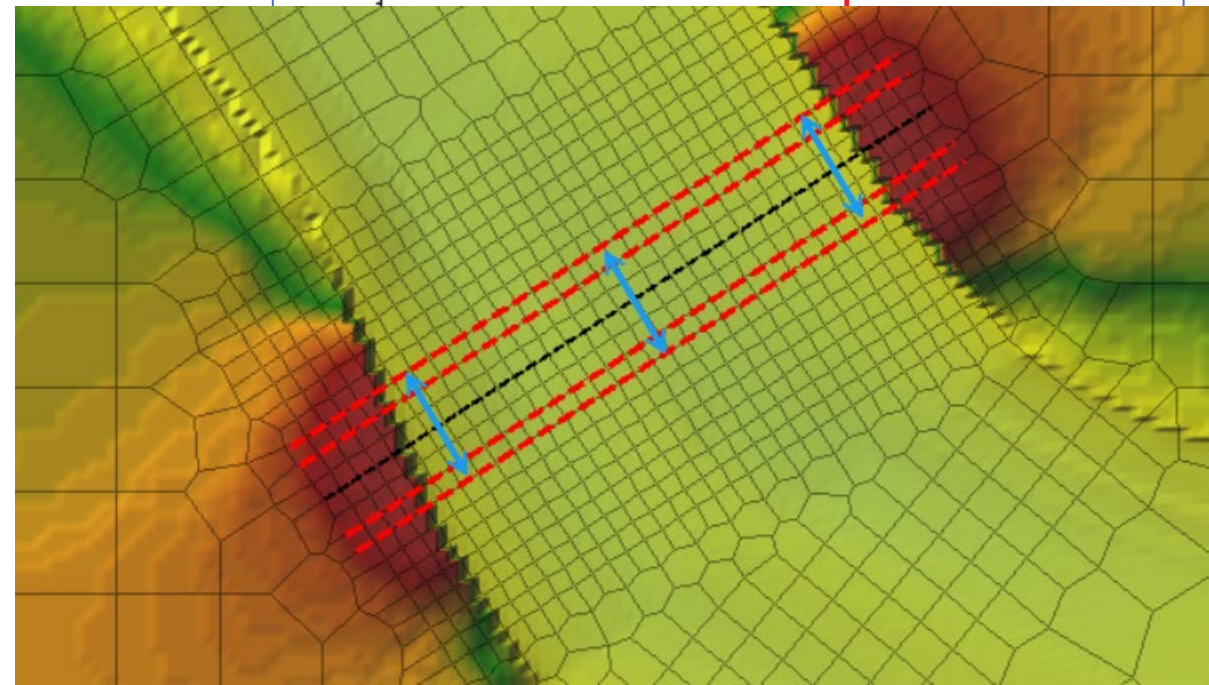
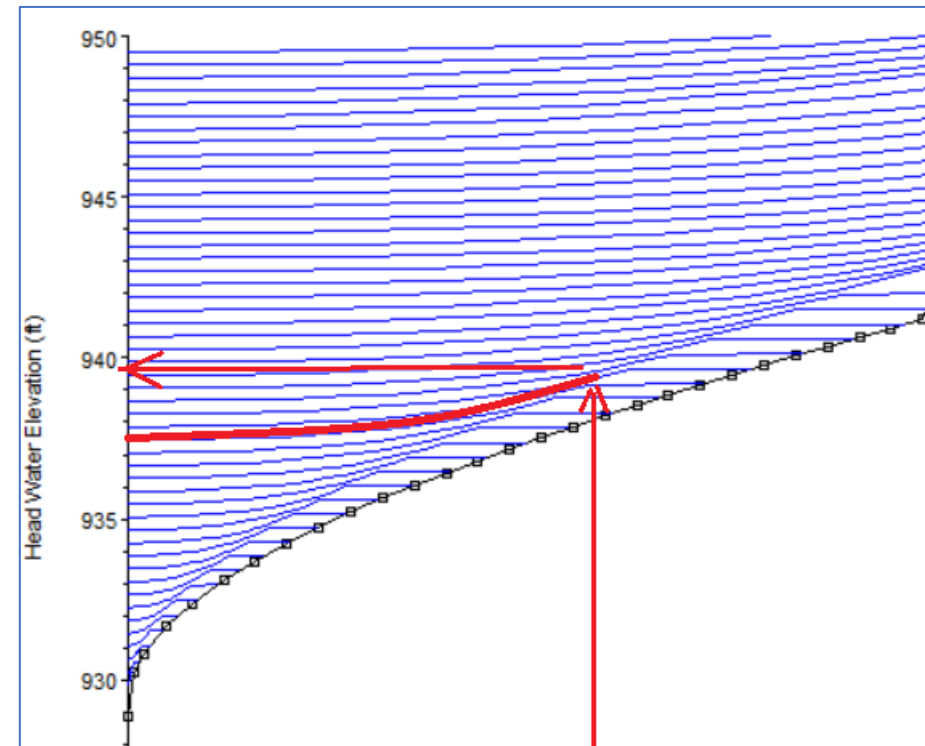
SA2D Conn: MLK Bridge (MLK Bridge) (Upstream)





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





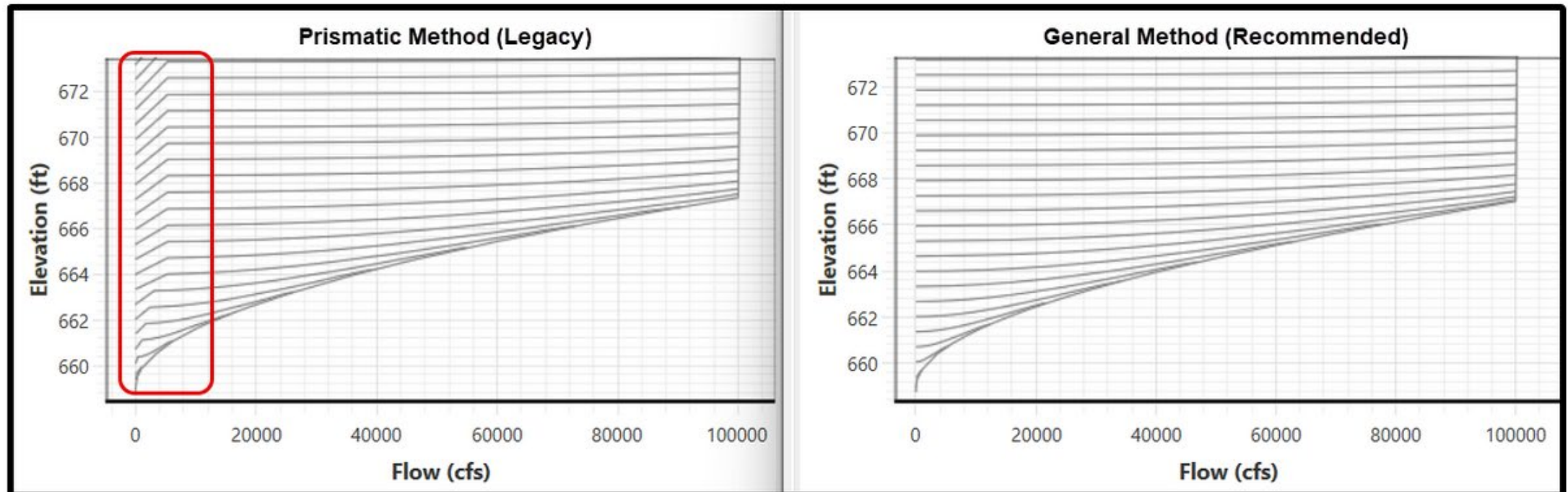
Version 6.5 Computational Improvement

- 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

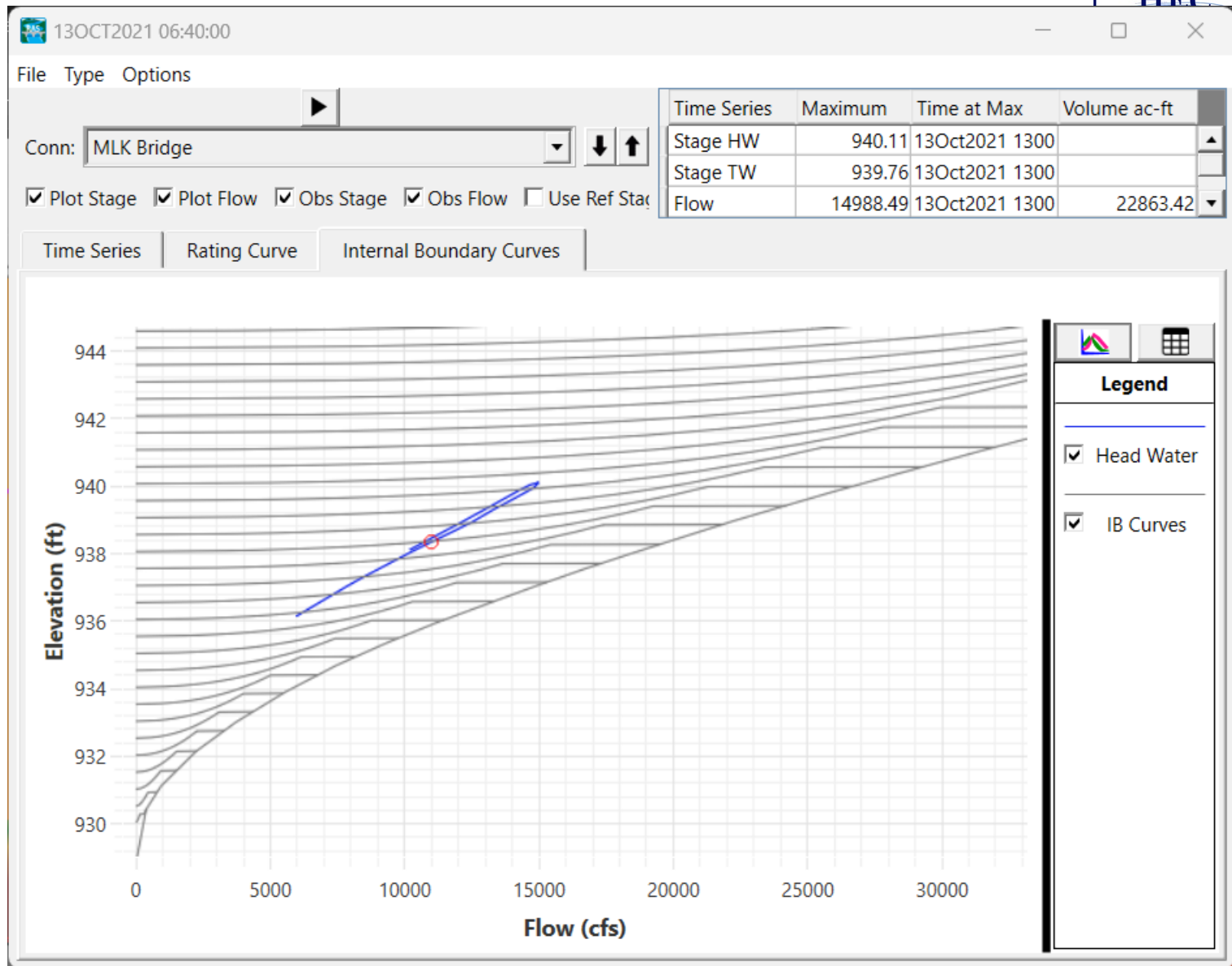
- Added Momentum (General) method implemented computes the losses using the general 1D momentum approach and works on both natural and prismatic channels.
- The Prismatic (Legacy) method overly sensitive to cross-section shape and bed slope.





