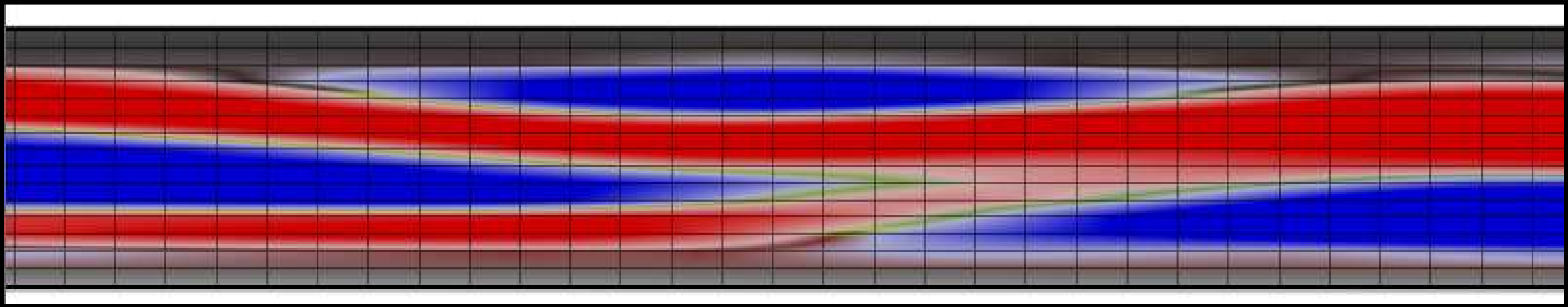
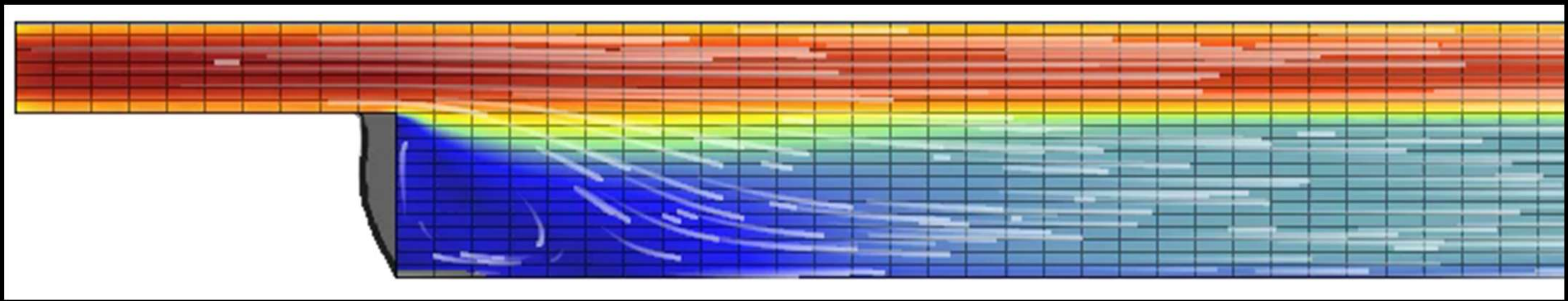
Mesh and Hydraulic Best Practices for HEC-RAS 2D Sediment Models





Stanford Gibson, PhD
Alex Sanchez, PhD

Big Ideas

- Sediment transport amplifies hydraulic modeling errors (in 1D and 2D)

- Calibrate and refine your hydraulic model *before* you add sediment.

Big Ideas

- Calibrate and refine your hydraulic model *before* you add sediment.

Stages of Sediment Calibration

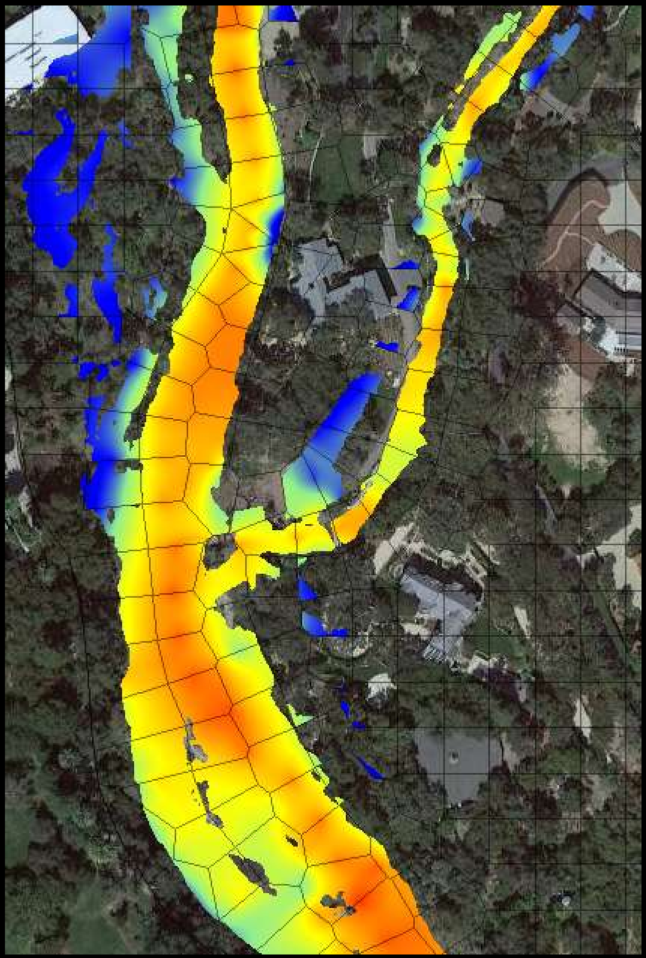
	Flow	Bed Elevation
Stage 1: Hydraulic Calibration	Variable	Fixed
Stage 2: Steady Flow Mobile Bed Analysis	Fixed	Variable
Stage 3: Dynamic Calibration	Variable	Variable
If Possible:		
Stage 4: "Validation" (Multiple Time Series Analysis)	Variable	Variable

Hydraulic Best Practices for 2D Sediment Modeling

1. Top Two Issues

2. Mesh Best Practices

3. Computational Best Practices

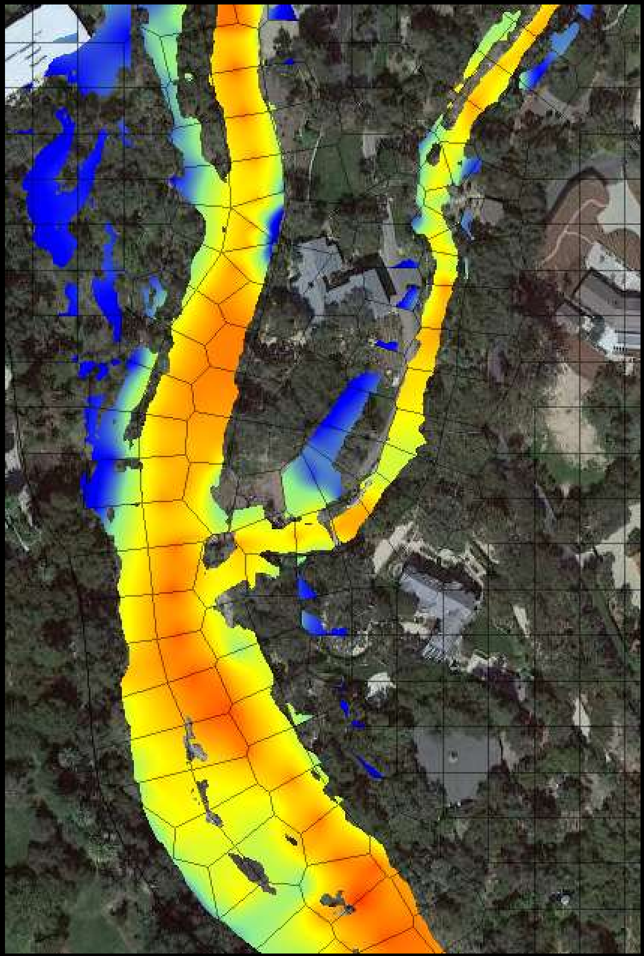


Hydraulic Best Practices for 2D Sediment Modeling

1. Top Two Issues
   - Time Step
   - Cell Faces and High Ground

2. Mesh Best Practices

3. Computational Best Practices




Your Time Step
Is Too (Darn) High

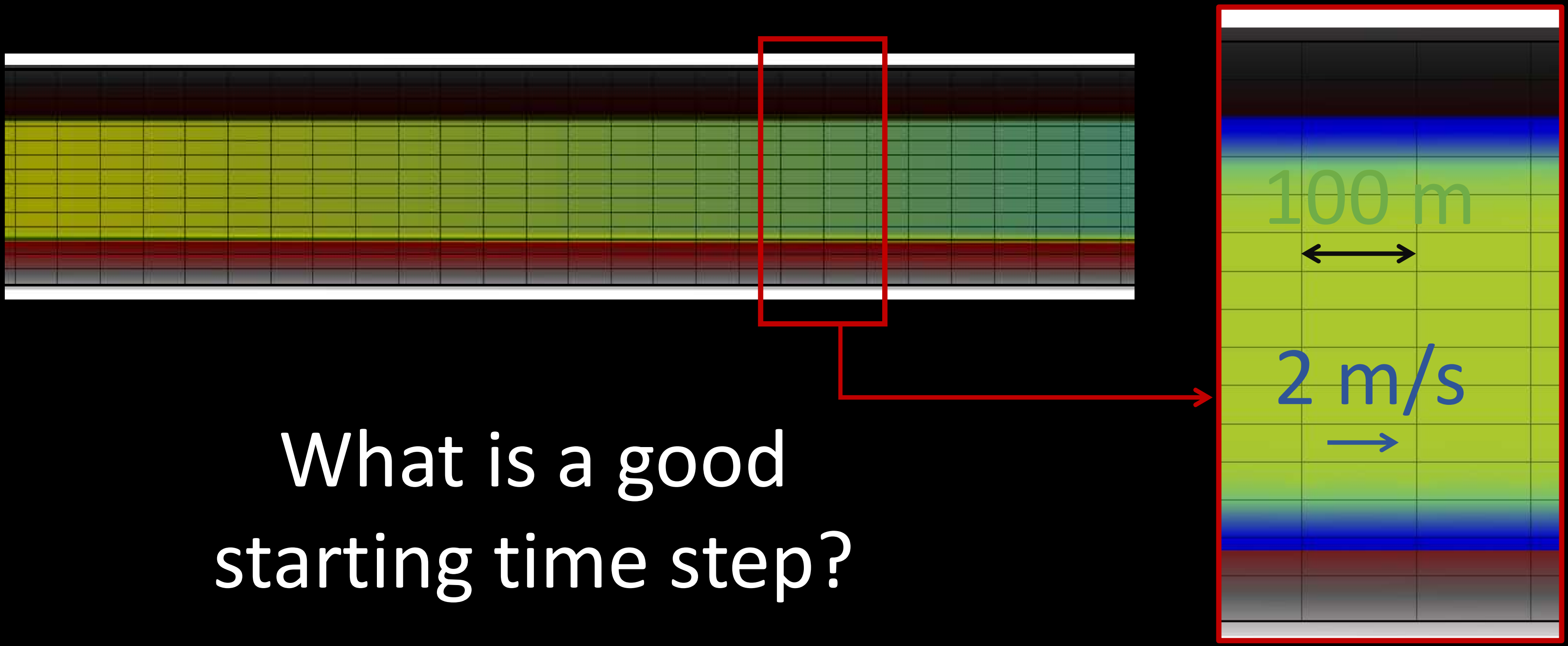
A 2D model has:

a regular cell size of 100m and

an average velocity of 2 m/s.

Hint:

$$C = \frac{V \, \Delta t}{\Delta x}$$



What is a good starting time step?

Hint:

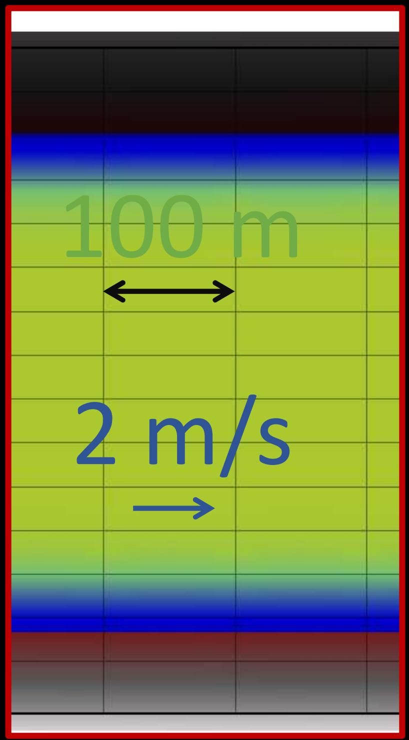
$$C = \frac{V\,\Delta t}{\Delta x}$$

A 2D model has:

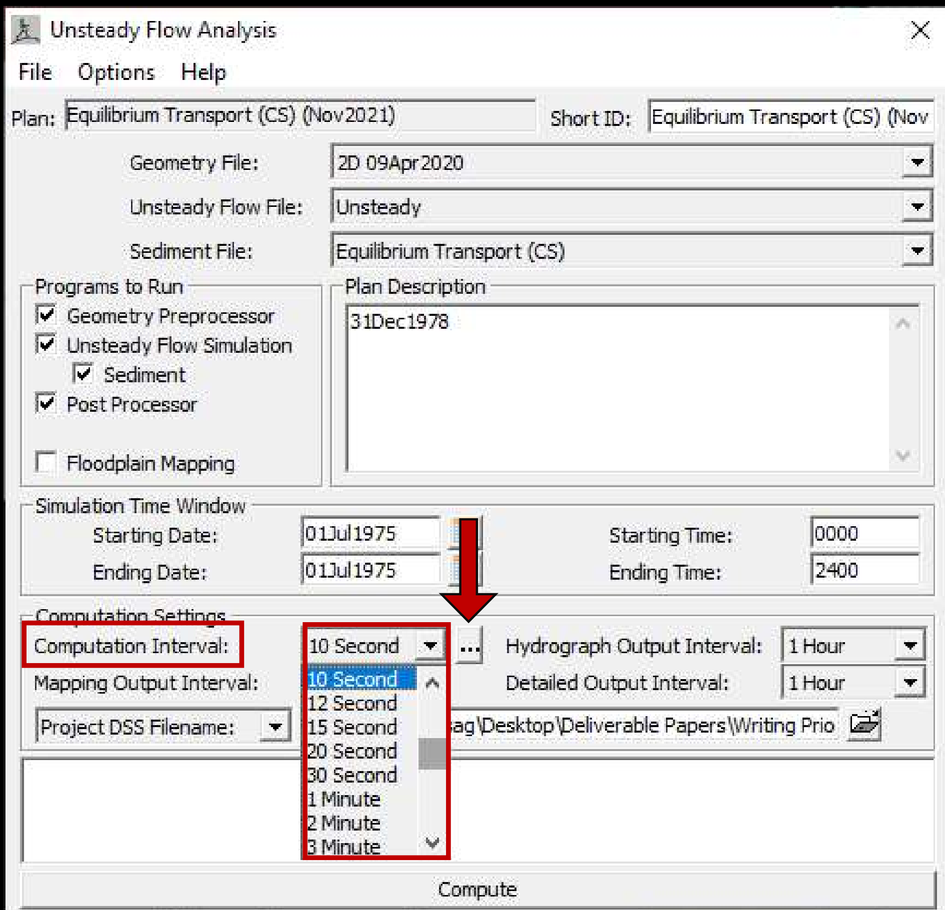
a regular cell size of 100m and
an average velocity of 2 m/s.

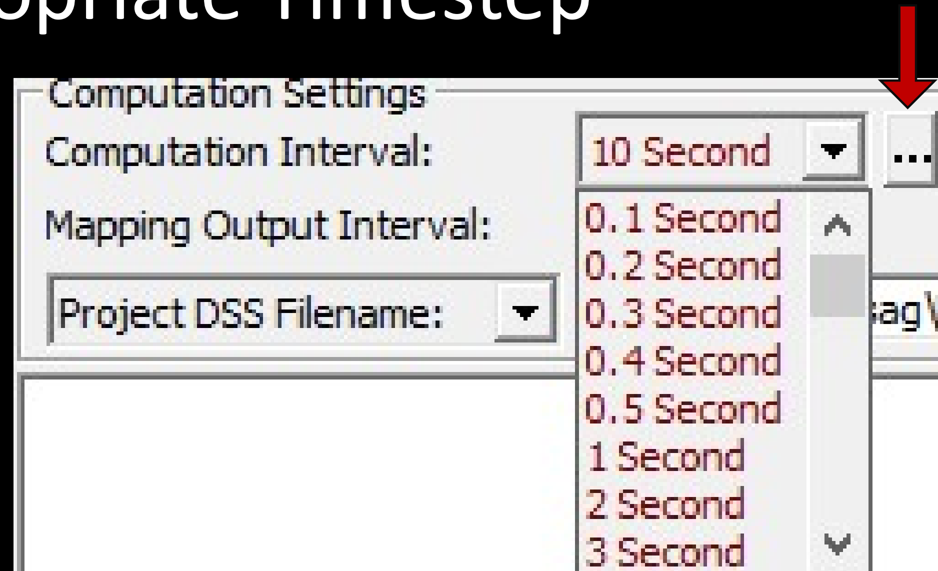
$$\Delta t = \frac{\Delta x\, C}{V}$$

$$\Delta t = \frac{100m\,(1)}{2\,m/s} = 50s$$



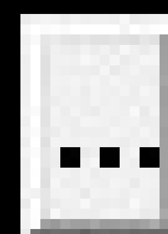
Selecting an Appropriate Timestep





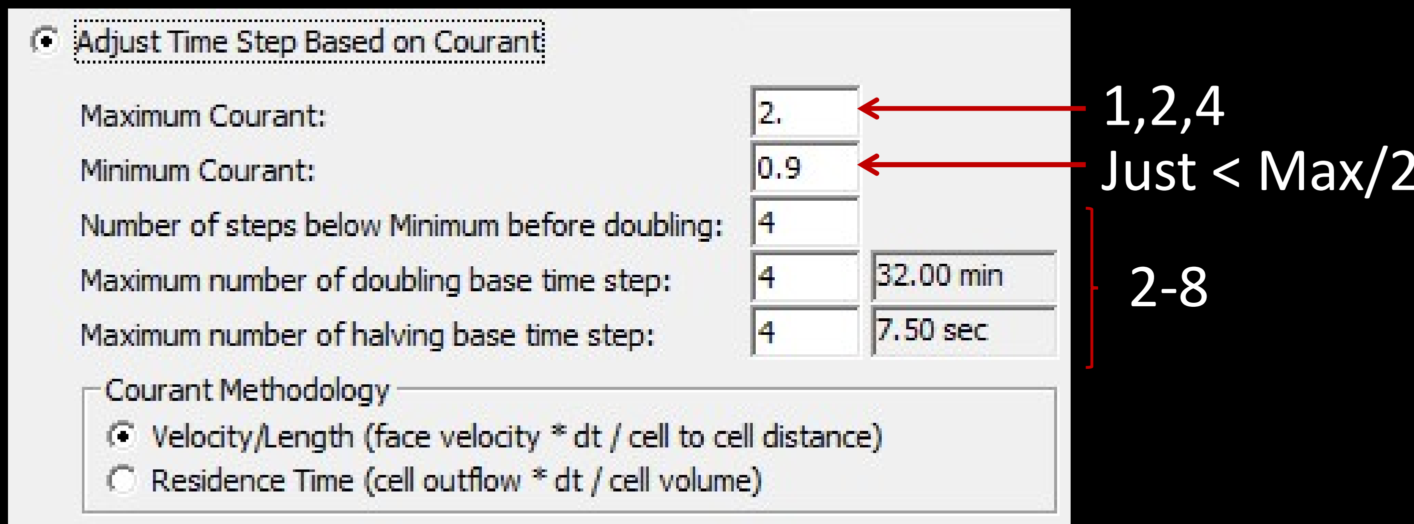
Or....

...let RAS compute it



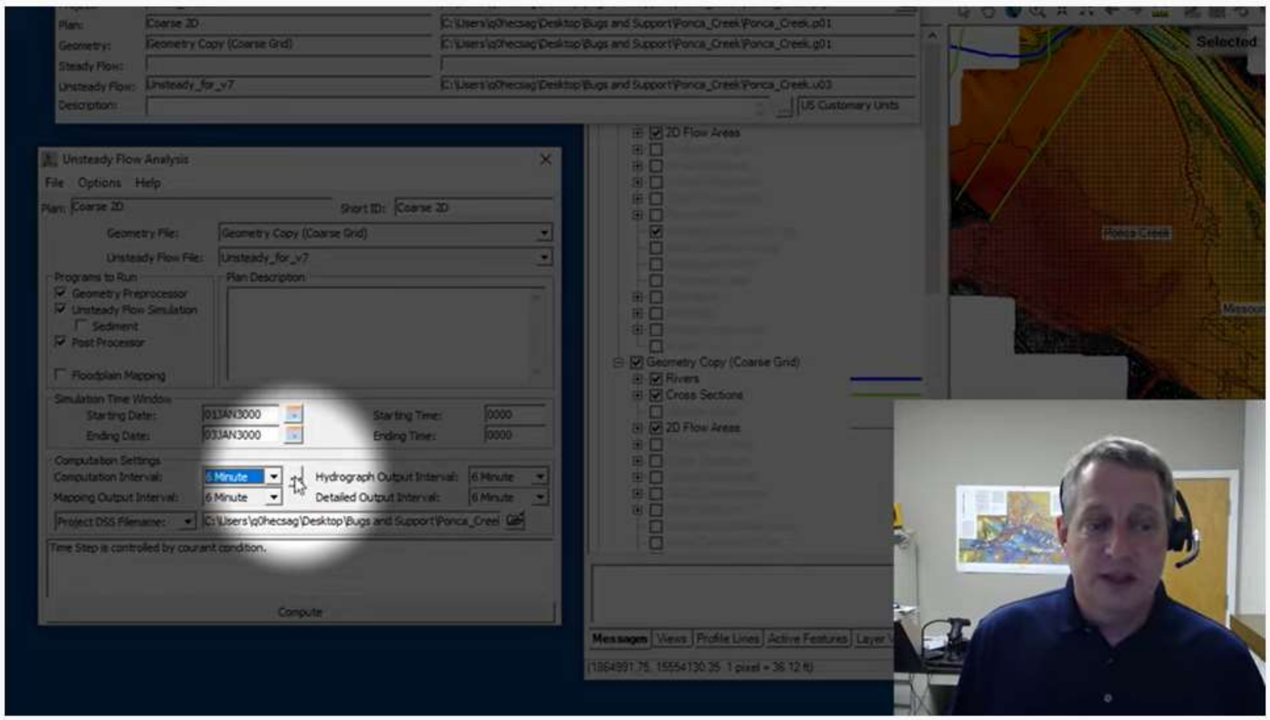
Selecting an Appropriate Timestep…

…Let RAS Do It



- Based on the "critical cell" – smallest or fastest
- Works best if cell size is relatively regular
- Can reach time steps <0.1s

Adaptive Time Step Video Tutorial



Variable Time Steps and Time Slicing in HEC-RAS

506 views • Nov 5, 2021 | 39 | DISLIKE | SHARE | SAVE | ...

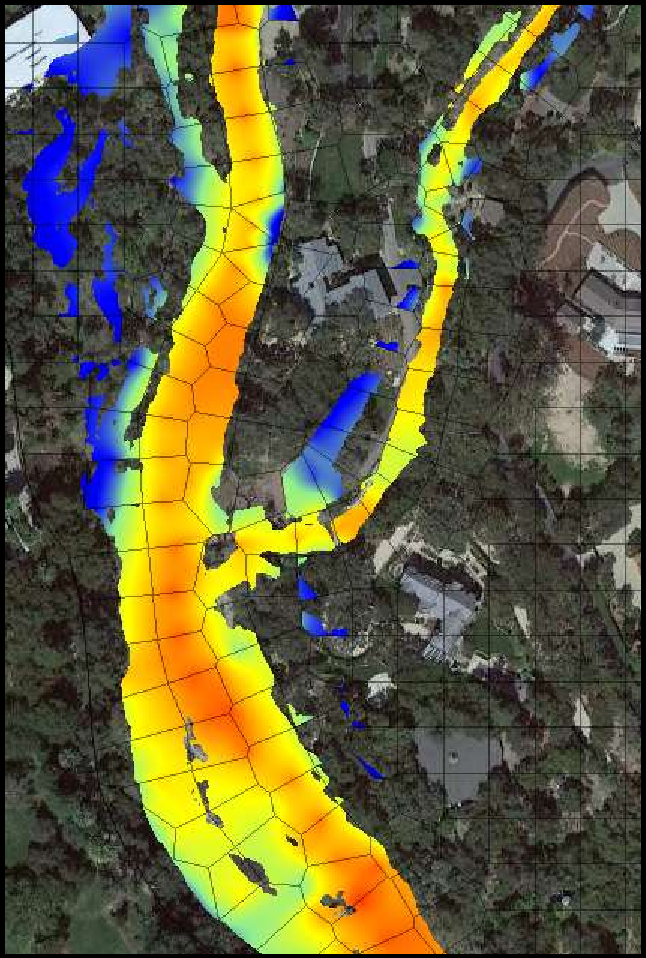
https://youtu.be/kcBrOML3iS0

Hydraulic Best Practices for 2D Sediment Modeling

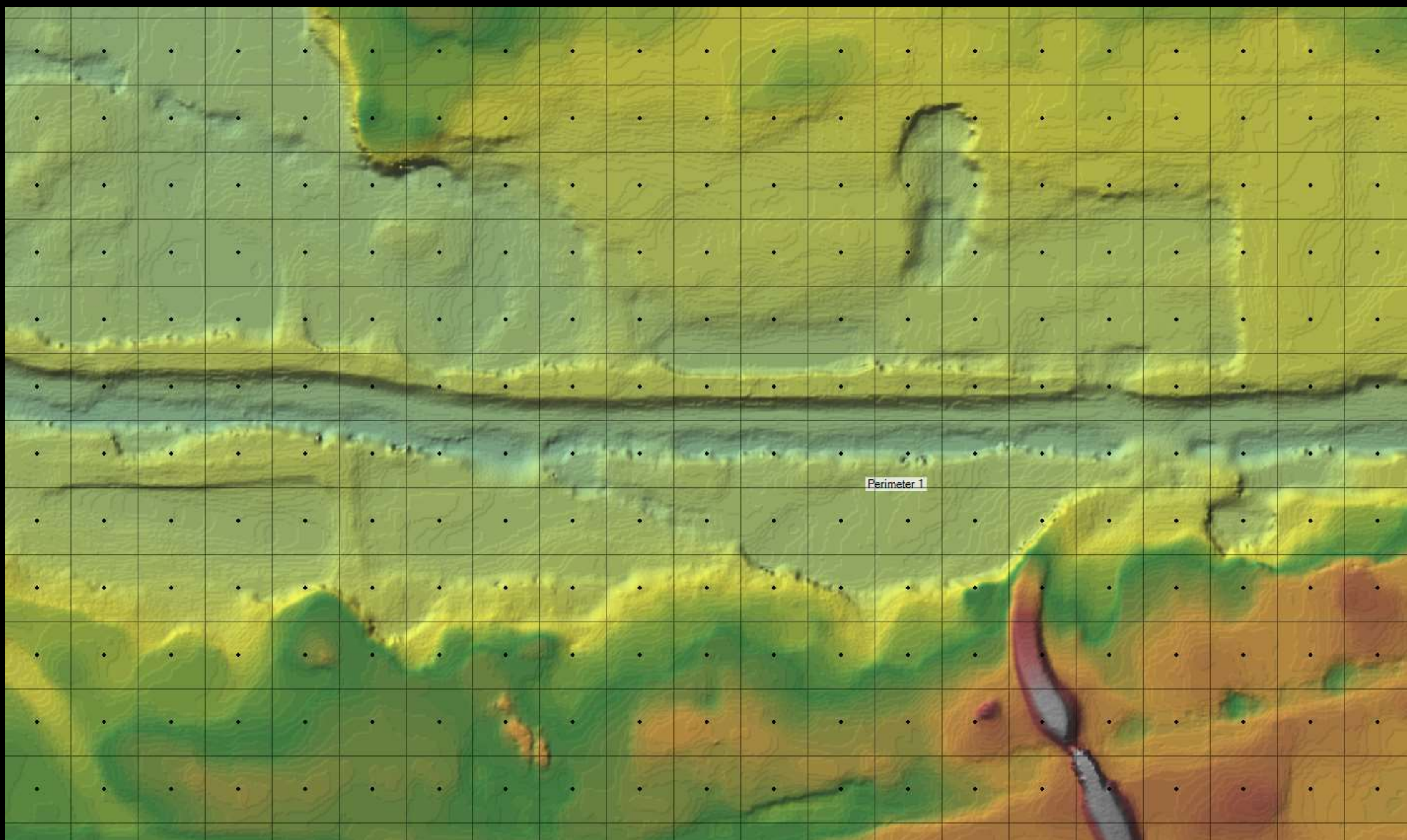
1. Top Two Issues
   - Time Step
   - Cell Faces and High Ground