Bridge Output

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





Bridge Output

RAS Mapper

File Project Tools Help

Selected Layer: Simple Bridge

- Plan
- Depth (Max)
- Velocity (13OCT2021 1
- WSE (13OCT2021 13:1

Simple Bridge

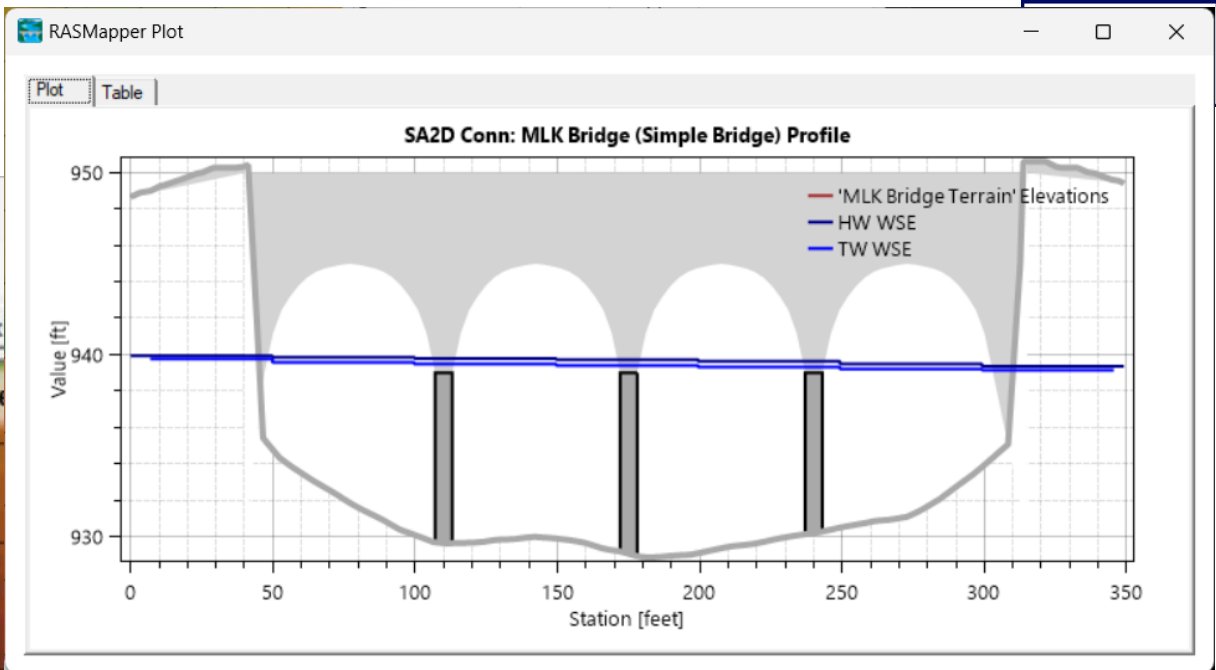
- Event Conditions
- Geometry
 - 2D Flow Areas
 - SA/2B Connections
 - Boundary Condition
- Plan
- Depth (1
- Velocity (13OCT2021 0
- WSE (13OCT2021 15:5

WithAbutment

- Event Conditions
- Geometry
- Plan
- Depth (13OCT2021 13:
- Velocity (13OCT2021 1
- WSE (13OCT2021 06:0

NoBridge

- Event Conditions
- Geometry
- Plan



All Enabled Results

- Mapping Time Series
- Subgrid Property Table

2D Area: White River (Simple Bridge)

Face #10708

- Results
- Selected Features (1 of 1)
- Find... Ctrl+F
- Plot Property Table

SA2D Conn: MLK Bridge (Simple Bridge)

- Plot SA2D Conn Data (All Enabled Results) **Simple Bridge**
- Results
- Mapping Results



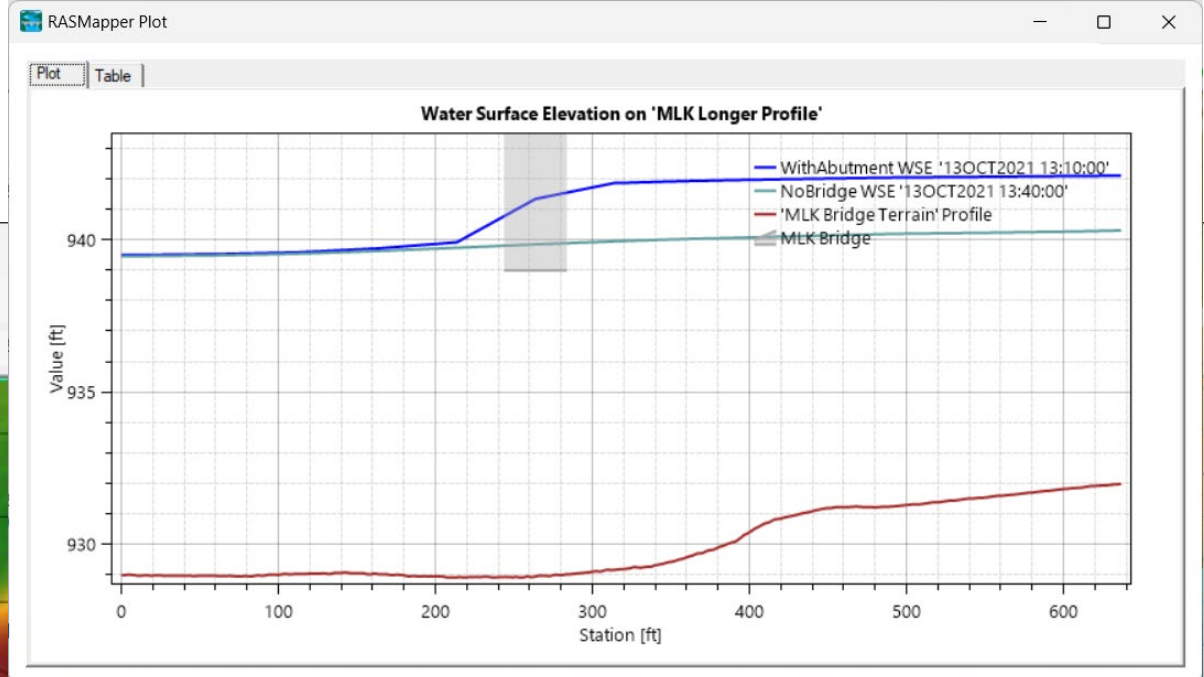
Bridge Output

RAS Mapper

File Project Tools Help

Max Min

- Features
 - Profile Lines
- Geometries
 - MLK Bridge
 - Simple Bridge
 - Bridge Refined Cells
 - NoBridge
- Plans
- Event Conditions
- Results
 - MLK Bridge
 - Refined Cells
 - Simple Bridge
 - Event Conditions
 - Geometry
 - Plan
 - Depth (13OCT2021)
 - Velocity (Max)
 - WSE (13OCT2021)
 - NoBridge
- Map Layers
 - Google Hybrid
 - Google Satellite
- Terrains
 - MLK Bridge Terrain



MLK Longer Profile

Mapping Results

- Time Series
- Profile
 - Fast
 - Detailed
 - Terrain
 - WSE
 - WSE (Without Terrain)
 - Depth

Rename

Delete

Import Polygons from Shapefile

Plot Tick Marks

Messages Views

(408813.91 1802888)