2. Mesh Best Practices

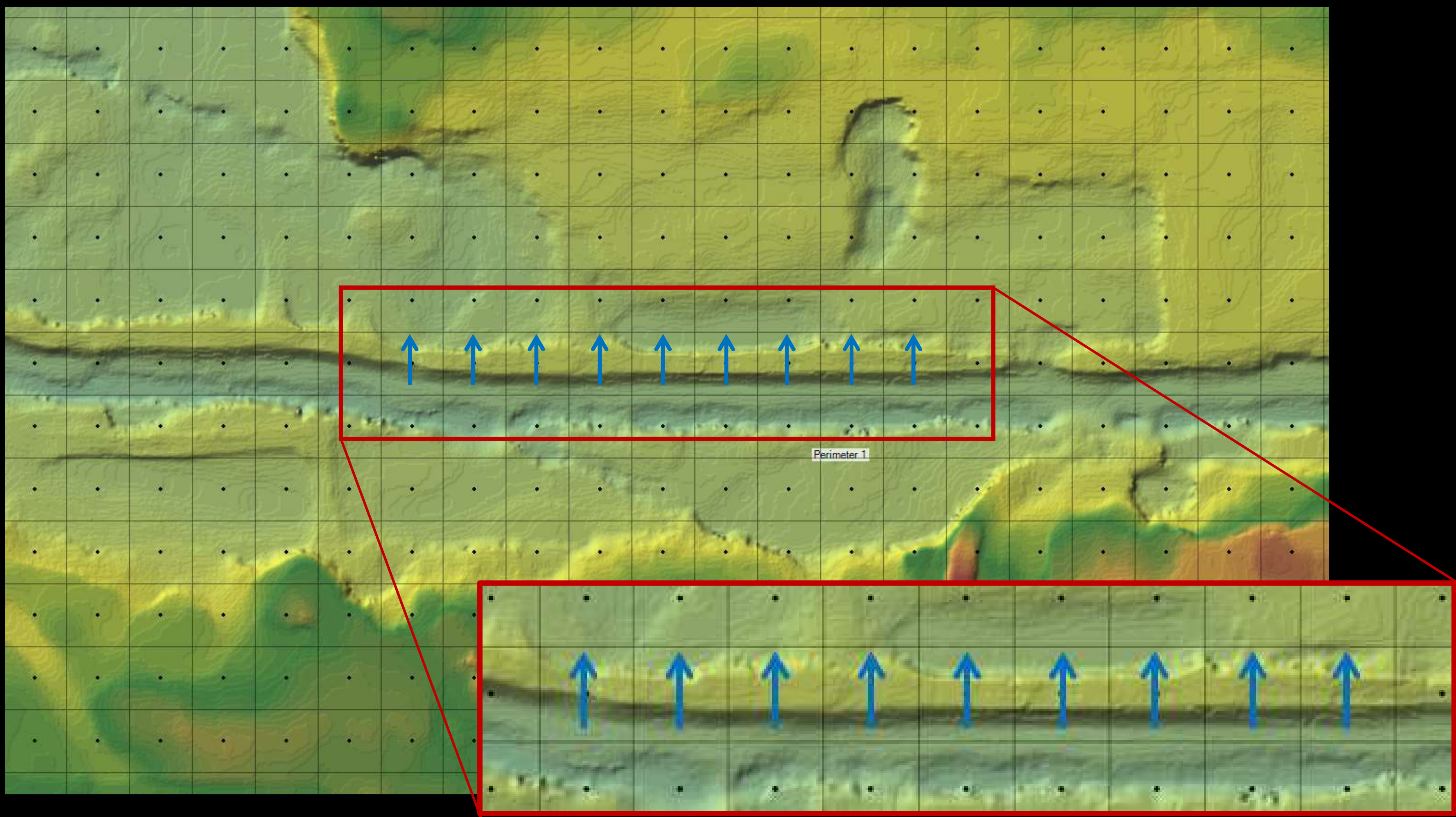
3. Computational Best Practices



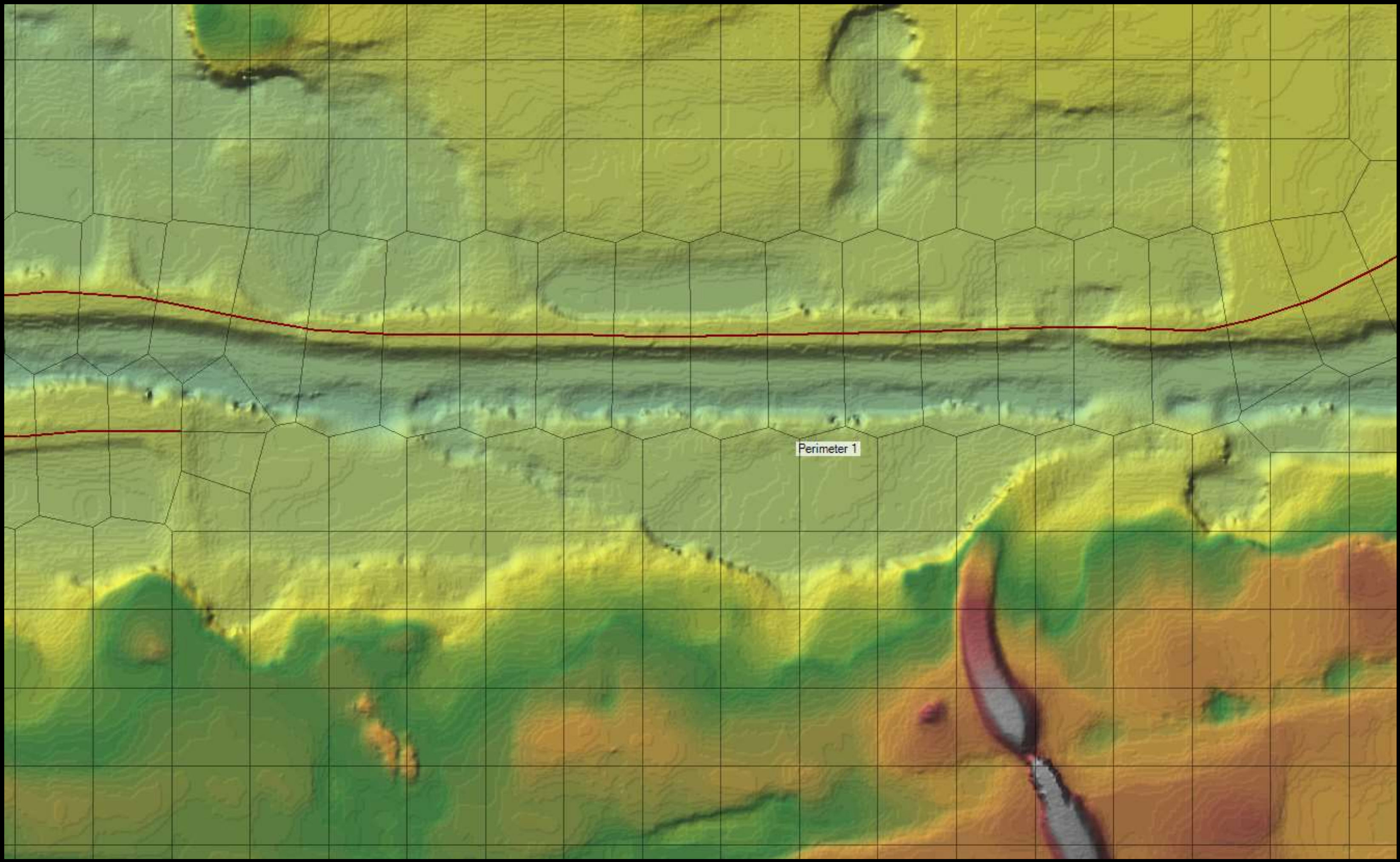
What is the biggest problem with this mesh?



Cell Edges Do Not Follow High Ground



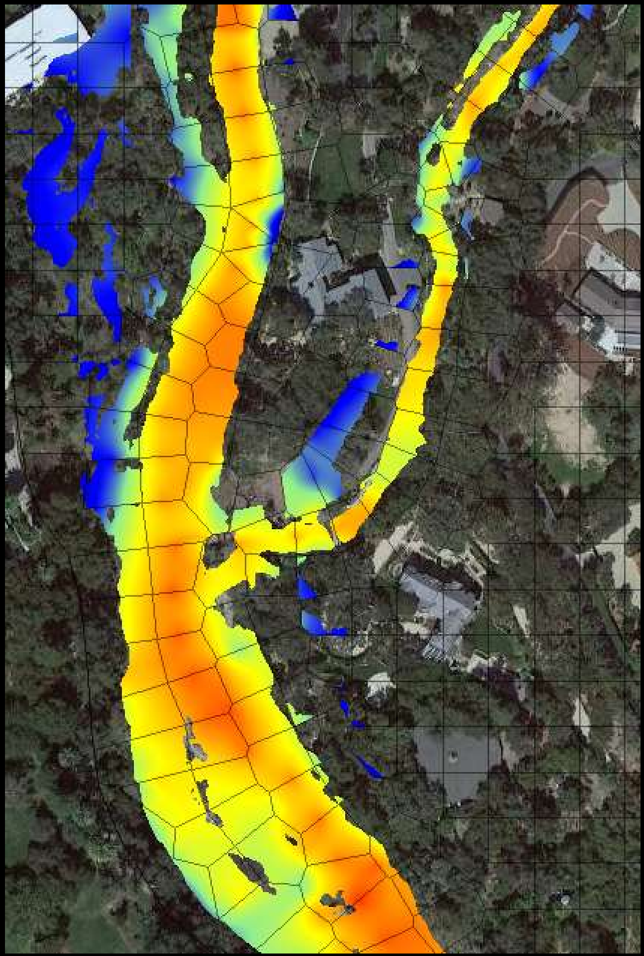
Add a Breakline (or a bunch)



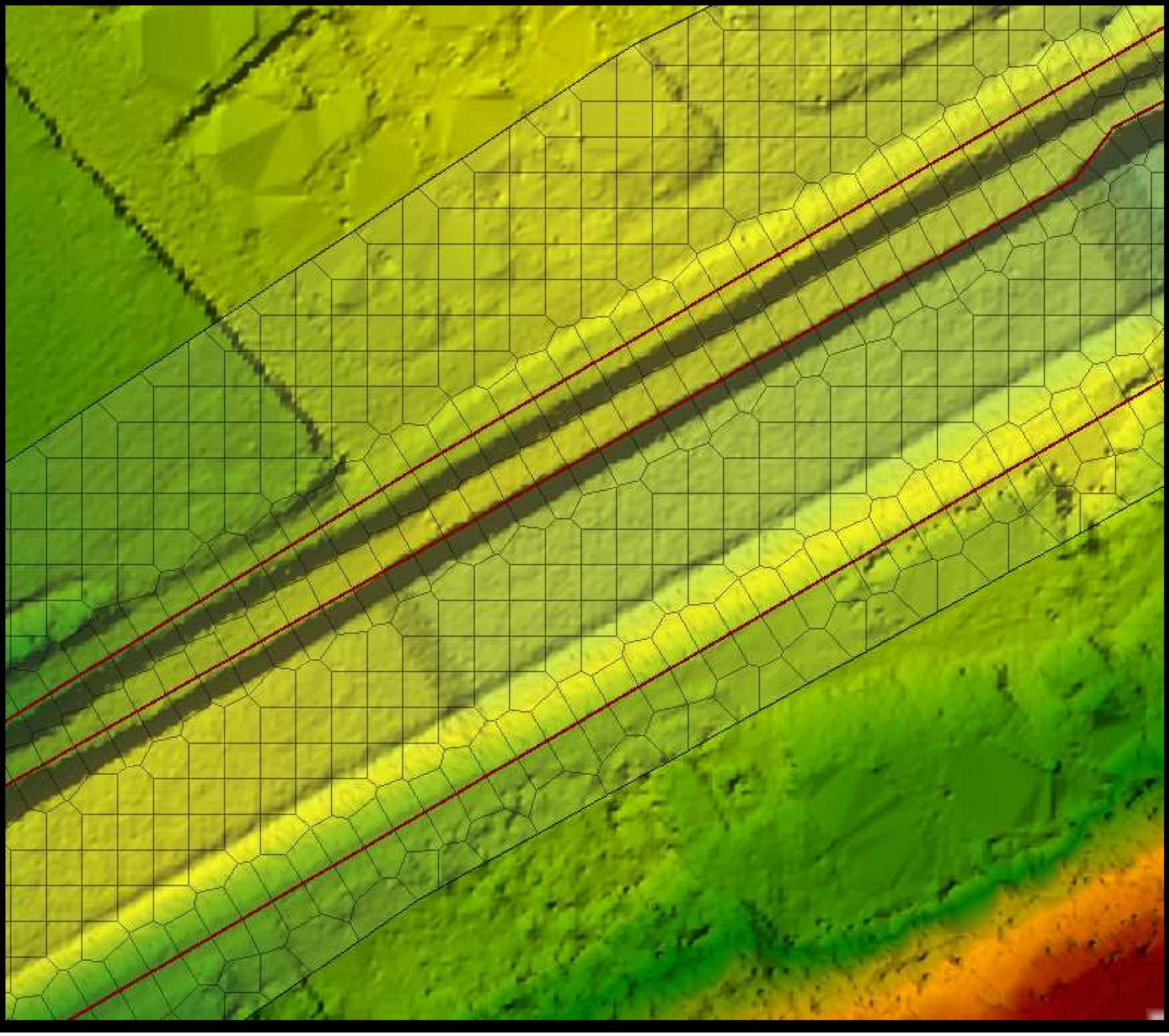
Take Away – Take Control of the High Ground

Hydraulic Best Practices for 2D Sediment Modeling

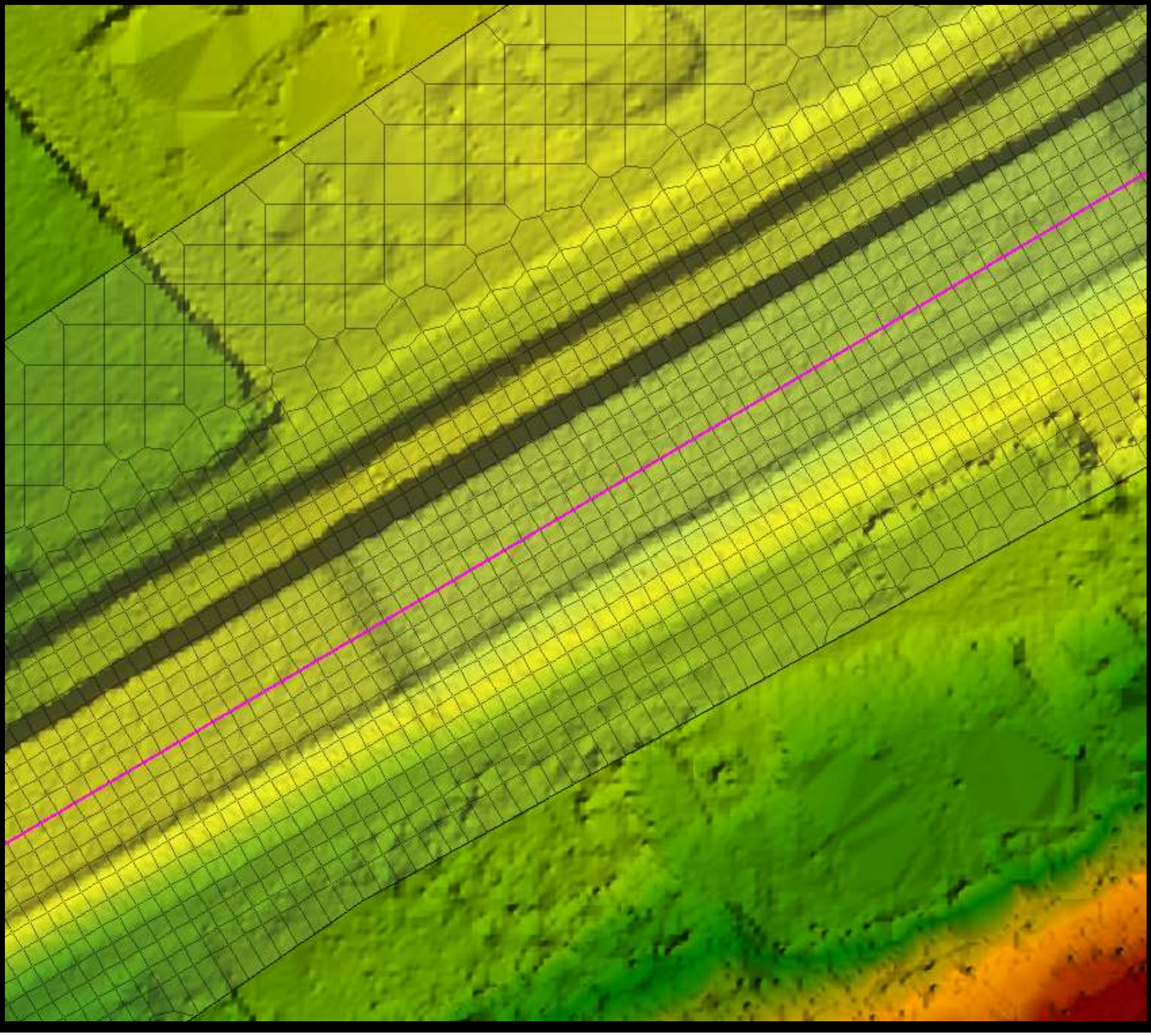
1. Top Two Issues
2. Mesh Best Practices
3. Computational Best Practices



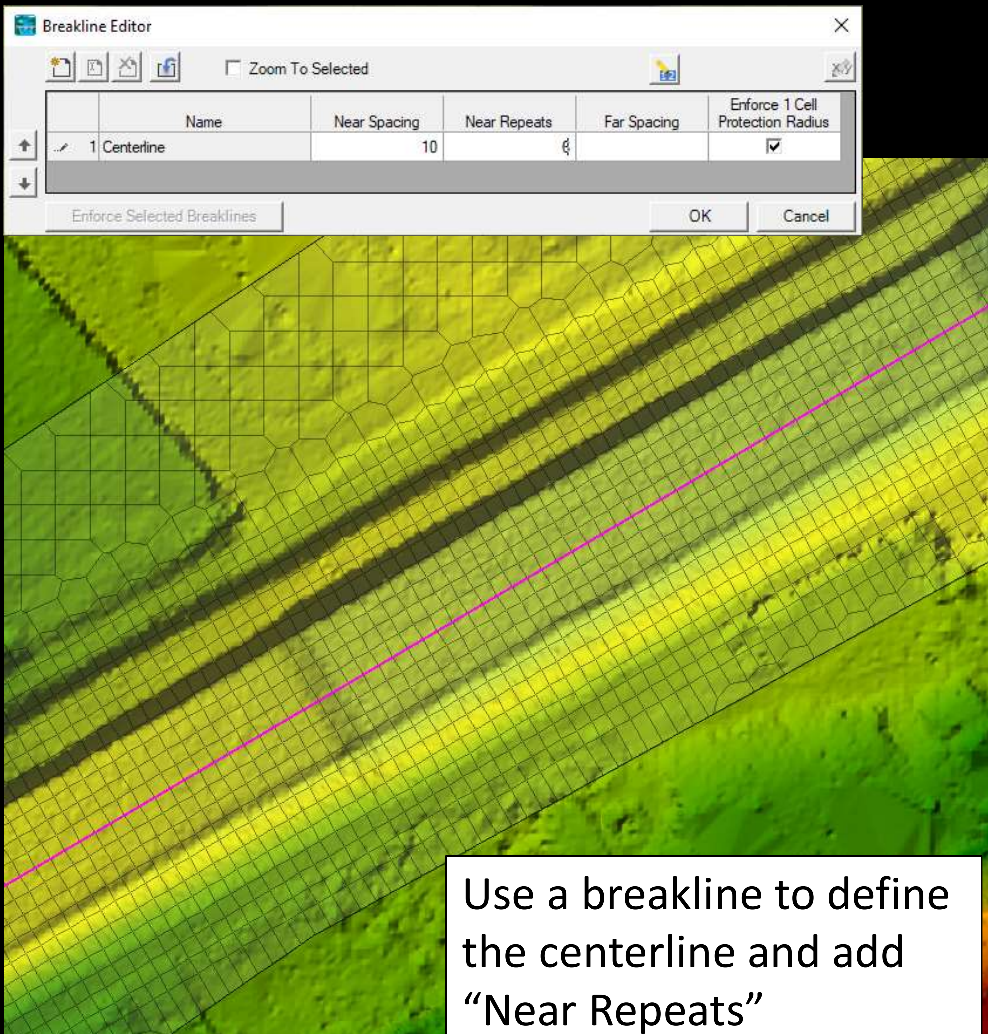
How Could We Improve This Mesh?



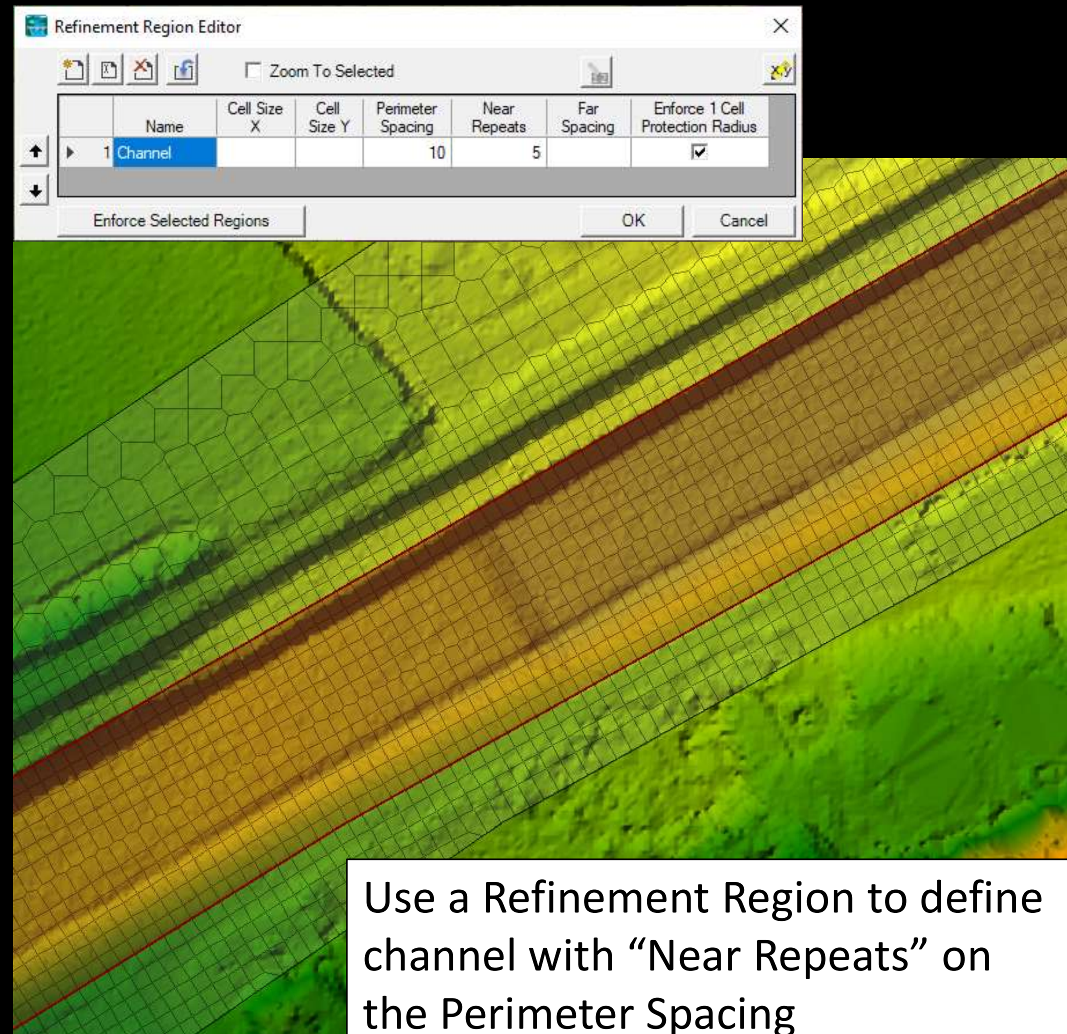
Align the Mesh with the Flow



Two Methods to Align Cells with Flow

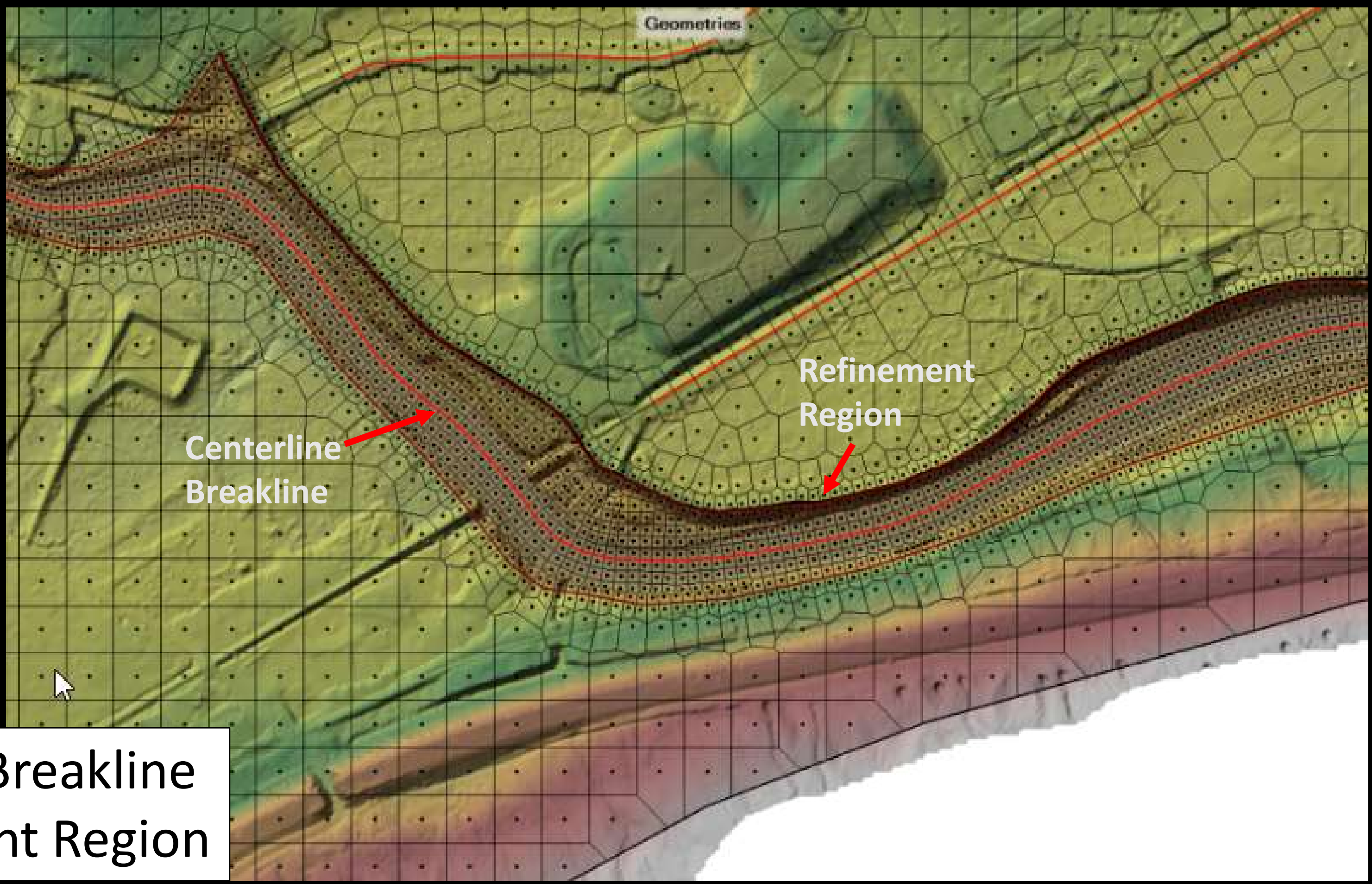


Use a breakline to define the centerline and add "Near Repeats"



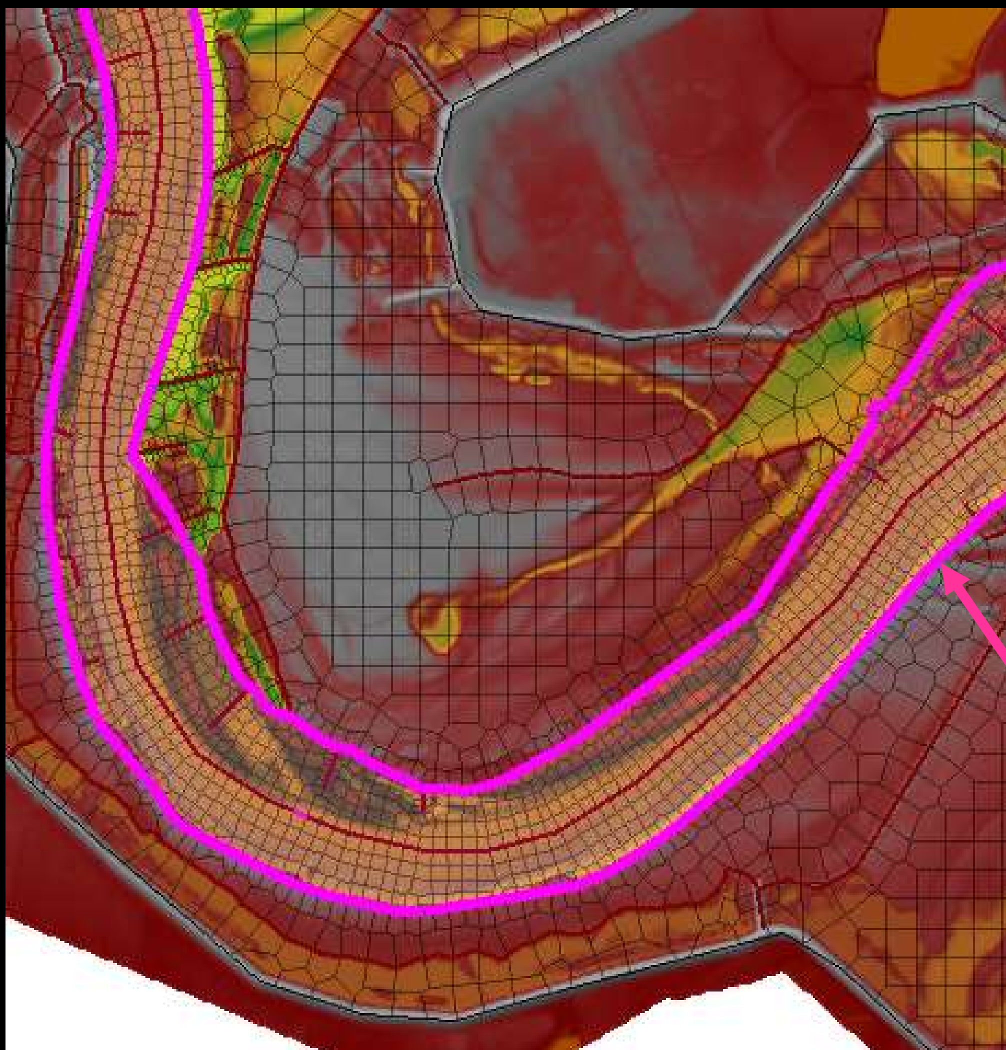
Use a Refinement Region to define channel with "Near Repeats" on the Perimeter Spacing

Best Practice – Use Them Together



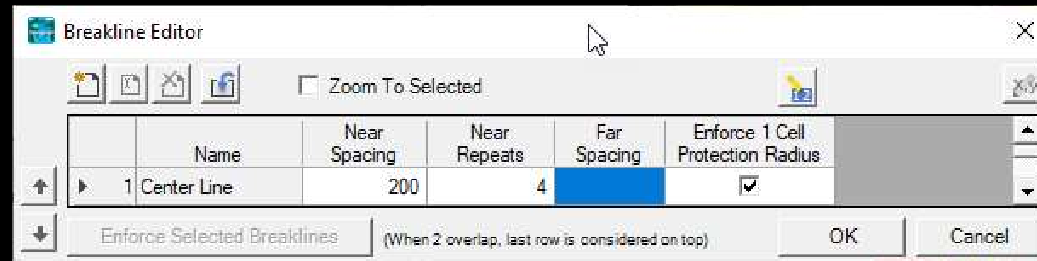
Centerline Breakline
+ Refinement Region

https://www.hec.usace.army.mil/confluence/rasdocs/r2dum/latest/development-of-a-2d-or-combined-1d-2d-model/development-of-the-2d-computational-mesh#id-.Developmentofthe2DComputationalMeshv6.0-MakingaChannelMesh