100 ft



Bridge Animation





Bridge Output

- Head loss through bridge

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

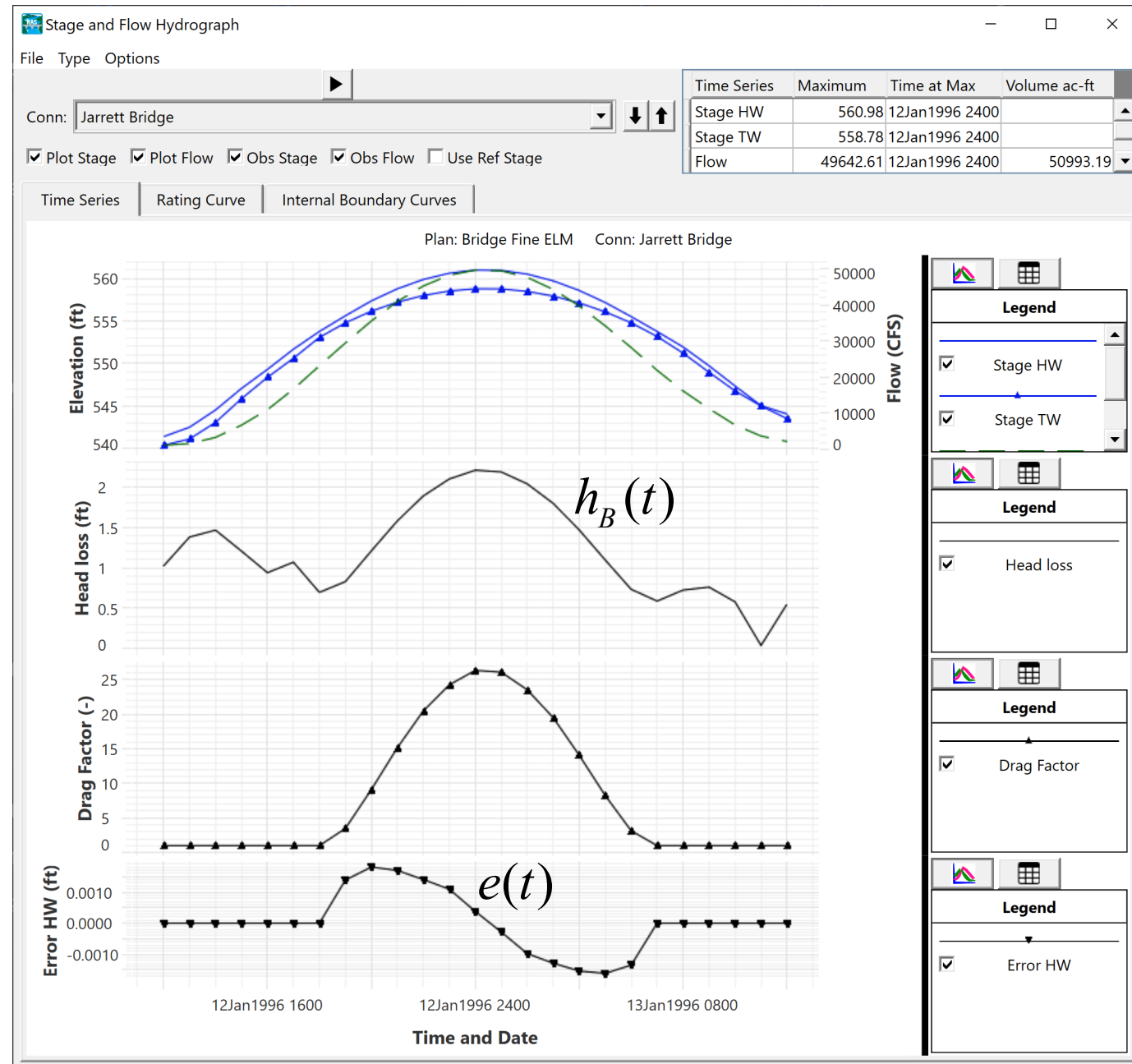
- Drag factor

- Limited to 1
- Constant under bridge

- Error

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

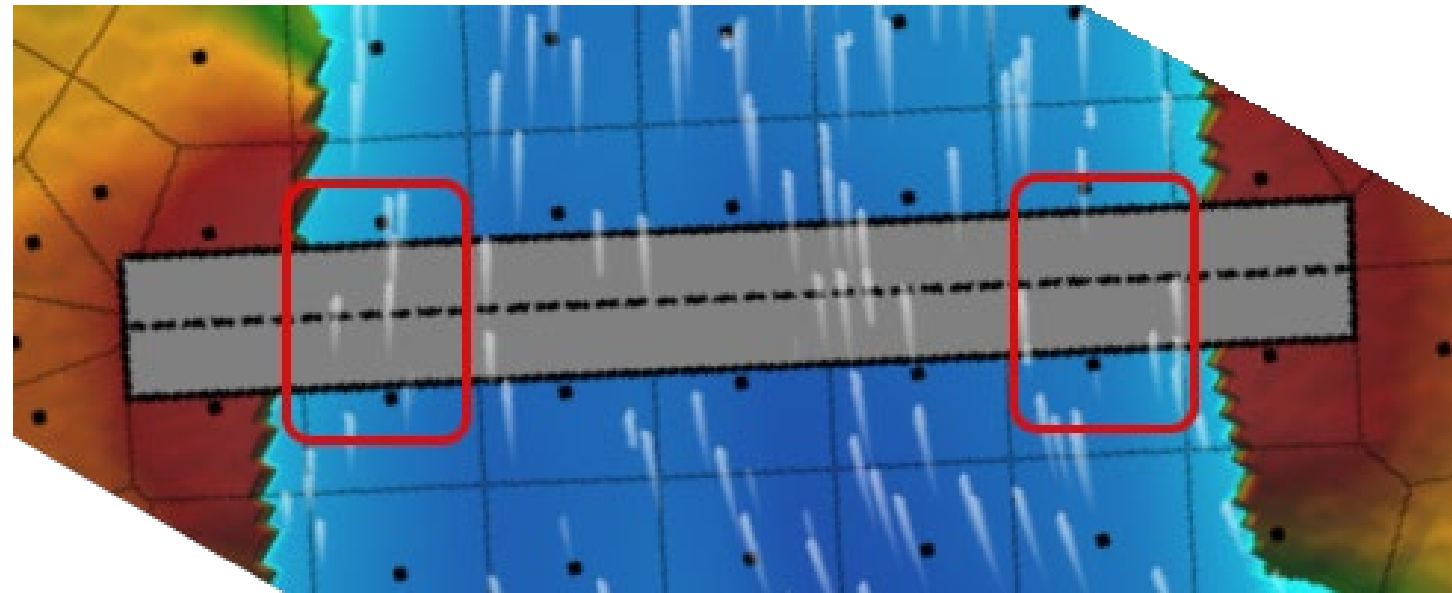
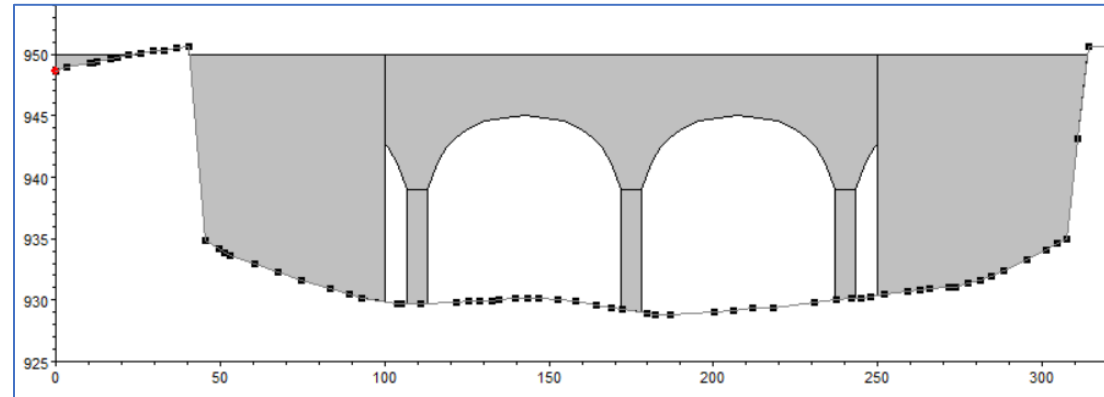
- Usually small but can be increase if controller has trouble especially during flow transitions





Limitations – Simplified 2D Bridge Modeling

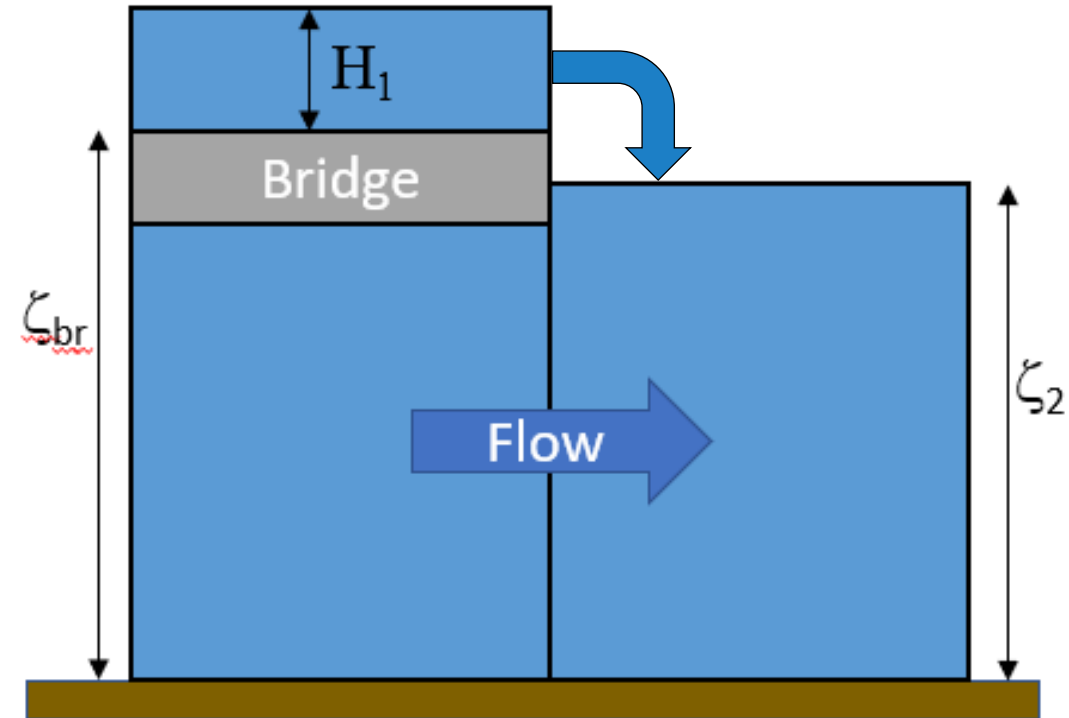
- Detailed velocities will not be correct. Appropriate solution for computing WSE.
 - Bridge geometry is included in HTab Curves but not Cell Property Tables
- Velocity traces through the abutments and piers, if not included in the terrain





Detailed Bridge Modeling

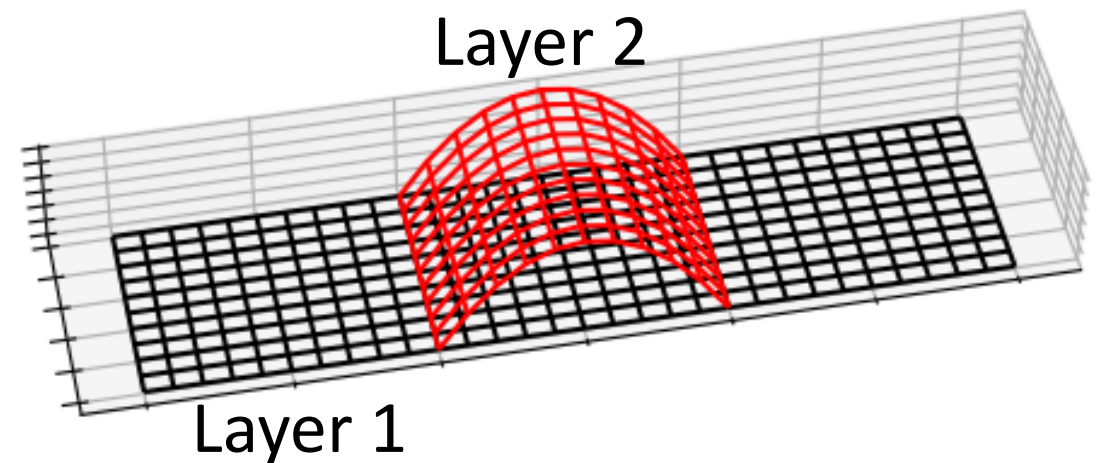
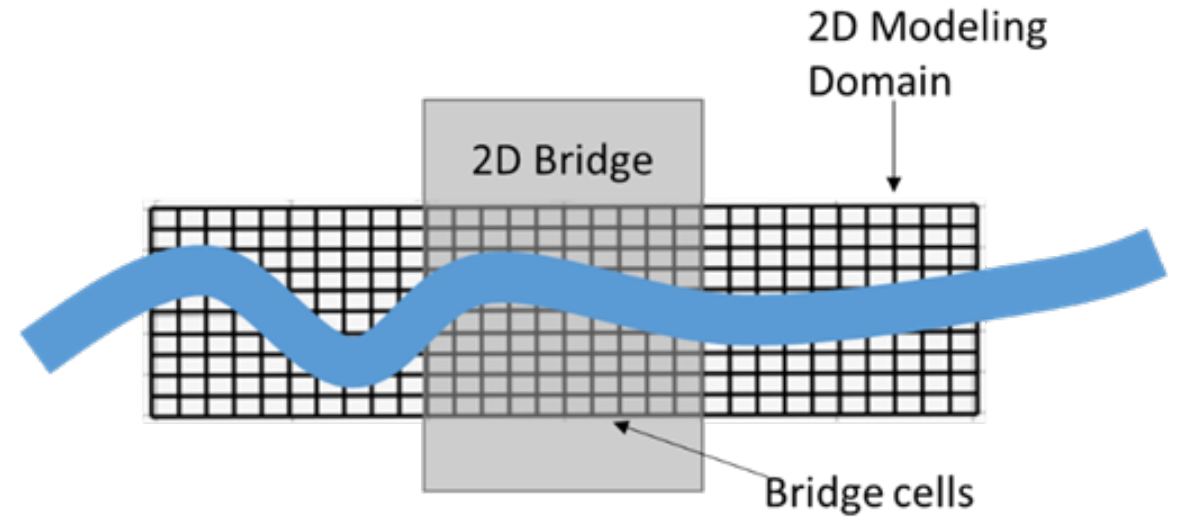
- Regular 2D Approach (2D)
 - Low flow conditions only (water below deck)
- Pressure/Overtopping (2Dx2)
 - Version 6.7 Betas (Official Release at end of FY)
 - Two-layer (2Dx2) mesh for bridges
 - Additional mesh above each bridge
 - Requires bridge deck geometry
 - All flow conditions
 - Minor Losses
- 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