Centerline breakline

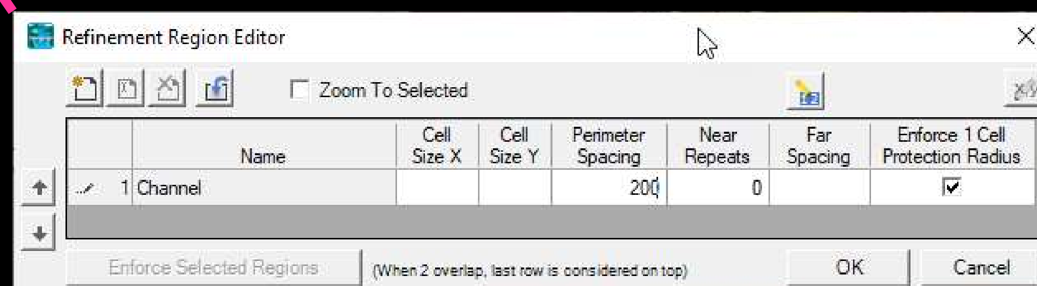
Near Repeats with Near Spacing



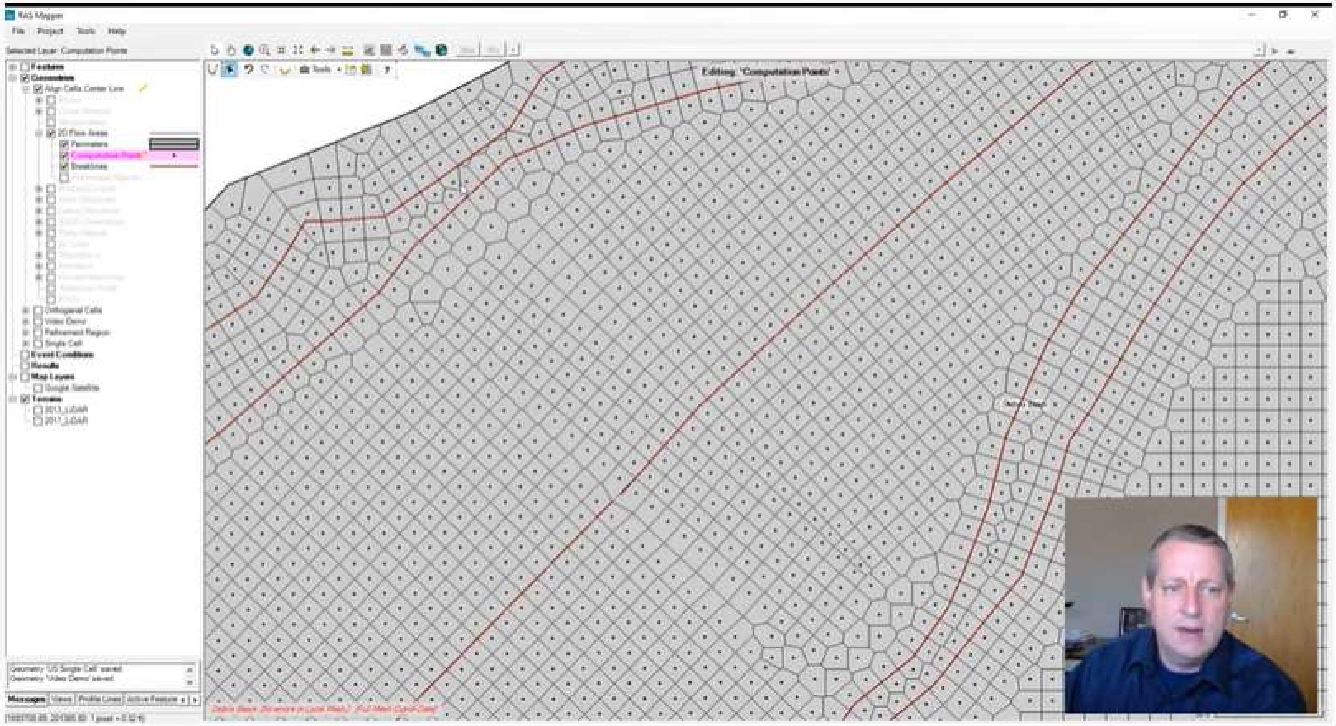
Refinement Region

Only Meant to Snap the Outside Cell Faces to Banks

Perimeter Spacing and Enforce Cell Protection Only



Alignment Video Tutorial

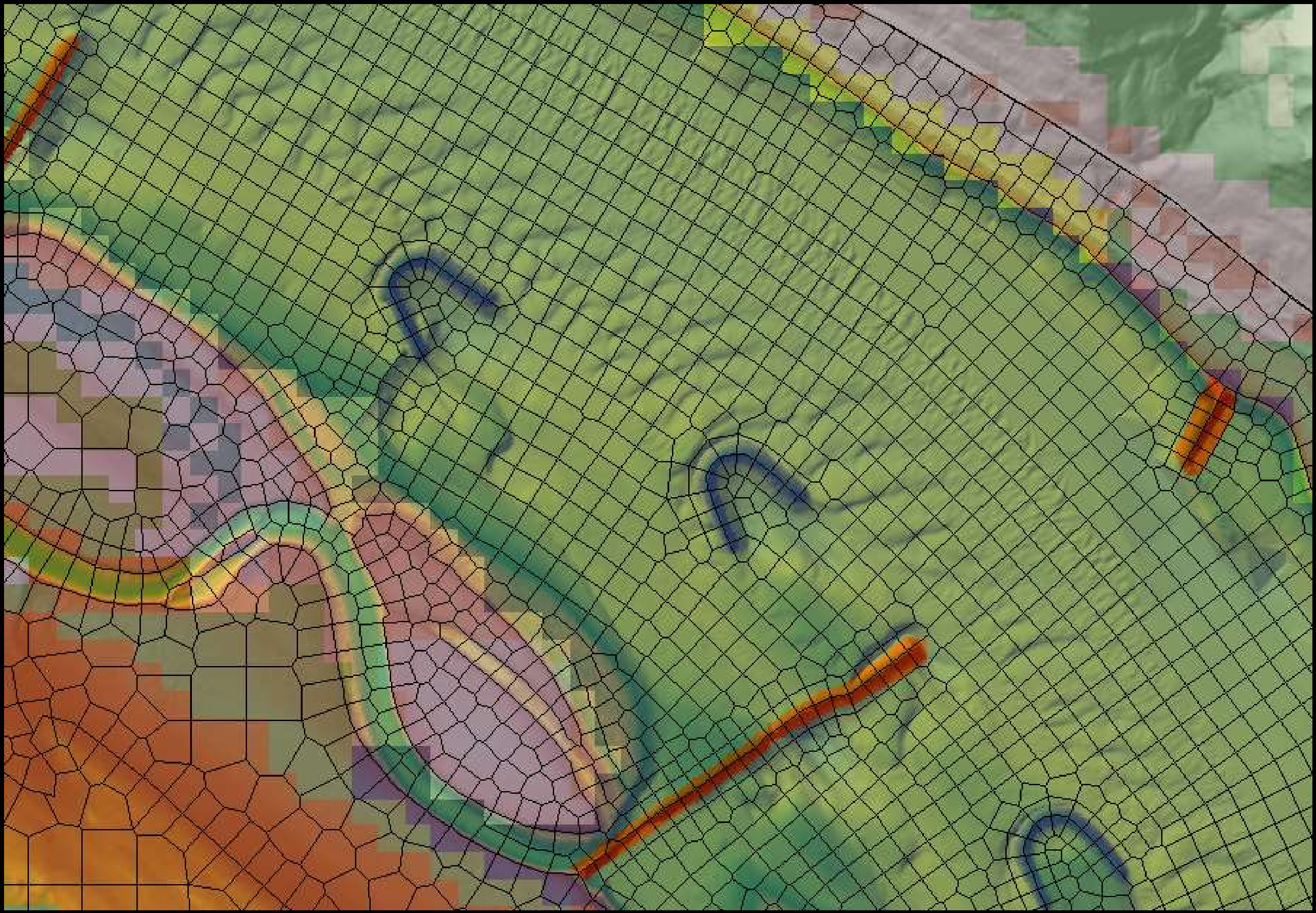


Align Cells with Flow Direction: HEC-RAS 2D Mesh

2,475 views... 73 DISLIKE SHARE SAVE ...

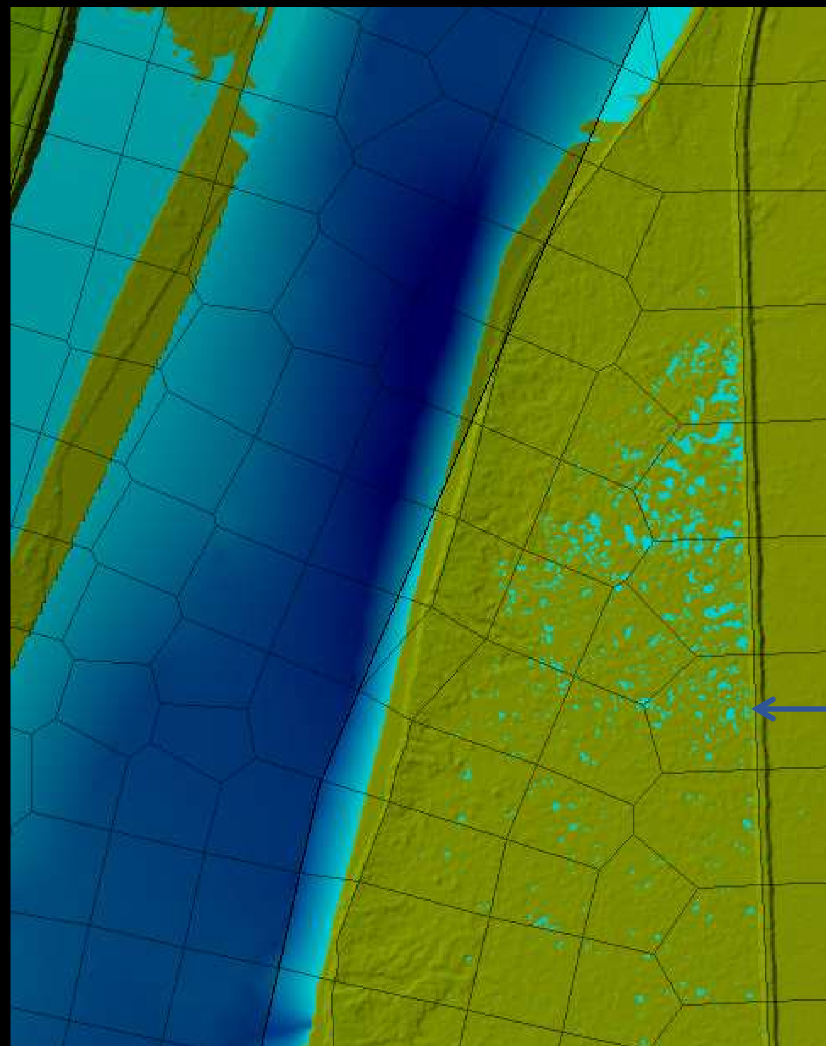
https://youtu.be/oTfFdSmXbYQ

Use Breaklines for Linear Structures



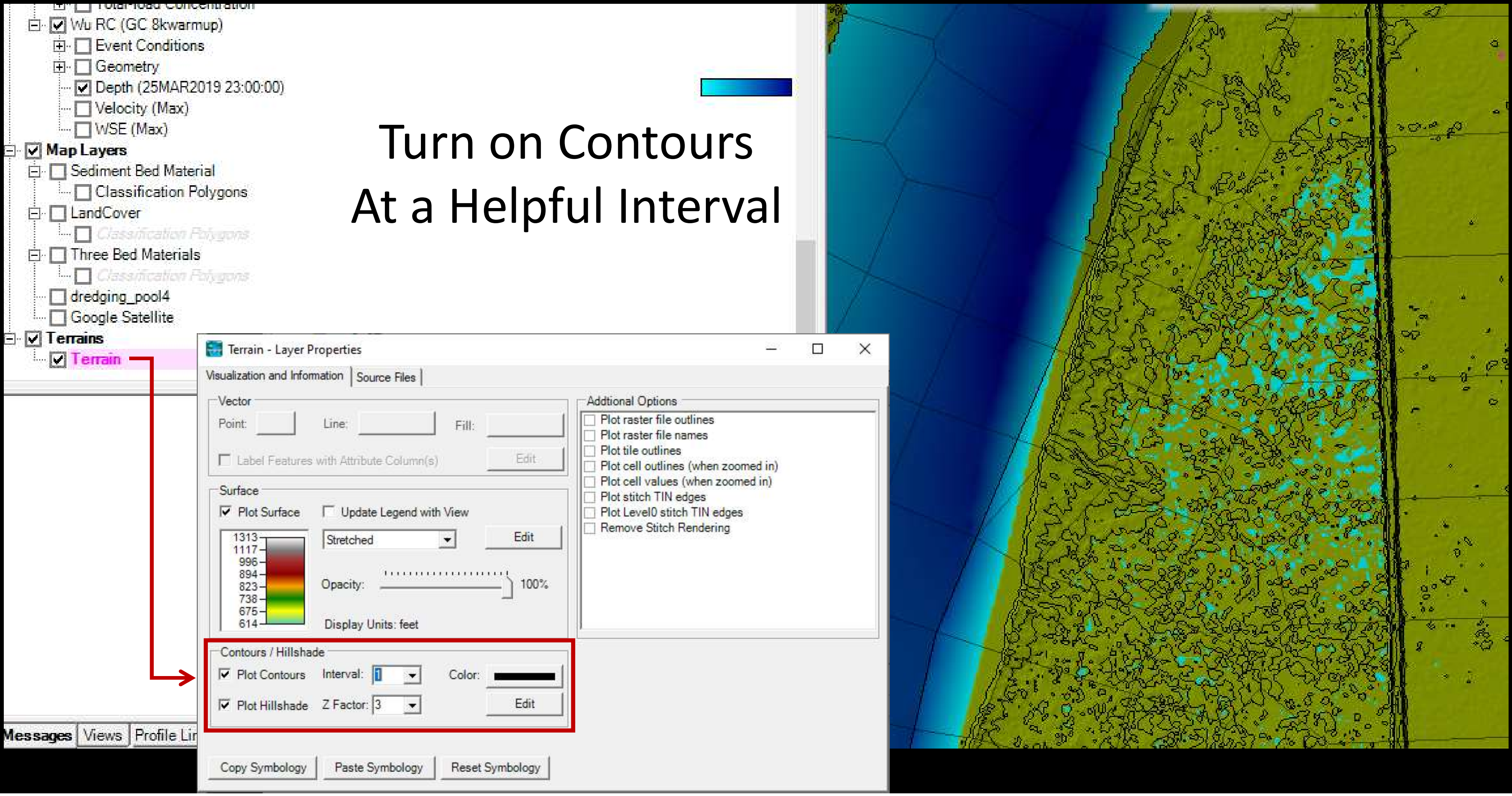
Developing a Quality, Aligned, Mesh Takes Time

Evaluating Connectivity



Where does this floodplain water come from?

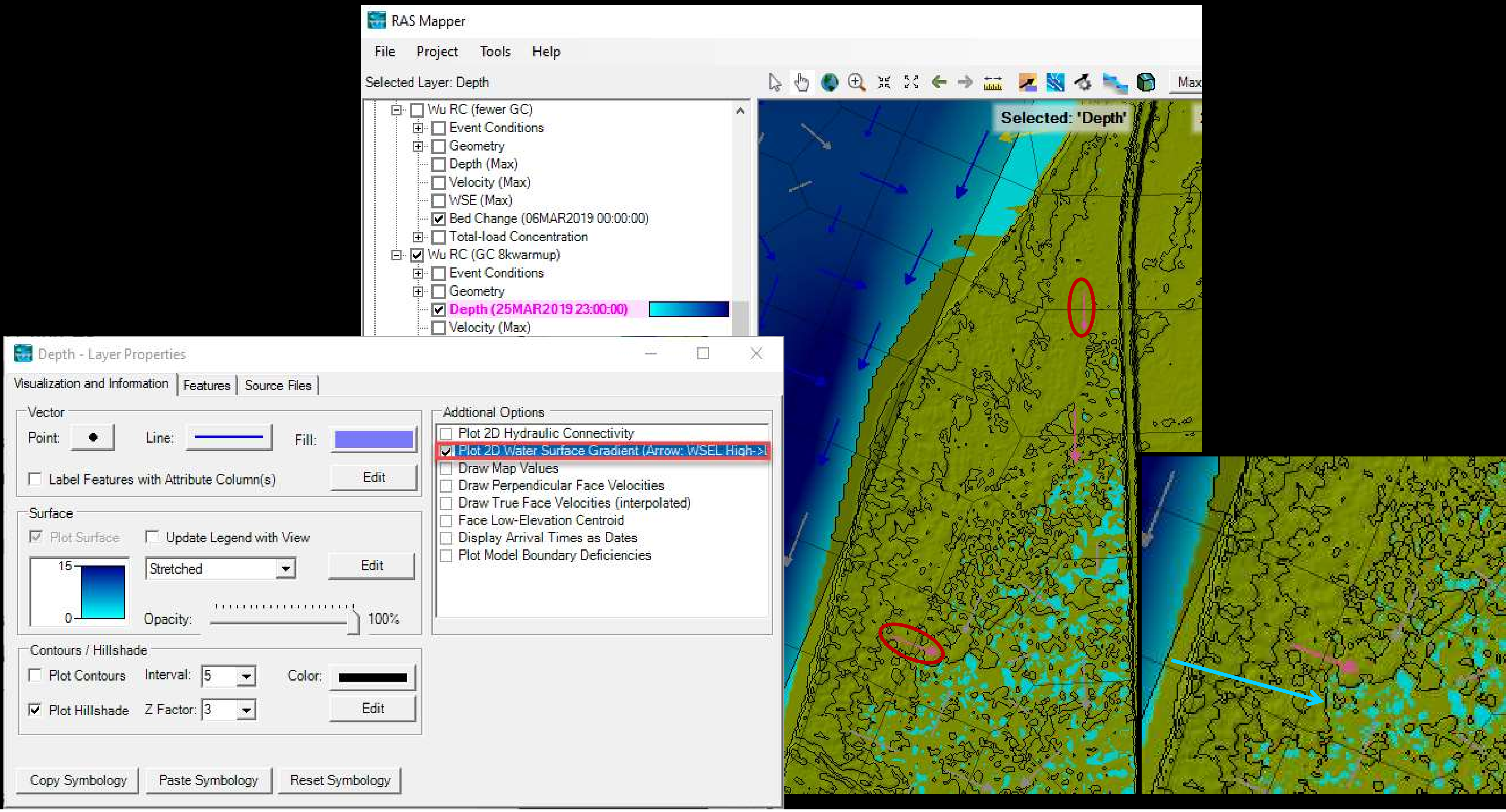
Evaluating Connectivity



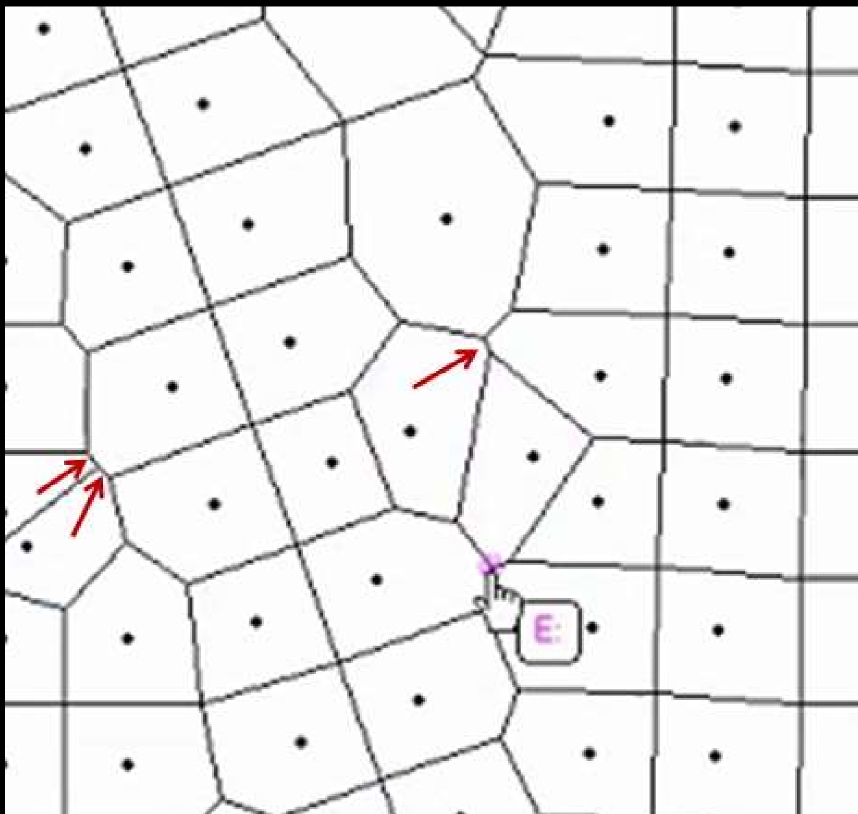
Turn on Contours

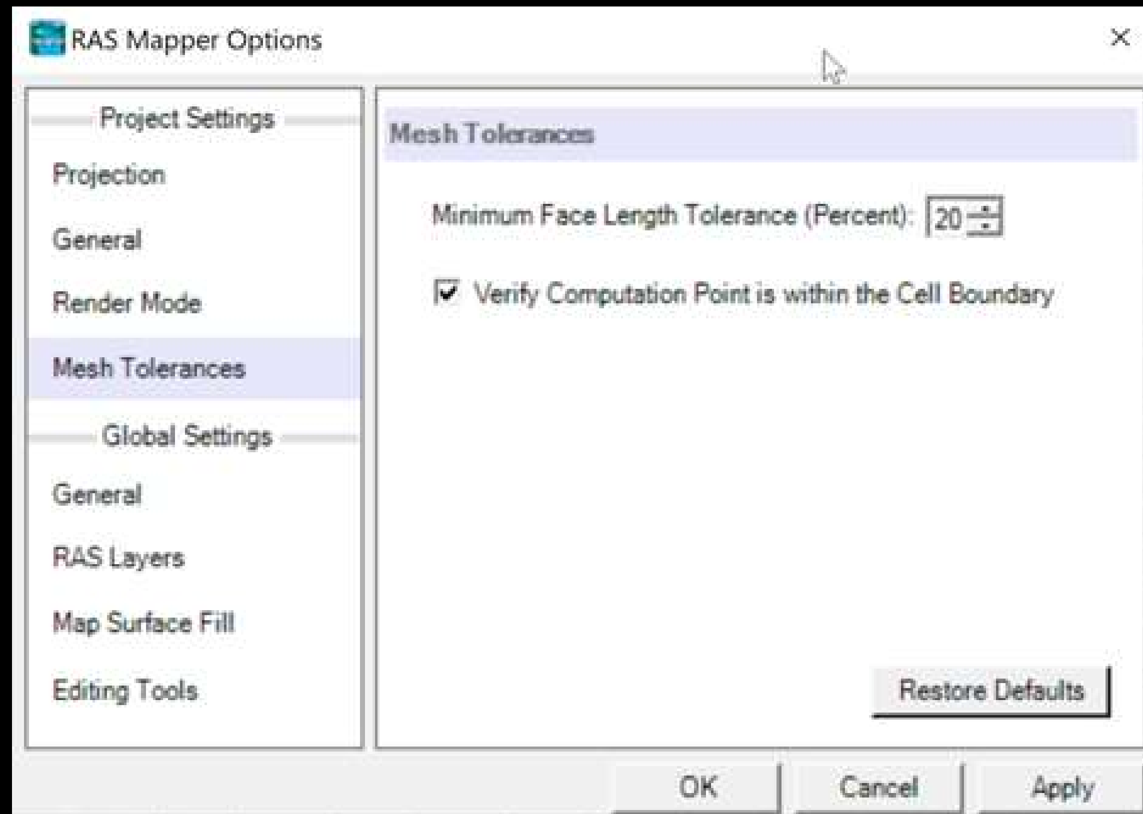
At a Helpful Interval

Evaluating Connectivity



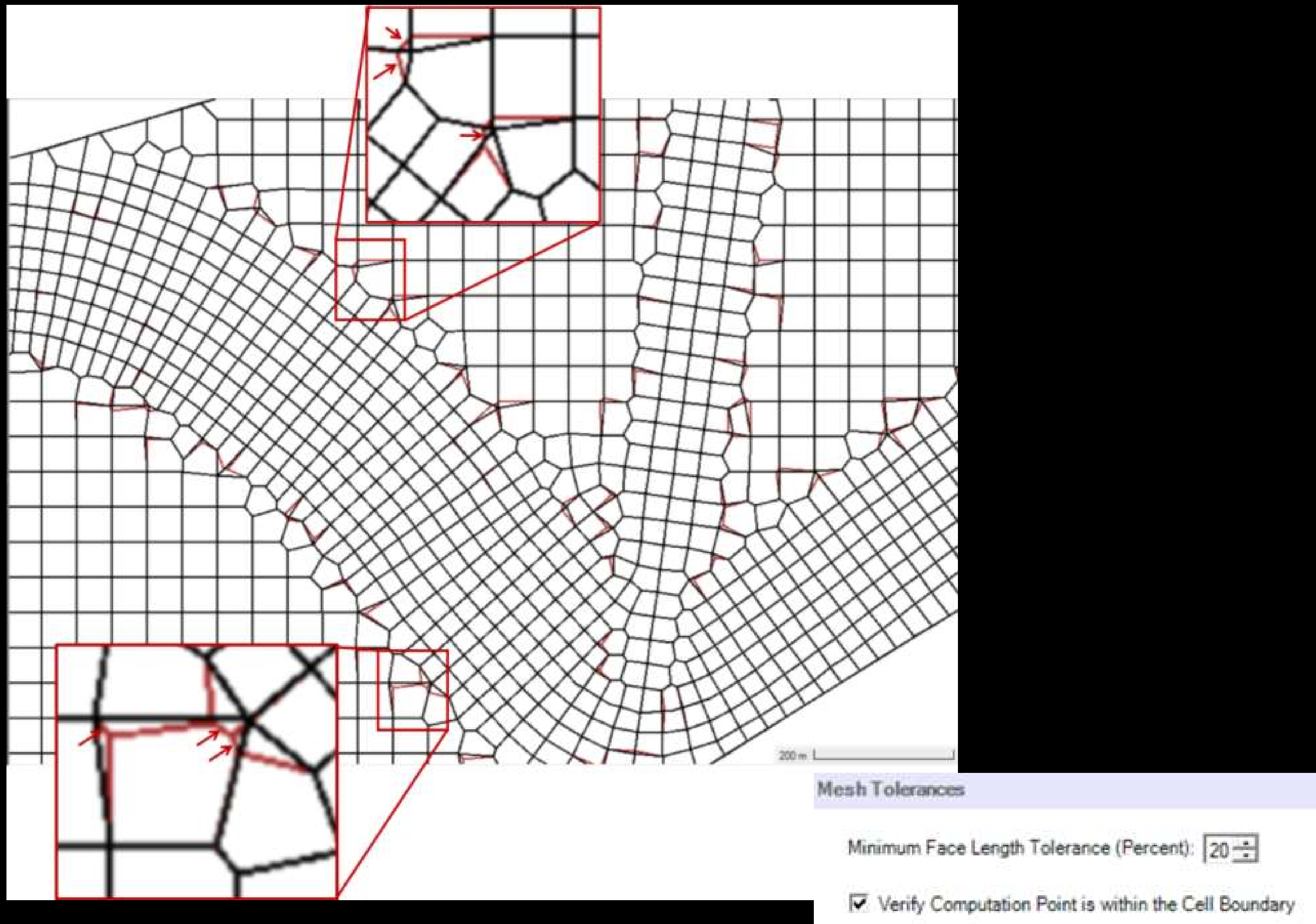
Avoid Tiny Cell Faces





This is much easier to fix in recent versions.
Use the Mesh Tolerances in Mapper Options

Avoid Tiny Cell Faces



Hydraulic Best Practices for 2D Sediment Modeling

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   - Hydraulic Warmup
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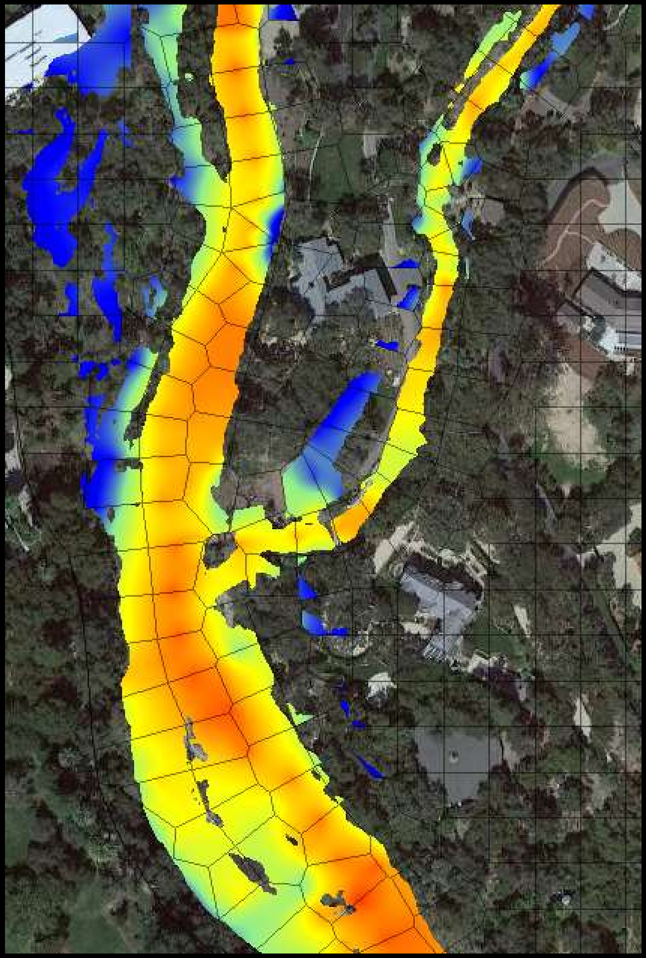
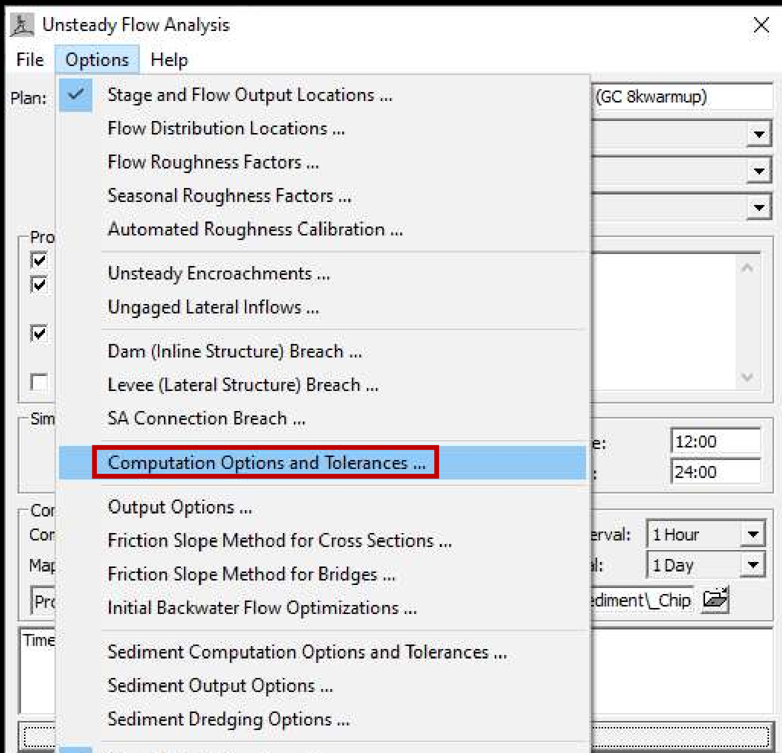
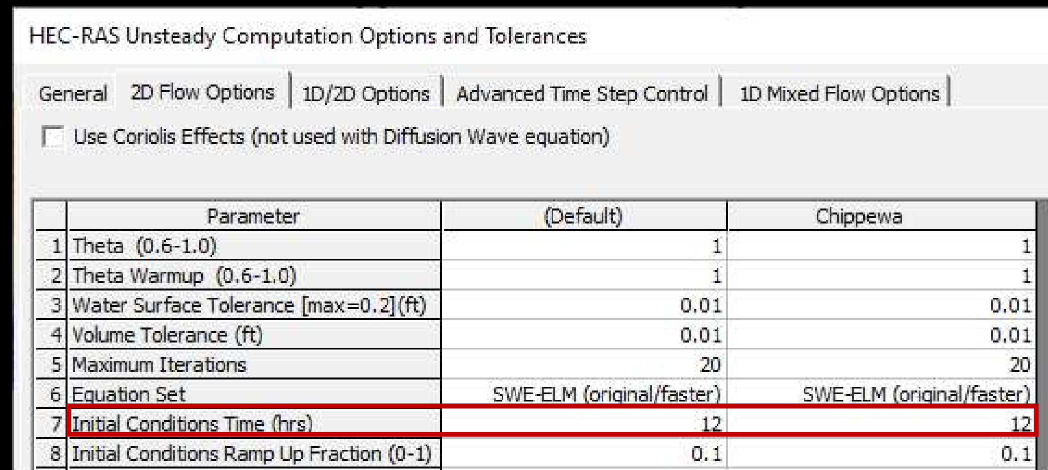
   - Turbulence and Mixing
   - Other Tips and Tricks



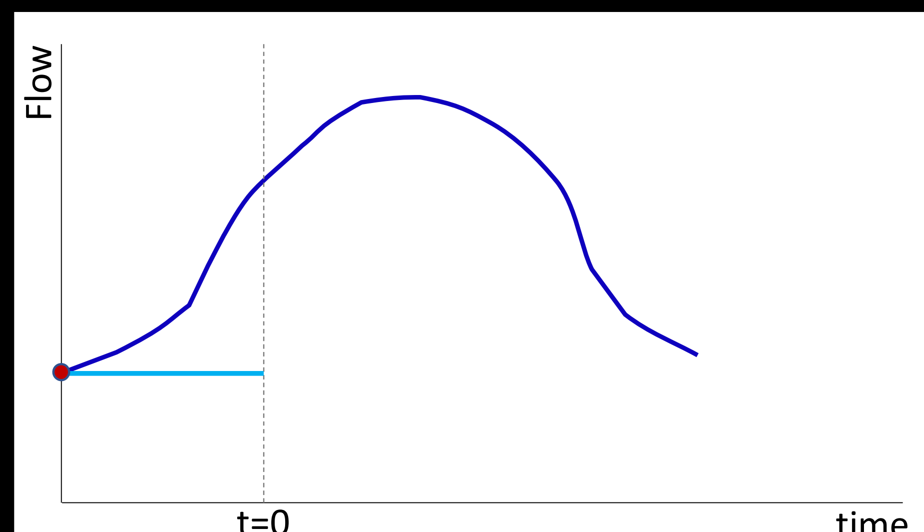
Initial Conditions: Hydraulic Warm Up/Ramp Up