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

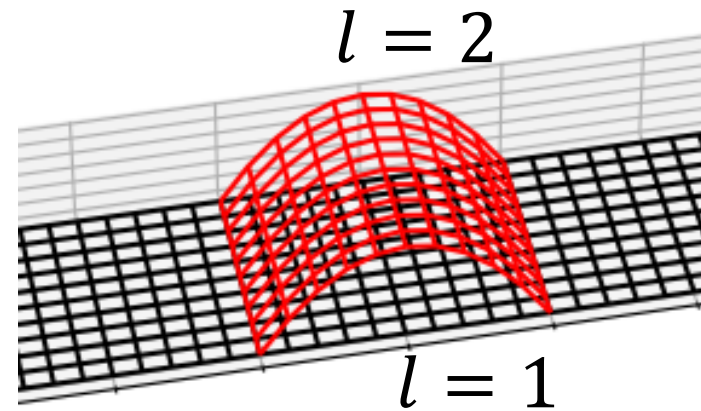
- Momentum

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

Hydraulic Head

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

$$H_2 = z_{s,2}$$



z_s : Water surface elevation

\mathbf{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

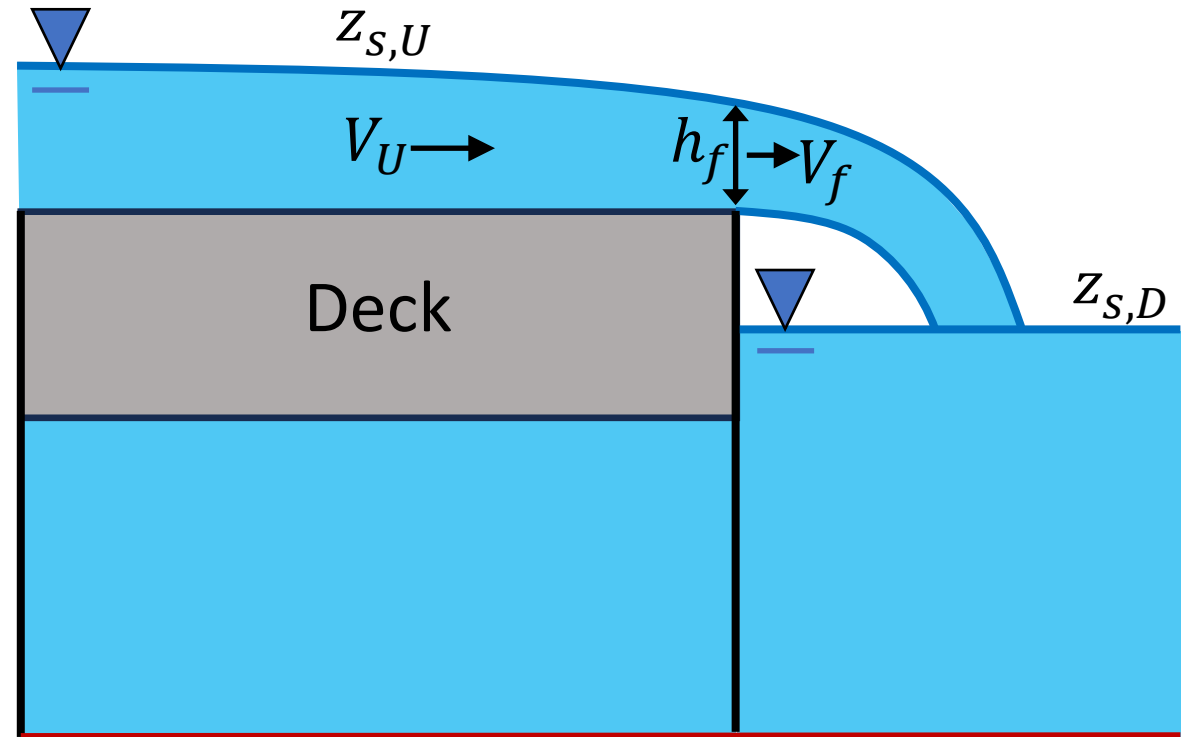
$$\frac{V_U^2}{2g} + z_{s,U} = \frac{V_f^2}{2g} + z_{b,f} + h_f$$

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

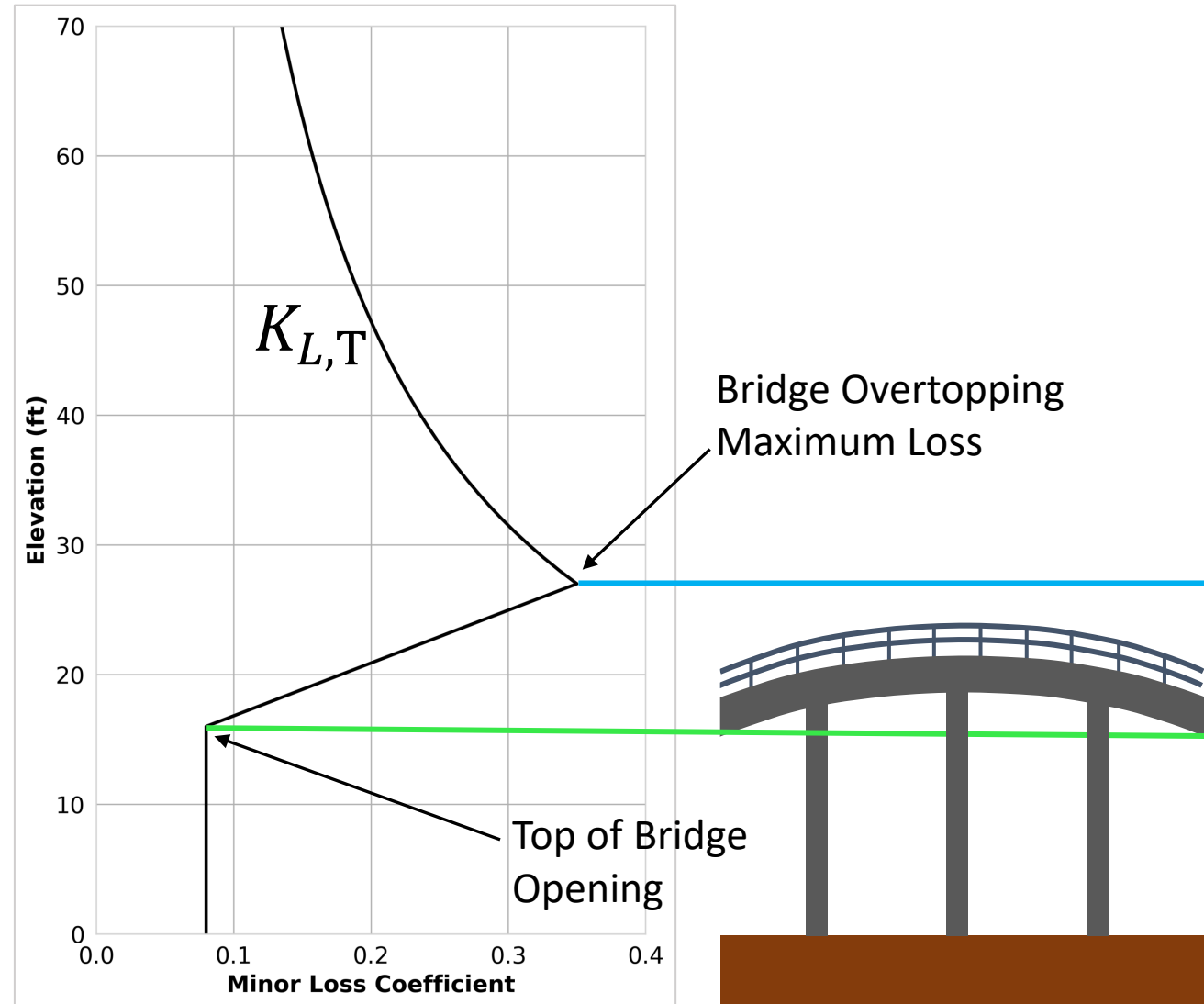
- For Pressure/Overtopping
- Minor Head Loss