	Parameter	(Default)	Chippewa
1	Theta (0.6-1.0)	1	1
2	Theta Warmup (0.6-1.0)	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	SWE-ELM (original/faster)	SWE-ELM (original/faster)
7	Initial Conditions Time (hrs)	12	12
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1

- 1D Unsteady Starts with a Steady Flow Run For Initial Conditions
- 2D Hydraulics Starts Dry: There is no “Steady Flow 2D”
- The “Ramp Up” Allows you to Reach “Dynamic Steady State”
- Giving a Model Enough Time to Reach Hydraulic Steady State is Critical for a Sediment Simulation



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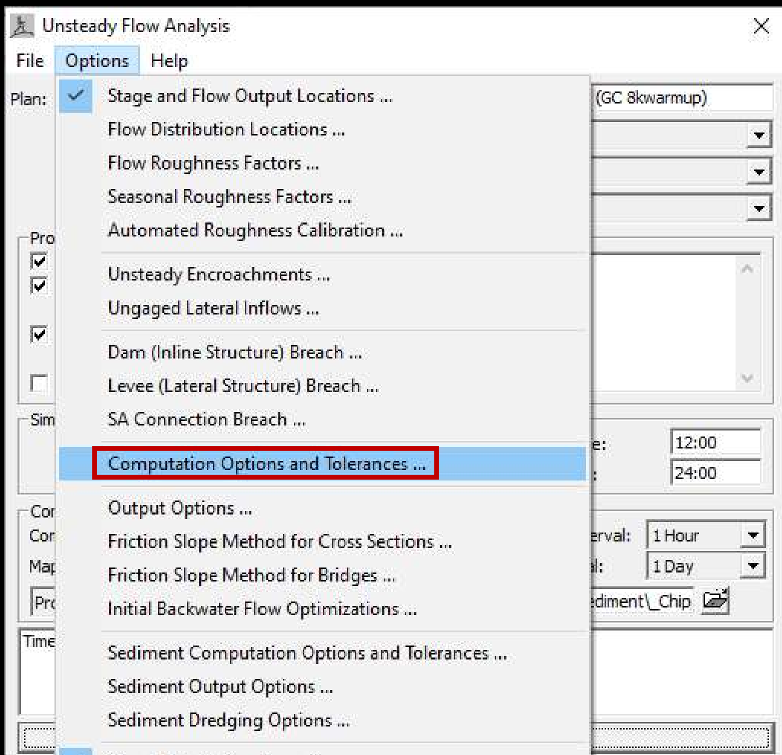

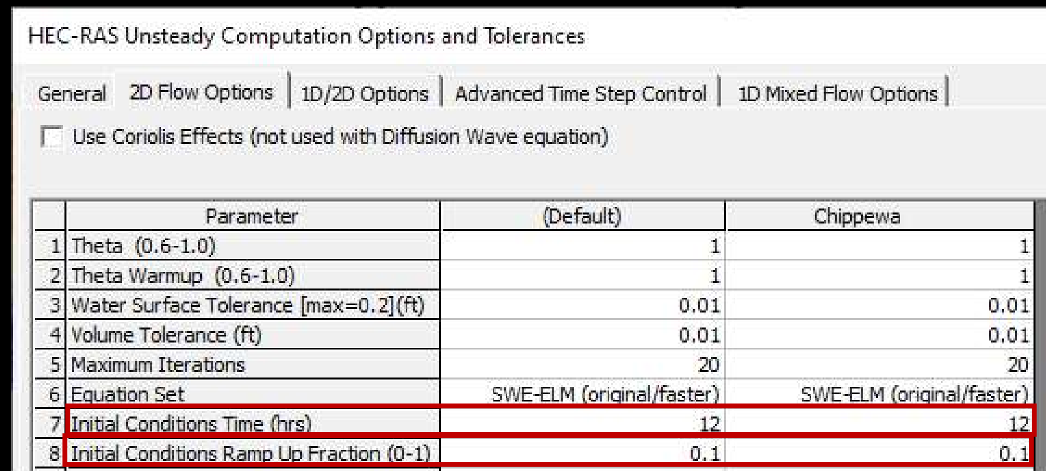

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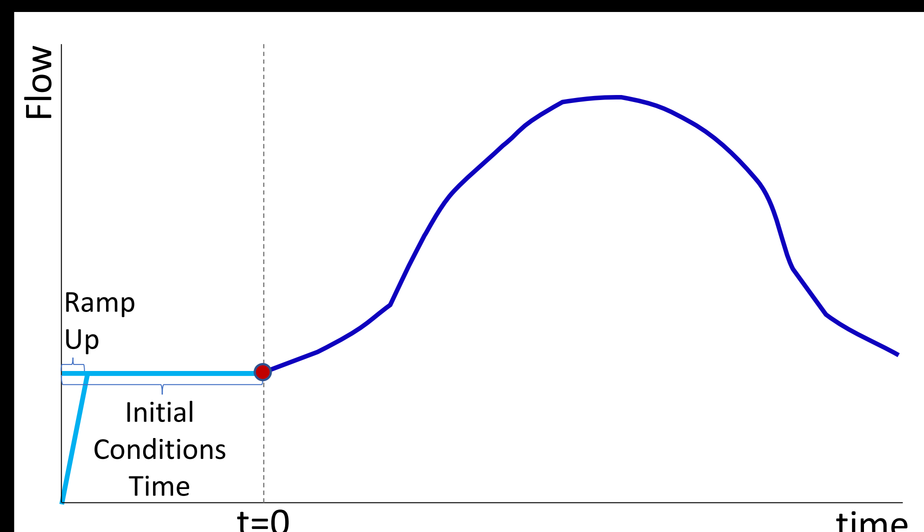
5	Maximum Iterations	20	20
6	Equation Set	SWE-ELM (original/faster)	SWE-ELM (original/faster)
7	Initial Conditions Time (hrs)	12	12
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1

- Note: The Initial Conditions Time Does not Use the Adaptive Time Step



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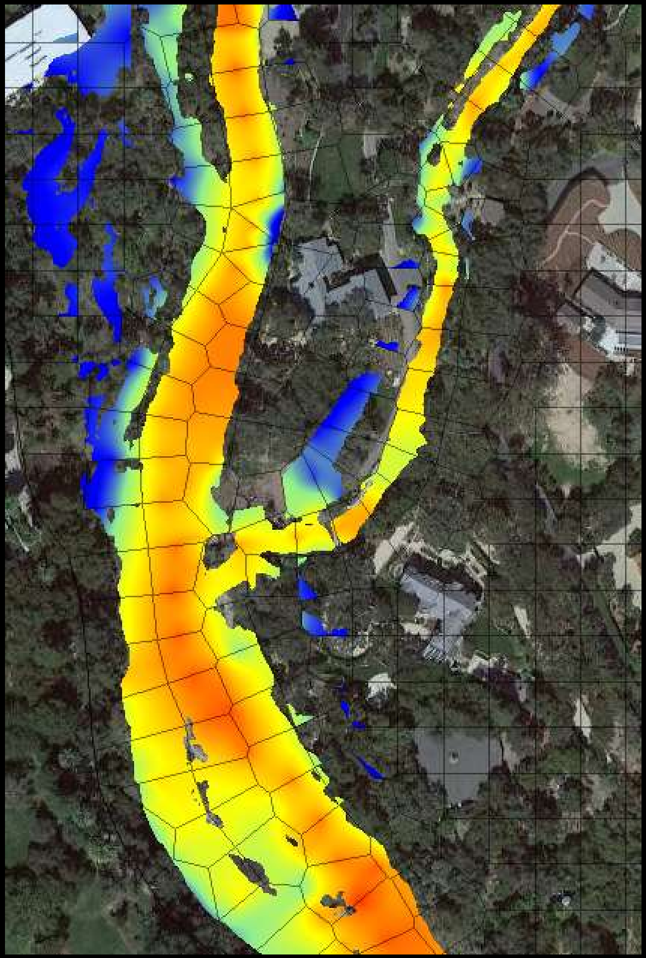
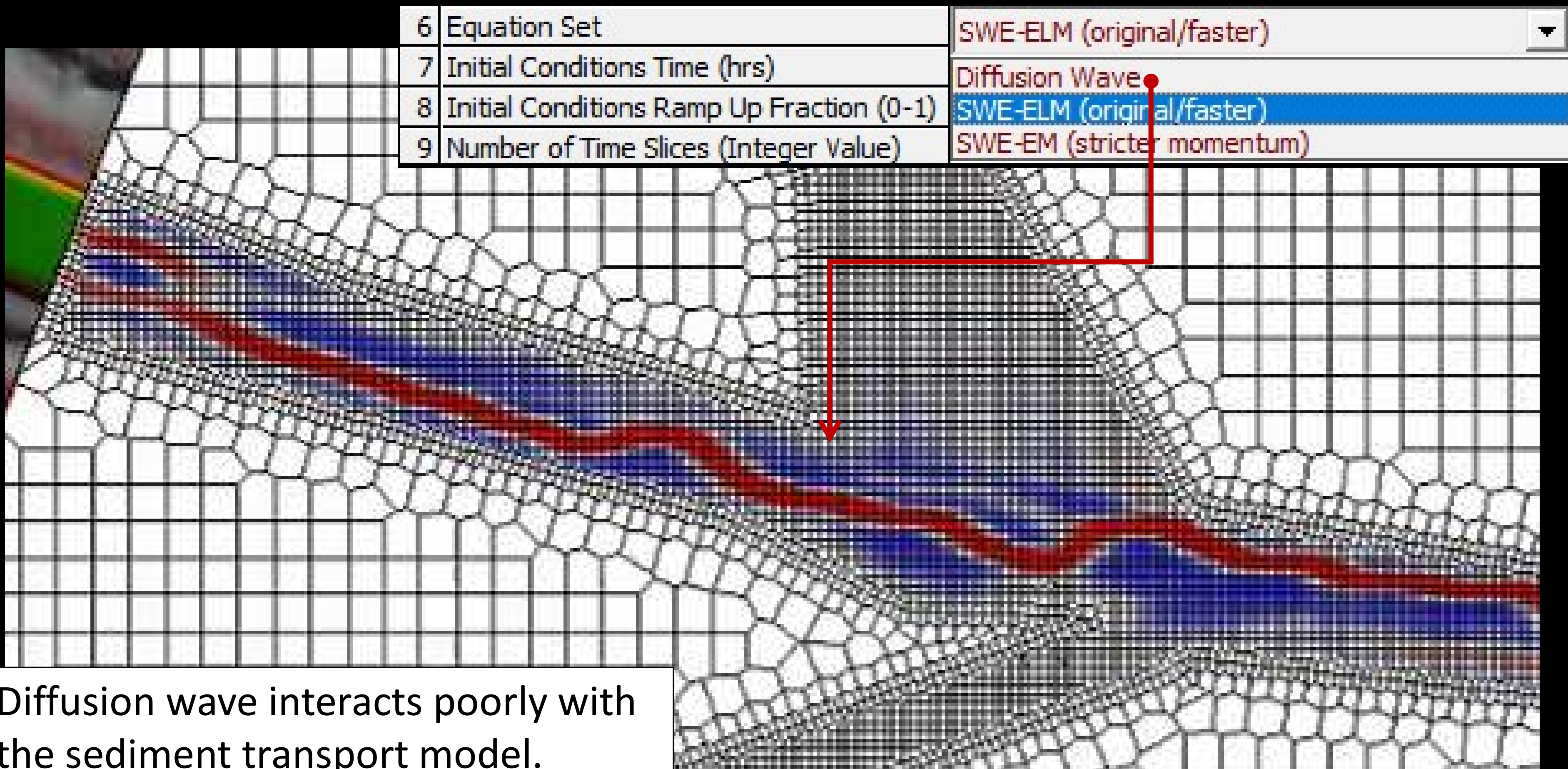
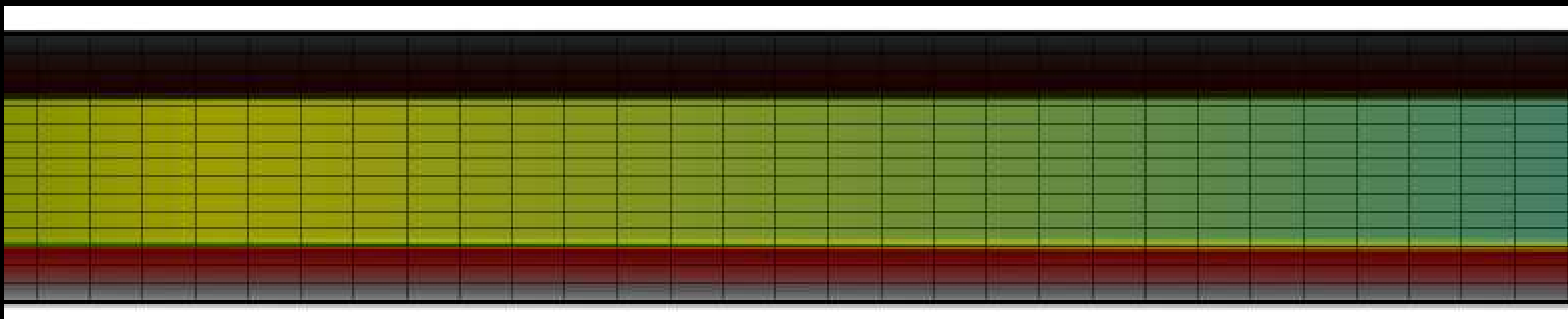


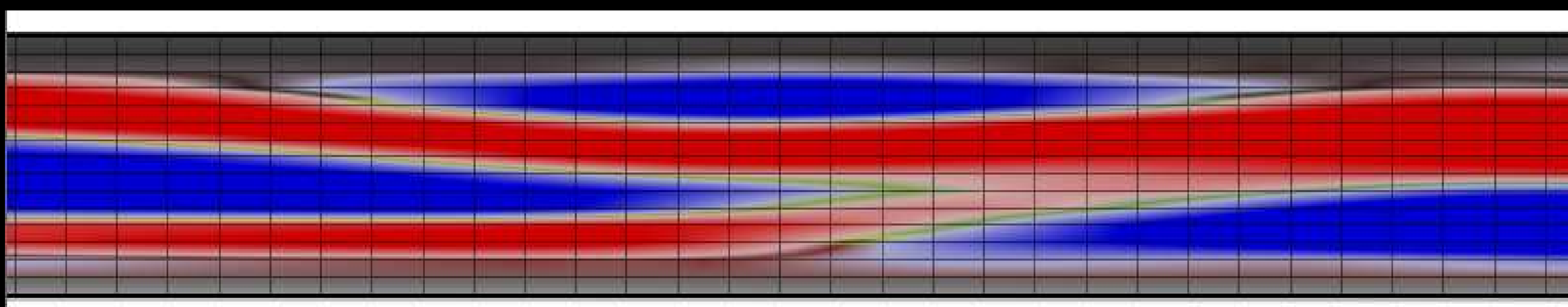
Always Use the Full Momentum Equations



Diffusion wave interacts poorly with the sediment transport model.