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

- Apportioning Minor Losses

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

- Note: Velocities area-averaged over bridge centerline

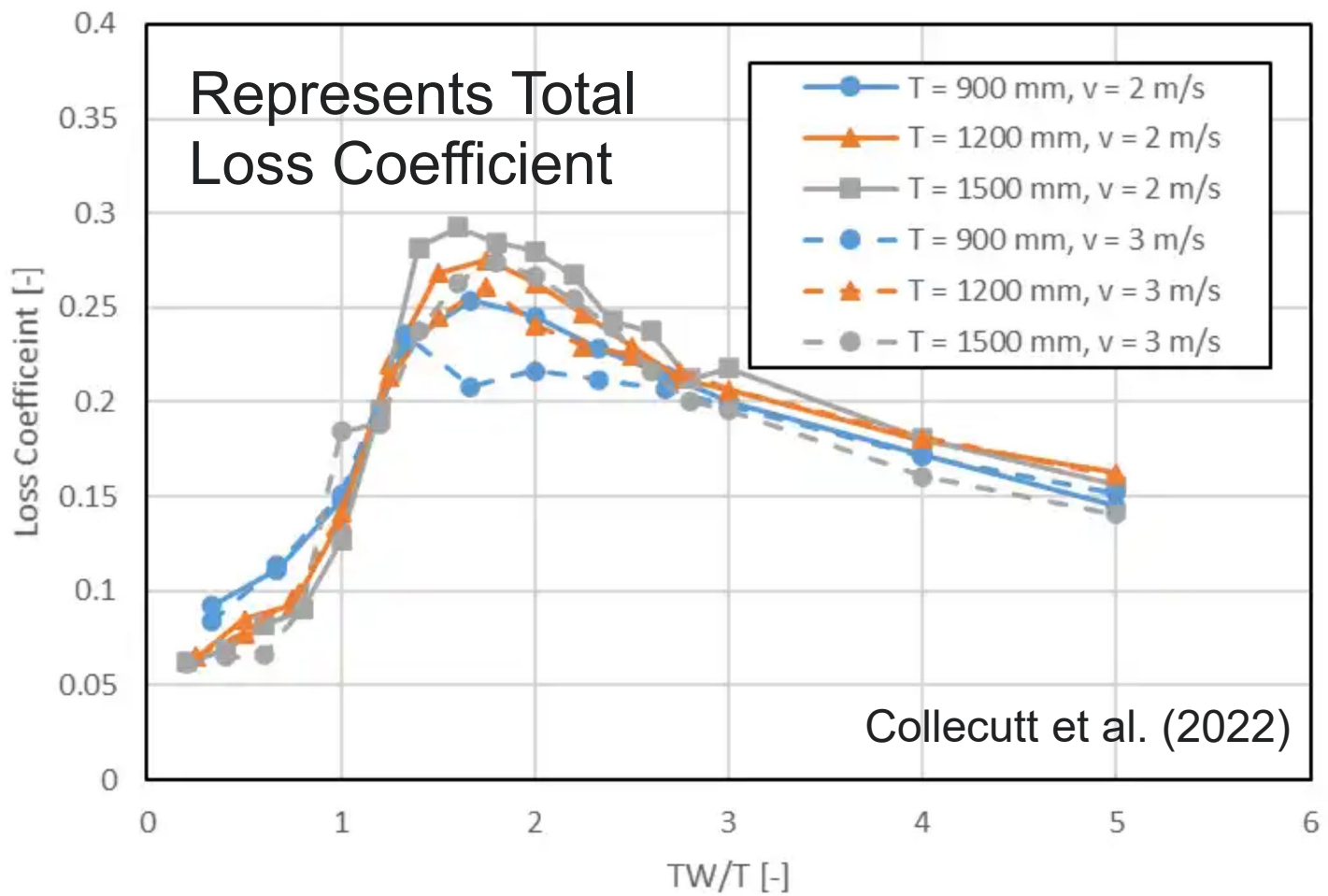
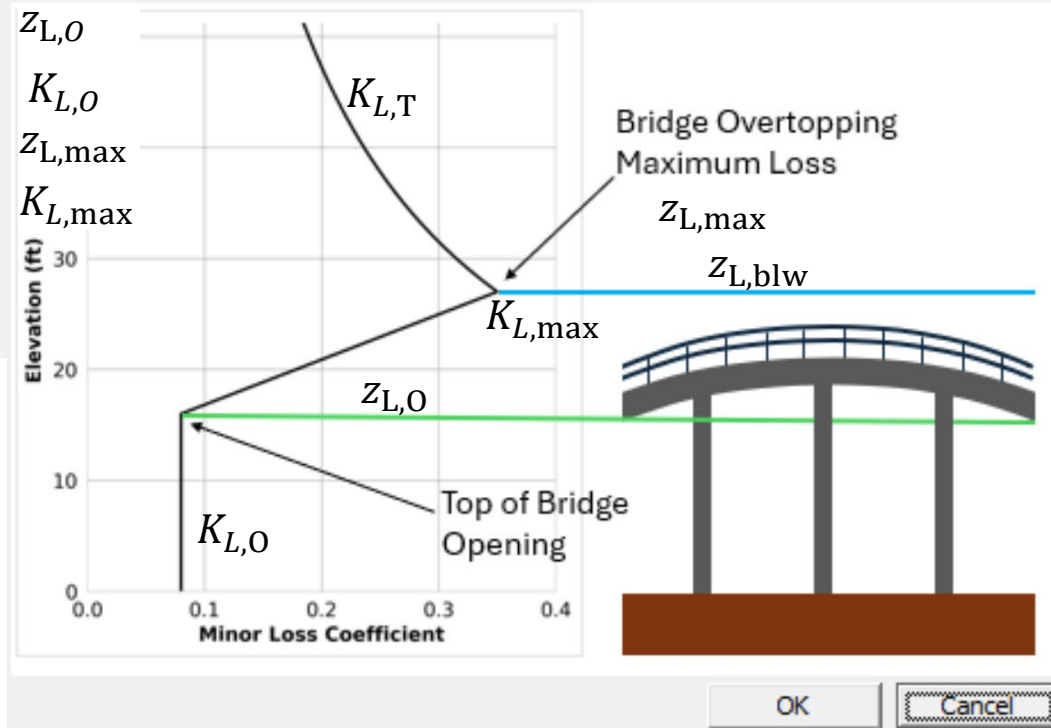




Minor Losses

Connection - 2D Bridge Parameters

Bridge Opening Top Elevation:	939.
Bridge Opening Loss Coefficient:	0.08
Bridge Overtopping Max Loss Elevation:	955.
Bridge Overtopping Max Loss Coefficient:	0.25
Deck/Roadway Surface Manning's n:	0.016



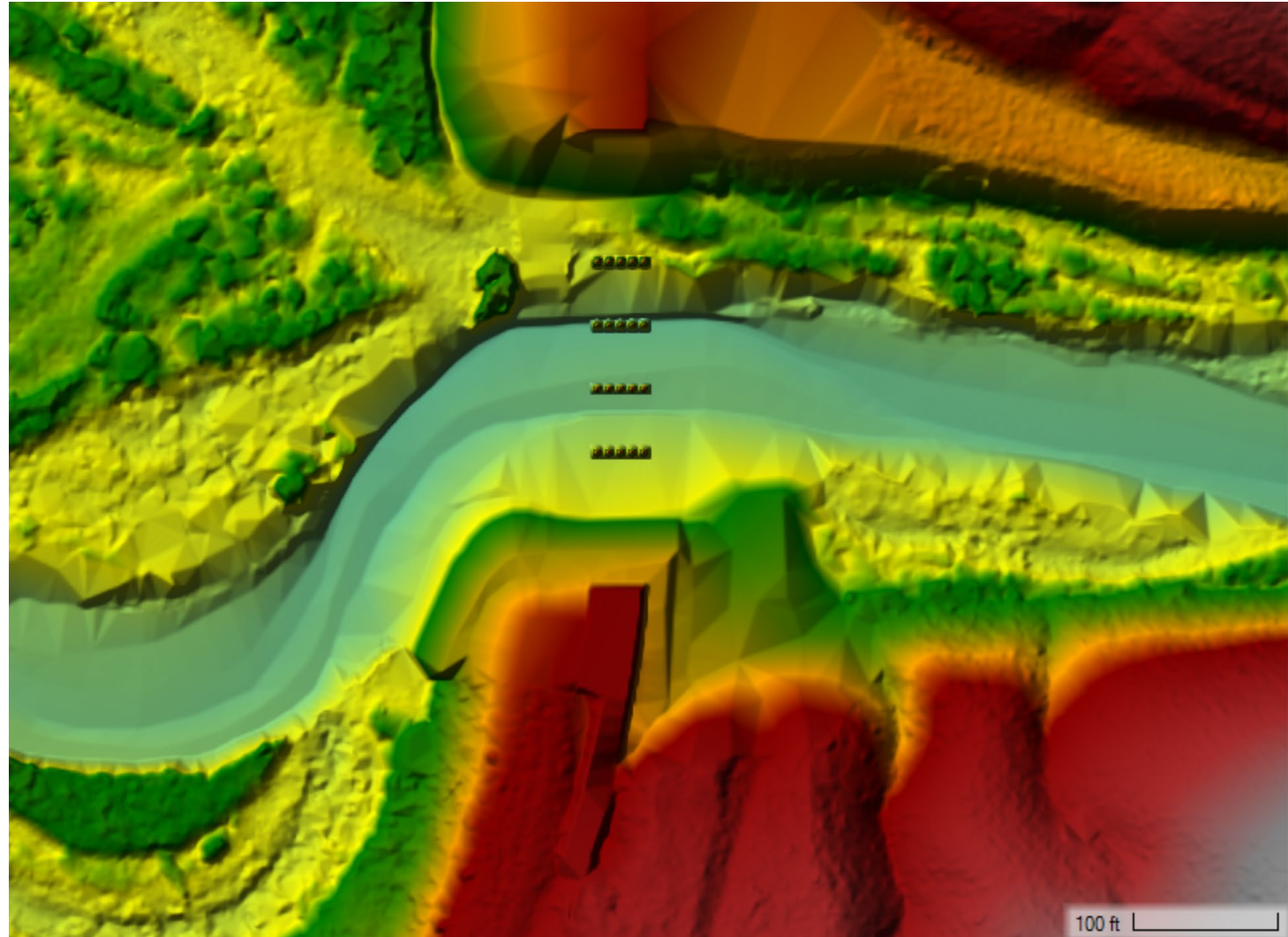
- Based on average water surface and velocities
- Minor Loss coefficient applied uniformly over and under bridge



Model Setup: Terrain



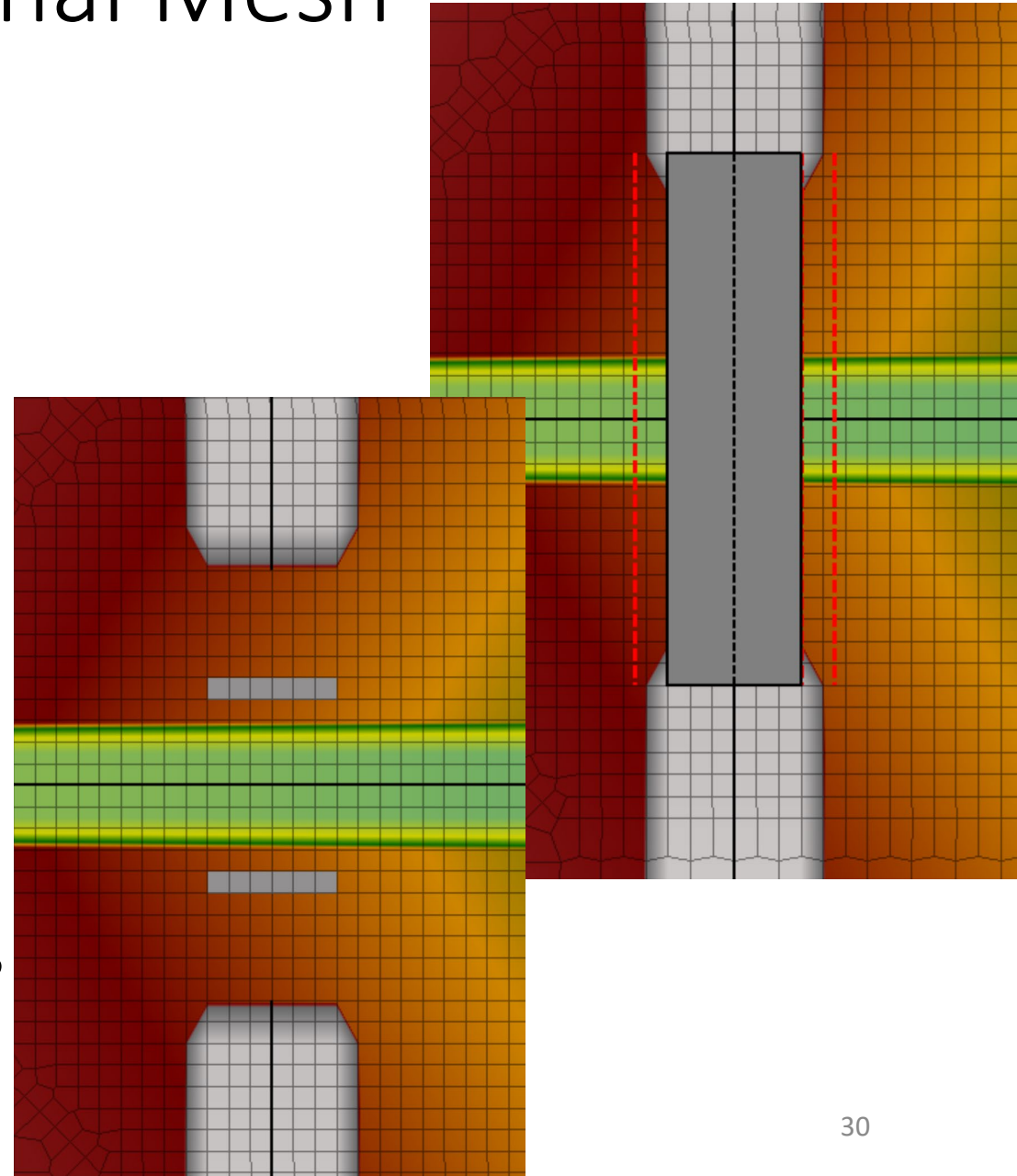
- Terrain MUST include
 - Piers
 - Embankments
- Only the deck is not included in the terrain





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

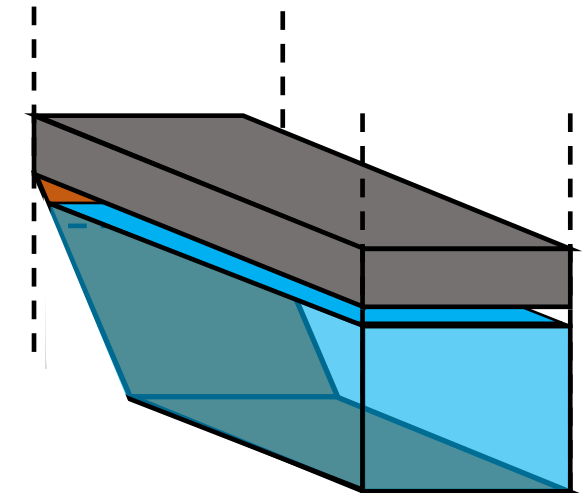
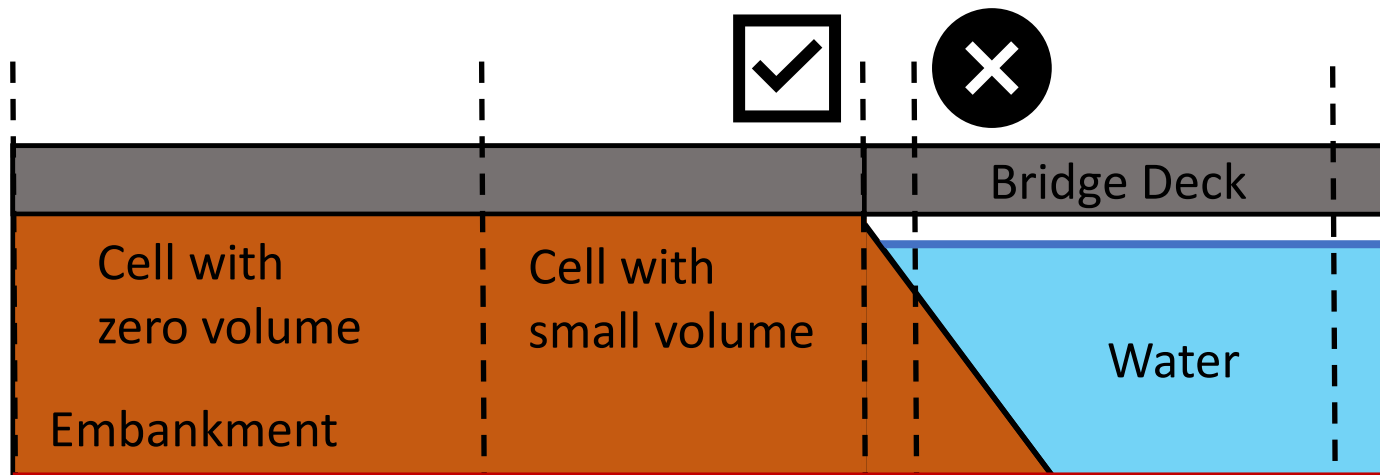




Model Setup: Computational Mesh

- 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

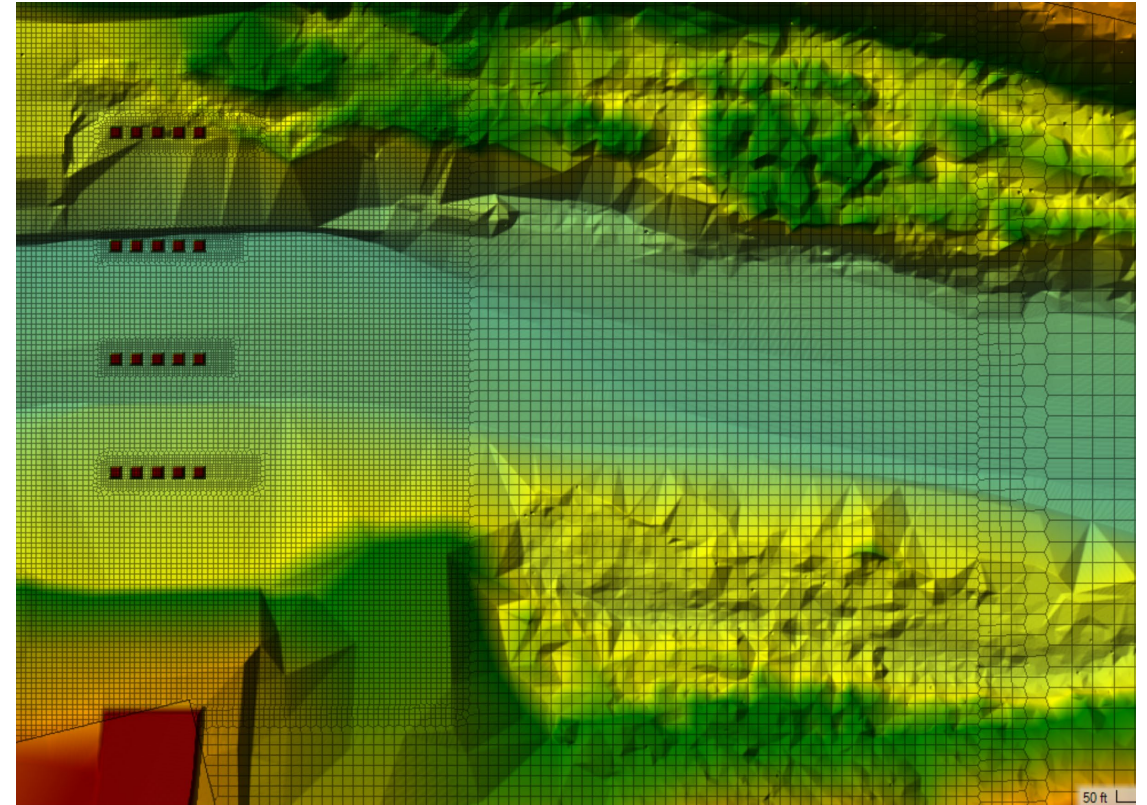
Performing Unsteady Flow Simulation HEC-RAS 6.7 Beta3 April 2025
 Removing below bridge deck cell 3135 from computations because of small volume
 Removing below bridge deck cell 3136 from computations because of small volume
 Removing below bridge deck cell 3137 from computations because of small volume
 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





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

HEC-RAS Unsteady Computation Options and Tolerances

General | 2D Flow Options | 1D/2D Options | Advanced Time Step Control | 1D Mixed Flow Options

Use Coriolis Effects (not used with Diffusion Wave equation)

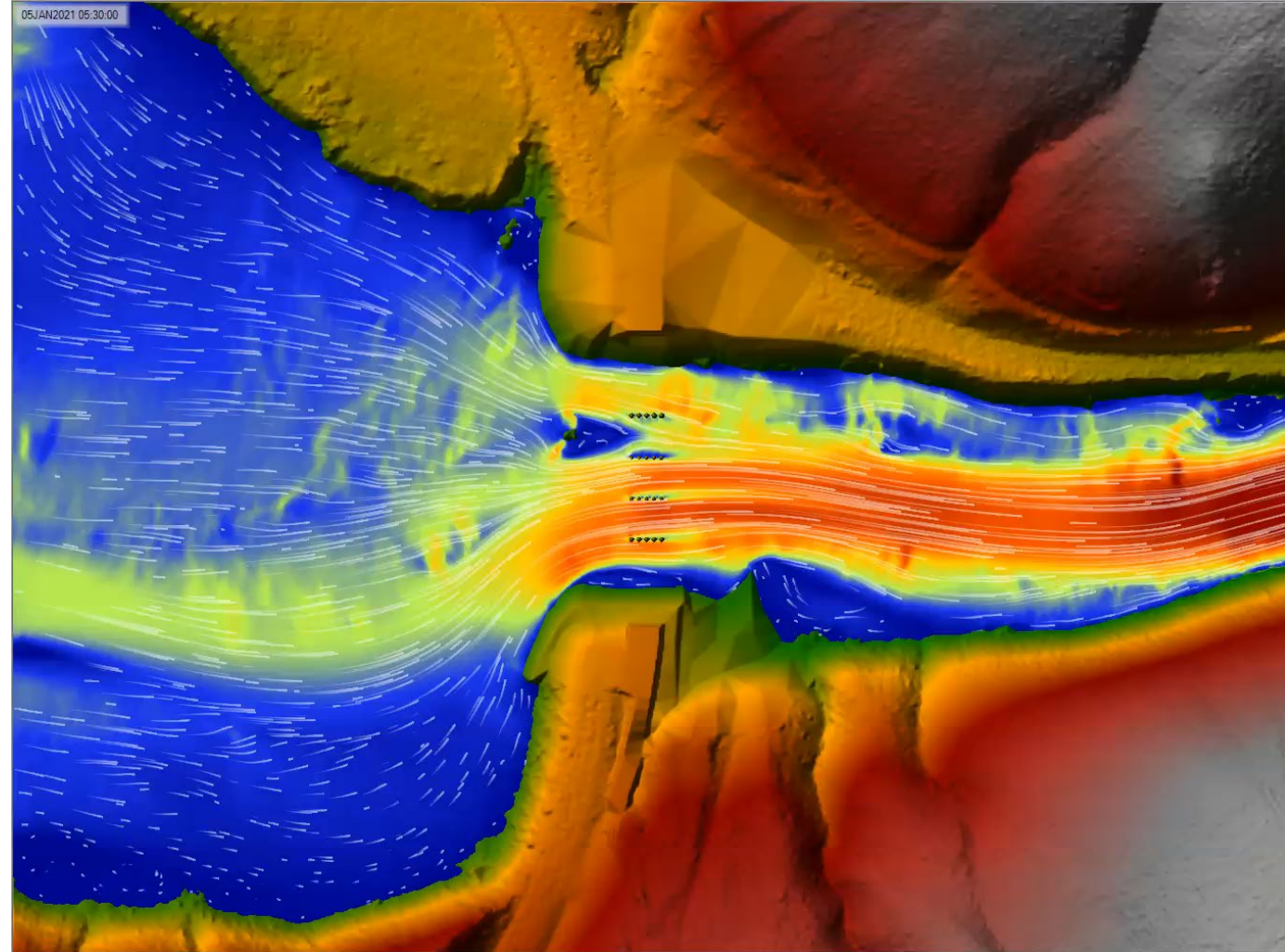
Parameter	(Default)	Perimeter 1
1 Theta (0.5-1.0)	1	1
2 Theta Warmup (0.5-1.0)	1	1
3 Water Surface Tolerance [max=0.2](ft)	0.01	0.01
4 Volume Tolerance (ft)	0.01	0.01
5 Maximum Iterations	20	20
6 Equation Set	Diffusion Wave	SWE-ELM (original/faster)
7 Initial Conditions Time (hrs)		Diffusion Wave
8 Initial Conditions Ramp Up Fraction (0-1)	0.1	SWE-ELM (original/faster)
9 Number of Time Slices (Integer Value)	1	SWE-EM (stricter momentum)
10 Turbulence Model	None	None
11 Longitudinal Mixing Coefficient	0.5	0.5
12 Transverse Mixing Coefficient	0.1	0.1
13 Smagorinsky Coefficient	0.05	0.05
14 Boundary Condition Volume Check	<input type="checkbox"/>	<input type="checkbox"/>
15 Latitude for Coriolis (-90 to 90)		
16 Solver Cores	All Available	4 Cores
17 Matrix Solver	PARDISO (Direct)	PARDISO (Direct)
18 Convergence Tolerance		
19 Minimum Iterations	0	0
20 Maximum Iterations	0	0
21 Restart Iteration	10	10
22 Relaxation Factor	1.3	1.3
23 SOR Preconditioner Iterations	10	10

OK Cancel Defaults ...



Model Setup: Turbulence

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

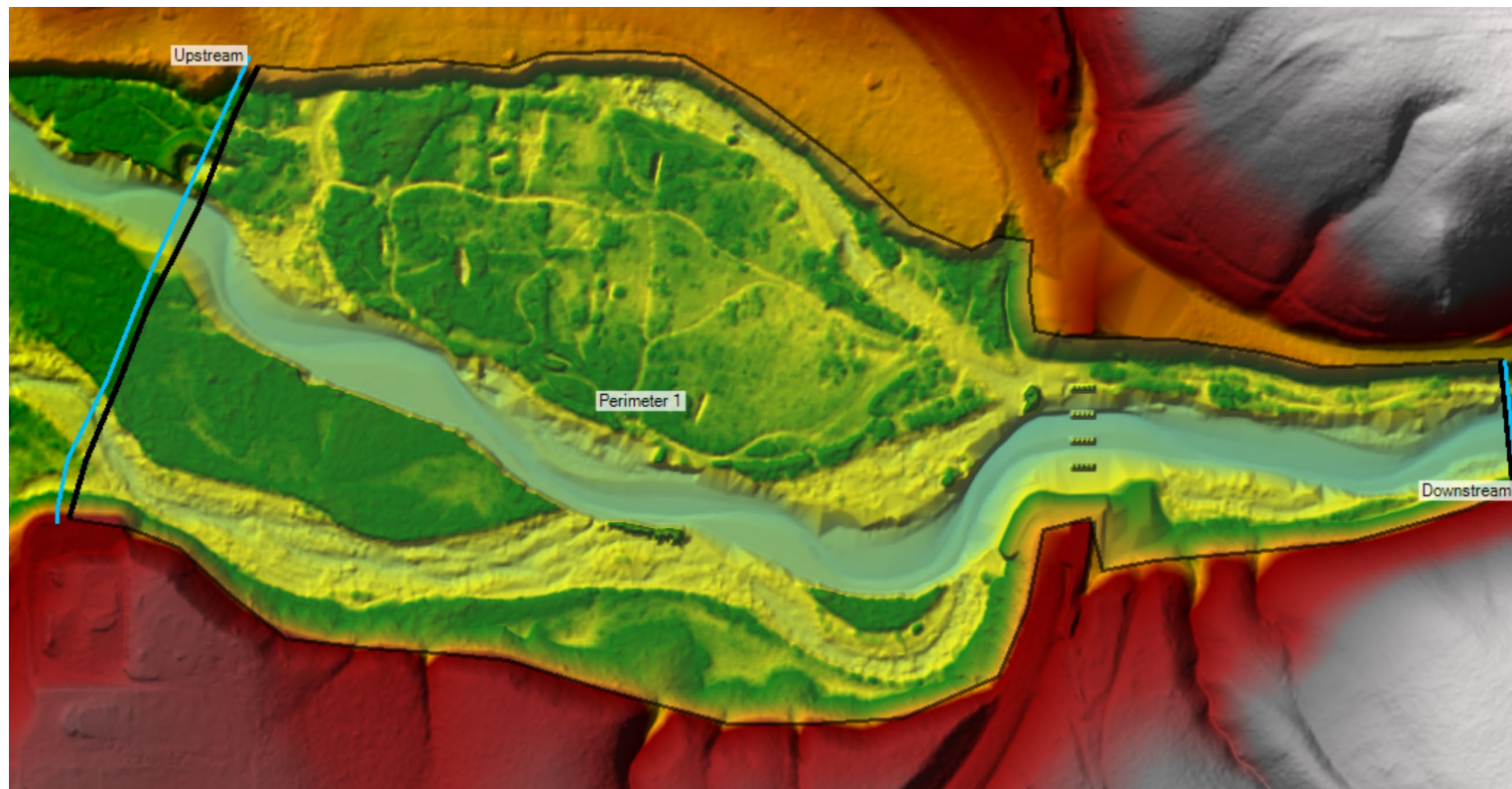


Turbulence		
1	Turbulence Method	Conservative
2	Longitudinal Mixing Coefficient	0.3
3	Transverse Mixing Coefficient	0.1
4	Smagorinsky Coefficient	0.05



Boundary Conditions

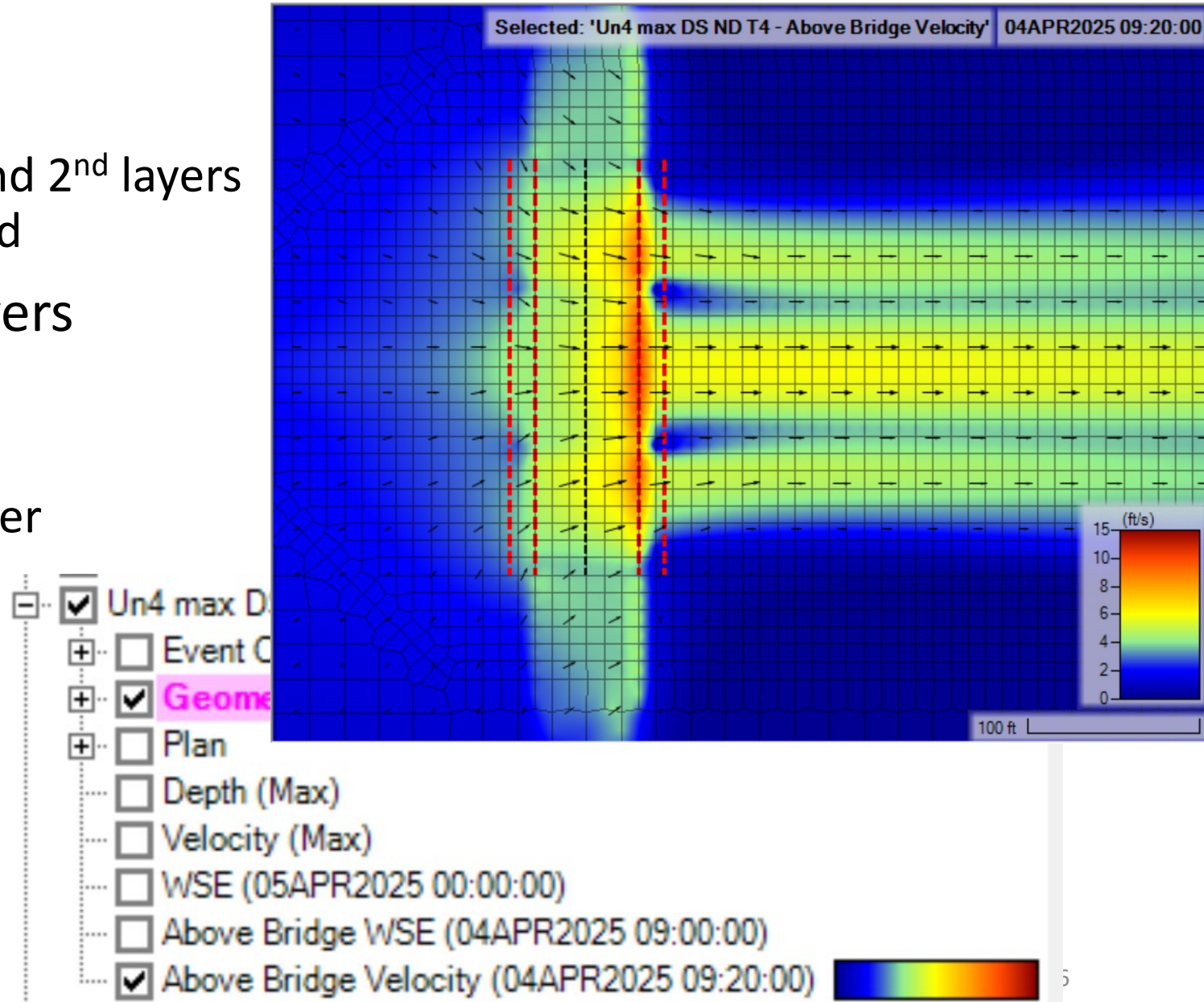
- Tempting to place them very close to the bridge but don't
- Perform sensitivity on boundary placement and boundary values (such as friction slope)
- Place boundaries in areas with 1D flow (i.e. no recirculation, or sharp contracts and expansions)





Mapping Output

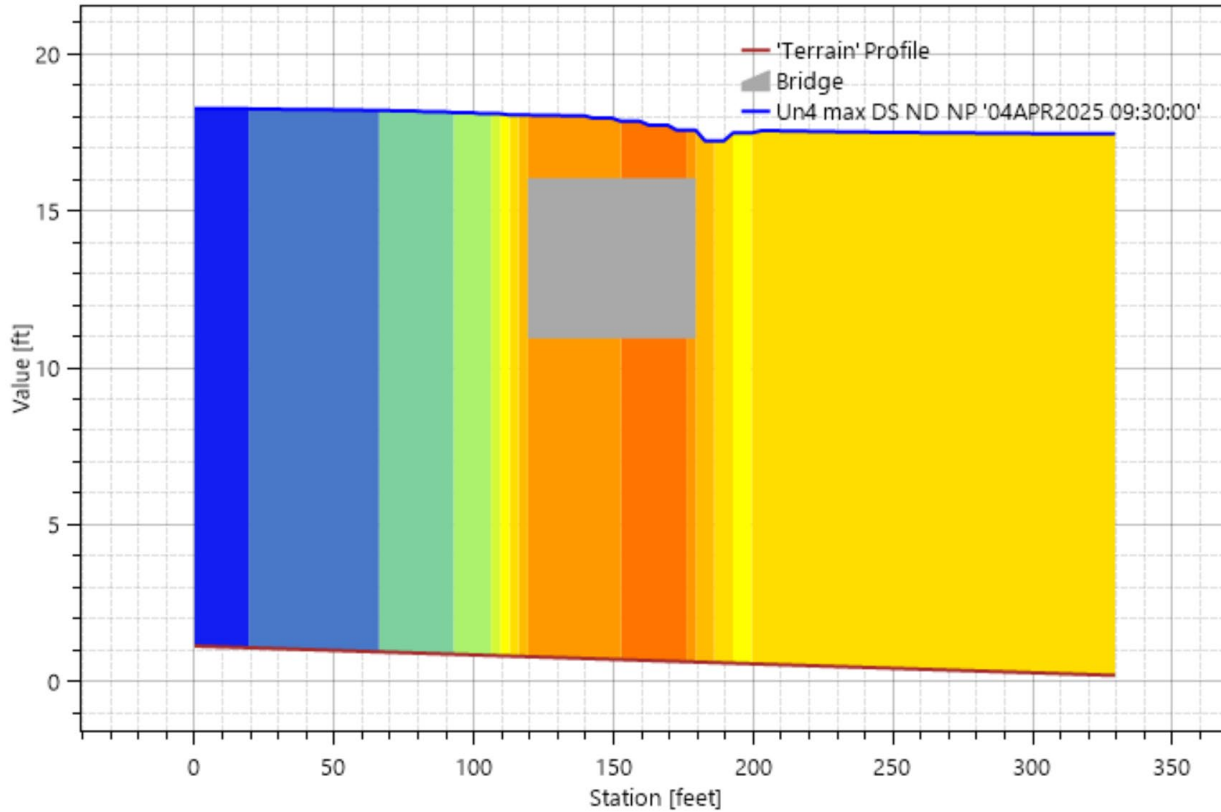
- Default **WSE**
 - Corresponds to max of the 1st and 2nd layers unless the flow is not pressurized
- Additional default Mapping layers
 - **Above Bridge WSE**
 - **Above Bridge Velocity**
 - 2nd layer output overrides 1st layer (not possible to view 2nd layer)





Profile Plots

Velocity against Terrain (colors) on 'Channel Centerline near Bridge'



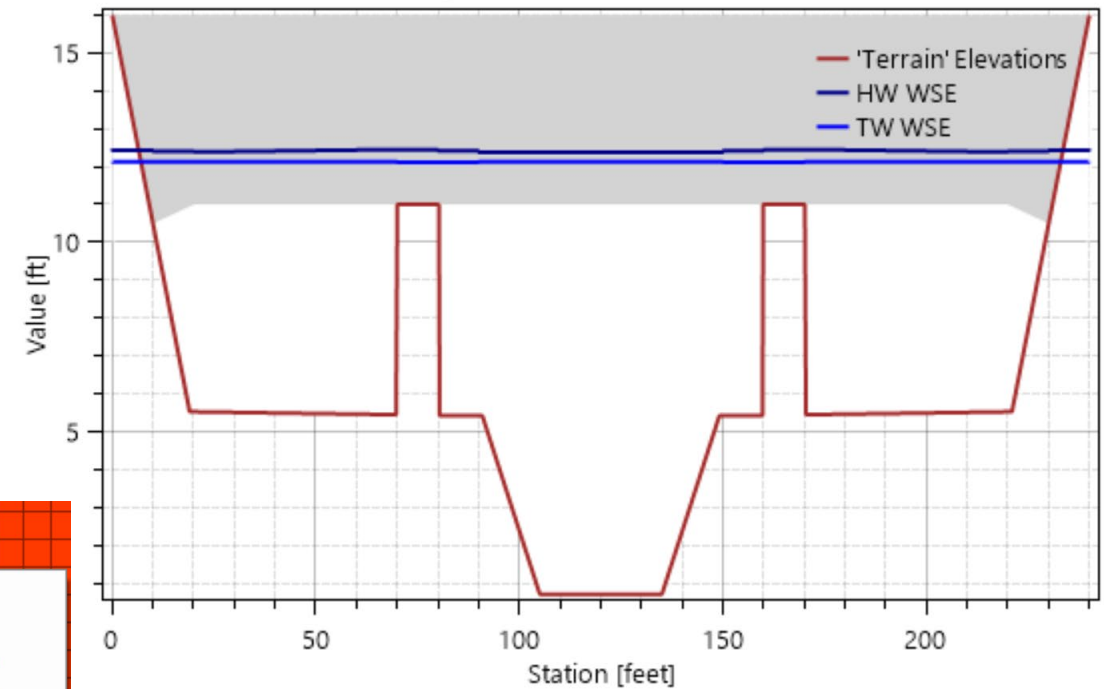
2D Area: Bridge2Dx2 (Un4 max DS ND T4)
Face #9466

- Results
- Selected Features (1 of 1)
- Find... Ctrl+F
- Plot Property Table

SA2D Conn: Bridge (Un4 max DS ND T4)

- Plot SA2D Conn Data (All Enabled Results)
 - Un4 max DS ND T4
- Results

SA2D Conn: Bridge (Un4 max DS ND T4) Profile [NO DATA]



Channel Centerline near Bridge

- Mapping Results
 - Rename
 - Delete
 - Import Polygons from Shapefile
 - SHP Export All Profile Lines to Shapefile
 - SHP Export Selected Profile Lines to Shapefile
- Time Series
 - Profile
 - Fast
 - Detailed
 - Terrain
 - WSE
 - WSE (Without Terrain)
 - Above Bridge Velocity
 - Velocity against Terrain



Time Series Plots

Select Variables

- Stage HW
- Stage TW
- Flow
- Stage Above Deck
- Stage Below Deck
- Flow Above Deck
- Flow Below Deck
- Velocity Above Deck
- Velocity Below Deck
- Head loss
- Depth HW
- Depth TW
- Velocity HW
- Velocity TW
- Minor Loss Coef Below
- Minor Loss Coef Above
- Minor Loss Coef Total
- Minor Head Loss

OK

Stage and Flow Hydrograph

File Type Options

Conn: Bridge

Plot Stage Plot Flow Obs Stage Obs Flow Use Ref Stage

Time Series	Maximum	Time at Max	Volume ac-ft
Stage HW	20.36	04Apr2025 1224	
Stage TW	20.15	04Apr2025 1225	
Flow	10378.88	04Apr2025 0842	13301.57

Time Series | Rating Curve

Plan: Un4 max DS ND T2 Conn: Bridge

Elevation (ft)

Flow (cfs)

Minor Loss Coef Total

Minor Head Loss (ft)

Time and Date

Legend

- Stage TW
- Flow
- Flow Above Deck

Legend

- Minor Loss Coef Total

Legend

- Minor Head Loss



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

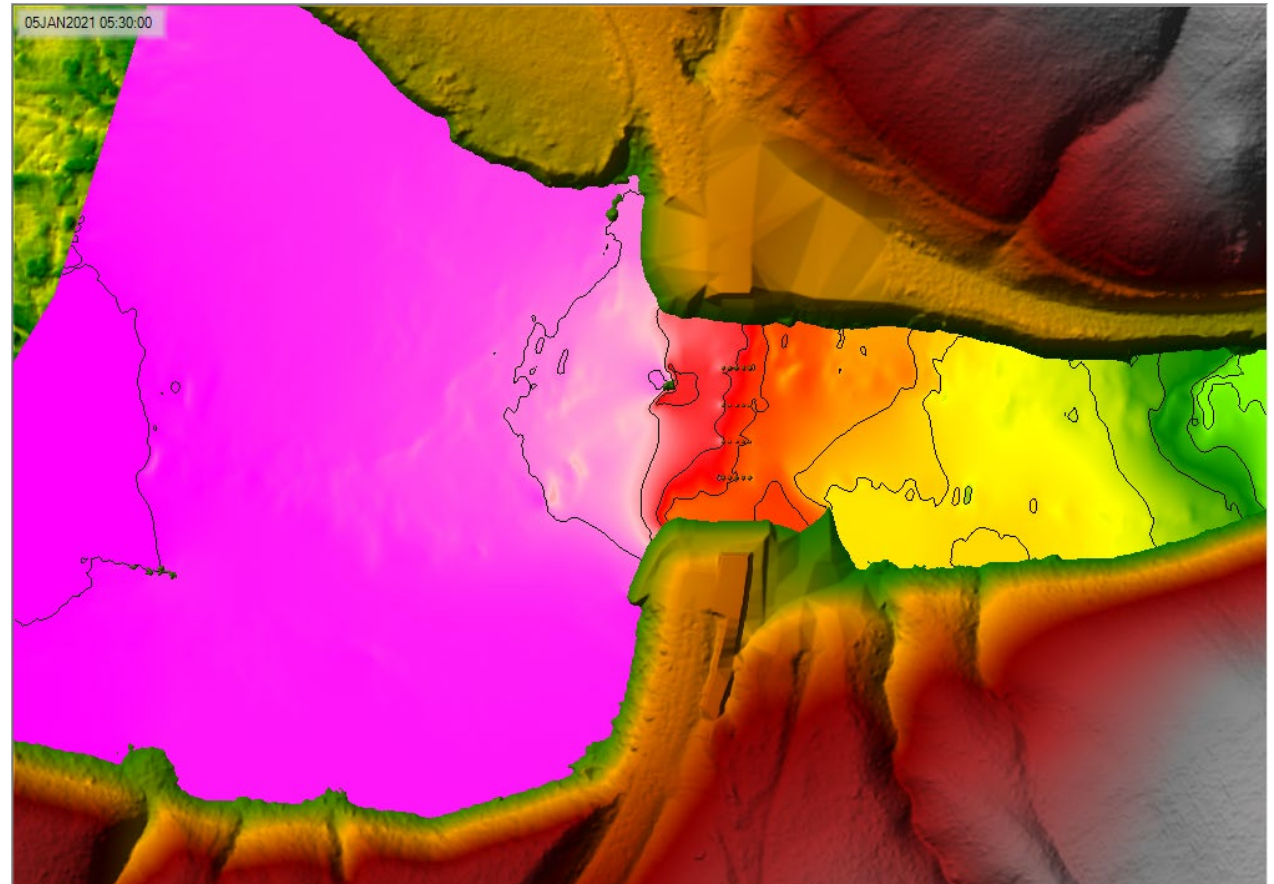


<https://www.northescambia.com/wp-content/uploads/2025/04/Flood-4004.jpg>



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?