Always Use the Full Momentum Equations





Diffusion Wave Result

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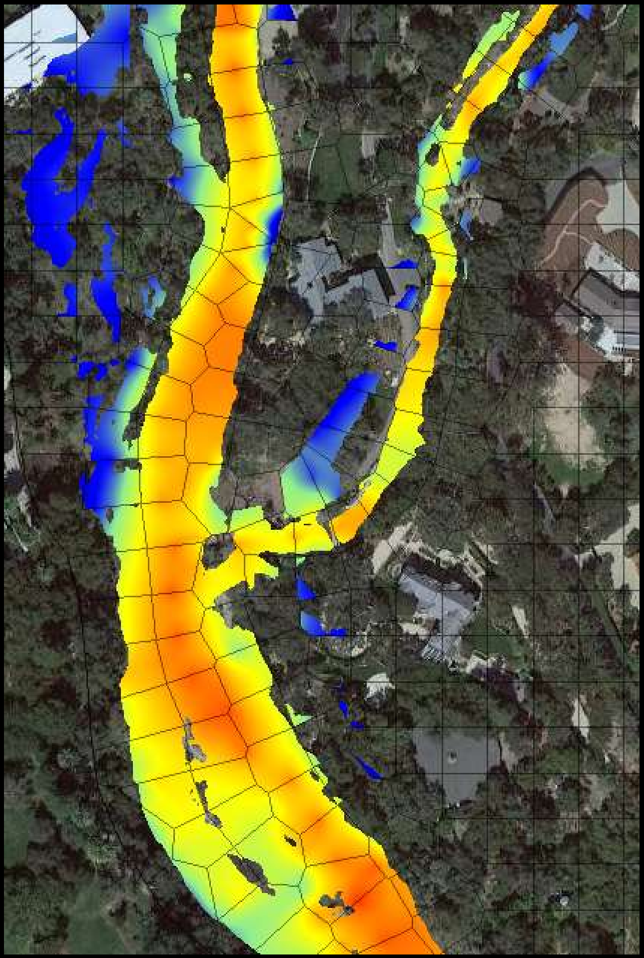
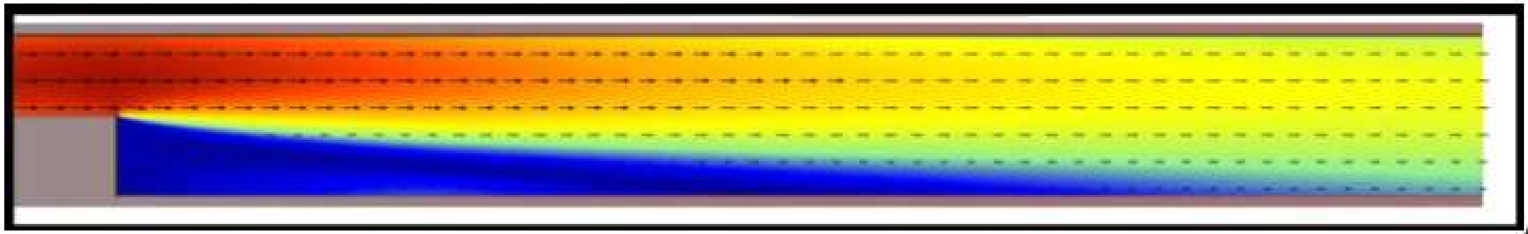
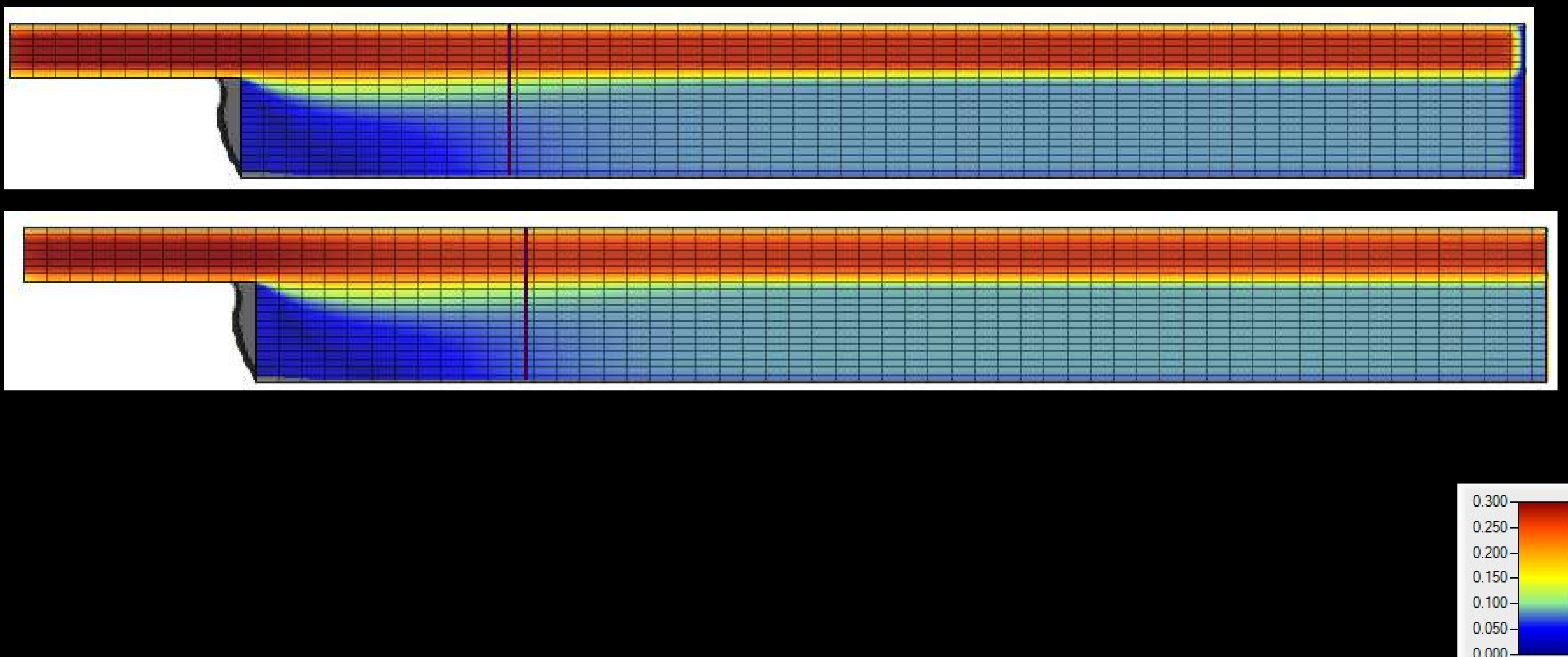


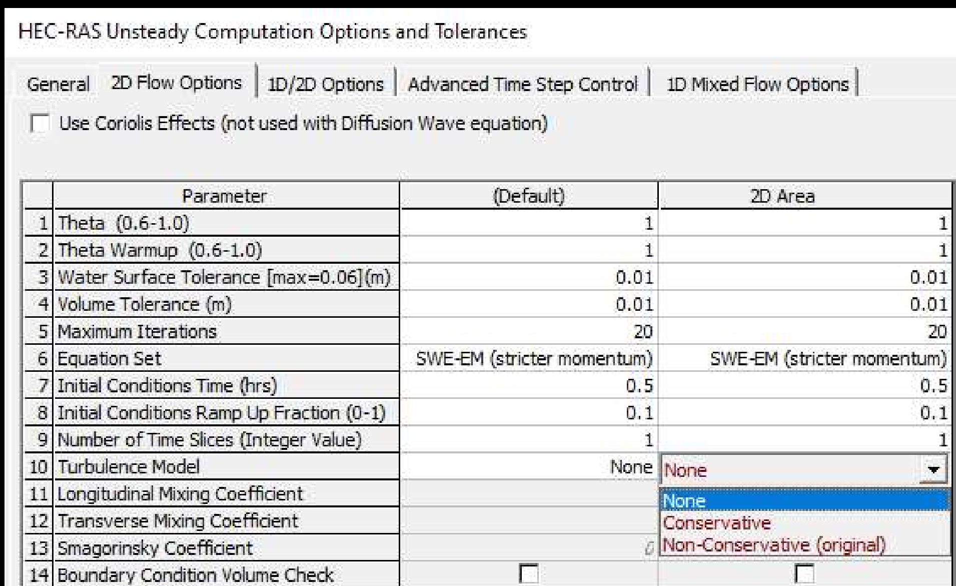
How does sediment transport laterally in RAS?
(Choose all that apply)



- ▲ Turbulence and mixing
- ◆ Numerical Dispersion
- ● Sediment Diffusion
- ■ Muskrat Metabolism


0.300
0.250
0.200
0.150
0.100
0.050
0.000

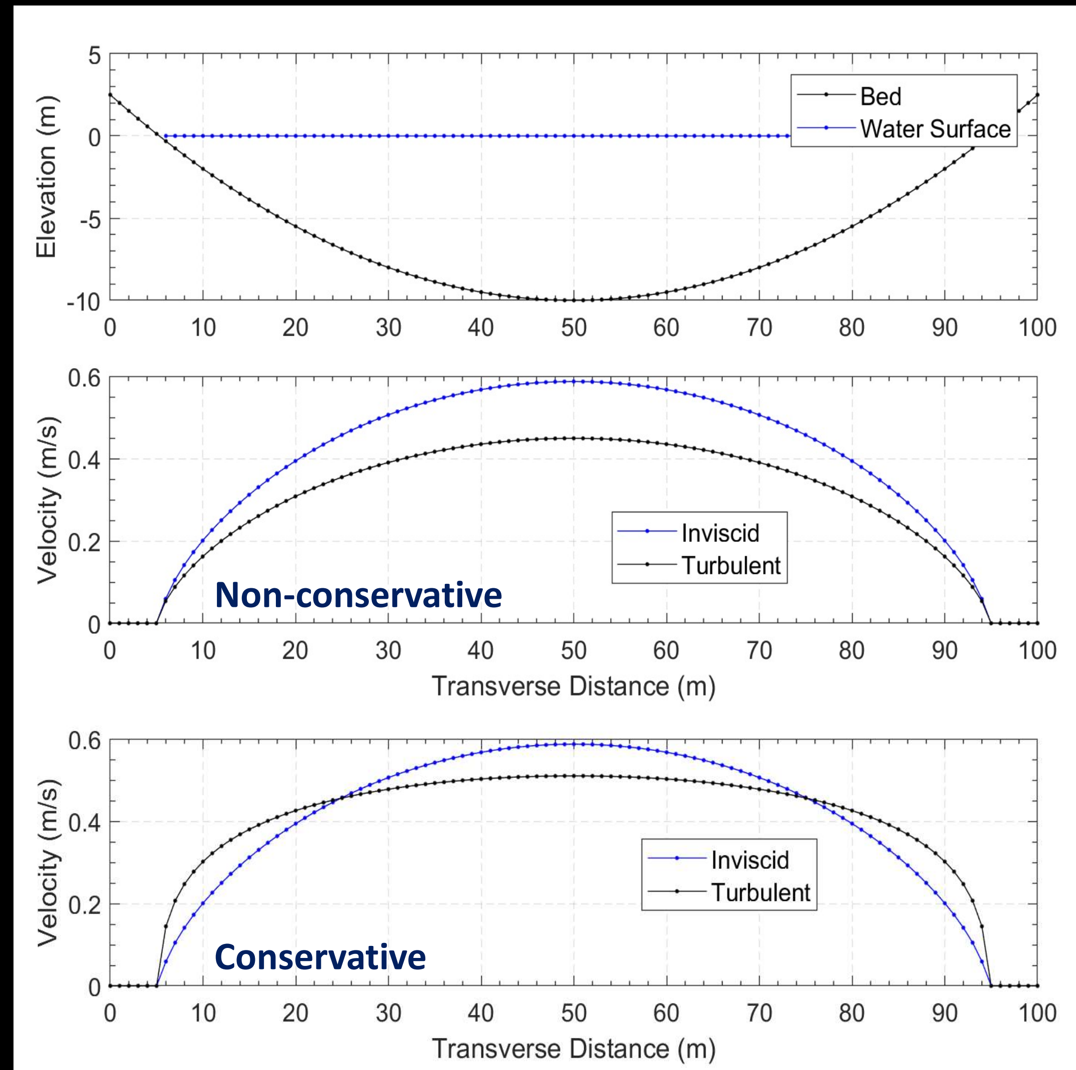
Turbulence Equations


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)	2D Area
1	Theta (0.6-1.0)	1	1
2	Theta Warmup (0.6-1.0)	1	1
3	Water Surface Tolerance [max=0.06](m)	0.01	0.01
4	Volume Tolerance (m)	0.01	0.01
5	Maximum Iterations	20	20
6	Equation Set	SWE-EM (stricter momentum)	SWE-EM (stricter momentum)
7	Initial Conditions Time (hrs)	0.5	0.5
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1
9	Number of Time Slices (Integer Value)	1	1
10	Turbulence Model	None	None
11	Longitudinal Mixing Coefficient		None
12	Transverse Mixing Coefficient		Conservative
13	Smagorinsky Coefficient		Non-Conservative (original)
14	Boundary Condition Volume Check	☐	☐



Turbulence Equations

Turbulence and mixing are essentially diffusion terms.

Non-Conservative

Assumes smoothly varying velocities (changes are gradual)

The eddy viscosity can come outside the derivative

But the spatial average drop – so this becomes a dissipation term not just a mixing term

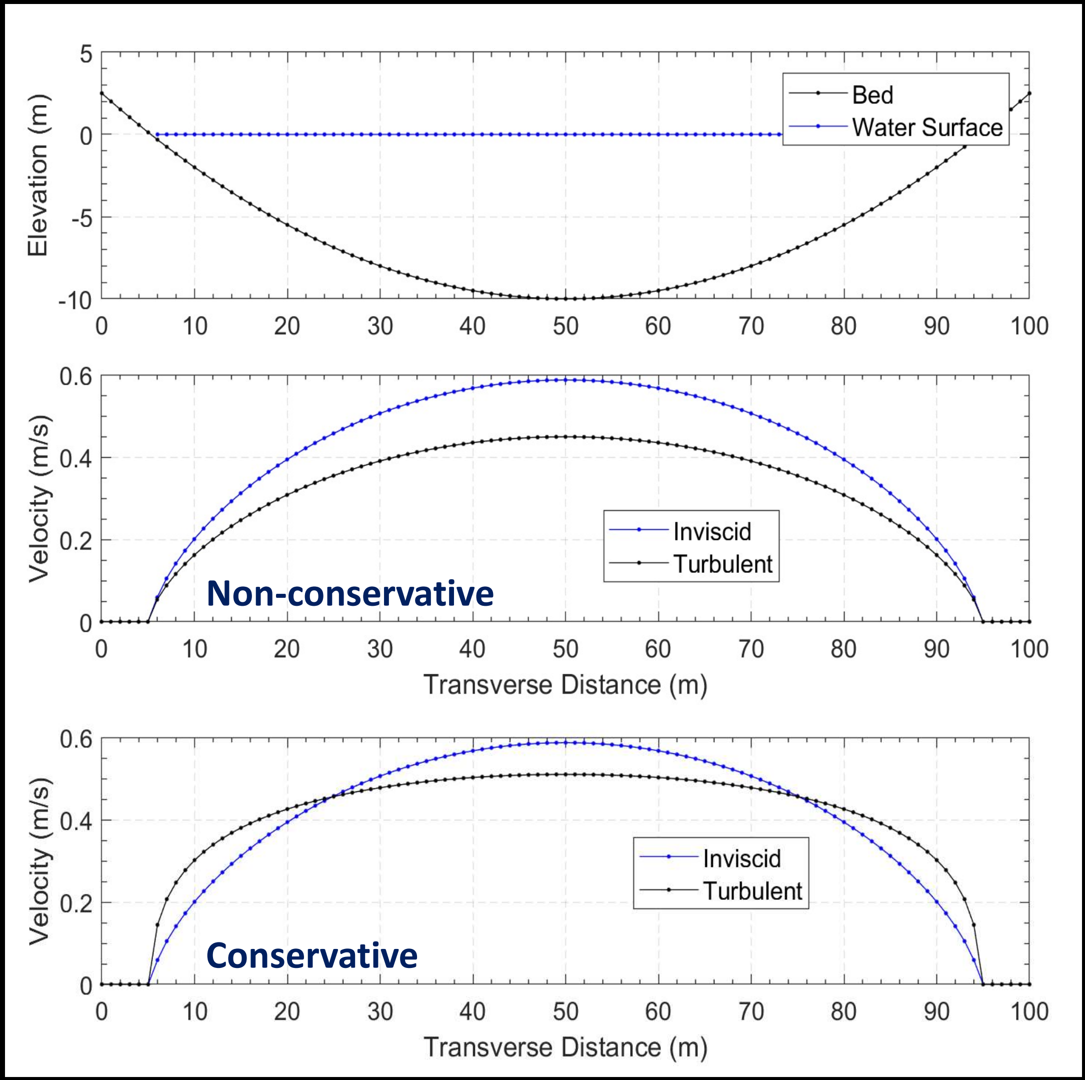
$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} - fv = -g\frac{\partial H}{\partial x} + \nu_t\left(\frac{\partial^2 u}{\partial y^2}\right) - c_f u$$

Conservative

Transforms the mixing term into the diffusive flux by moving the coefficient inside the derivative and multiplying by h/h

This is a finite volume approach and yields a conservative formulation

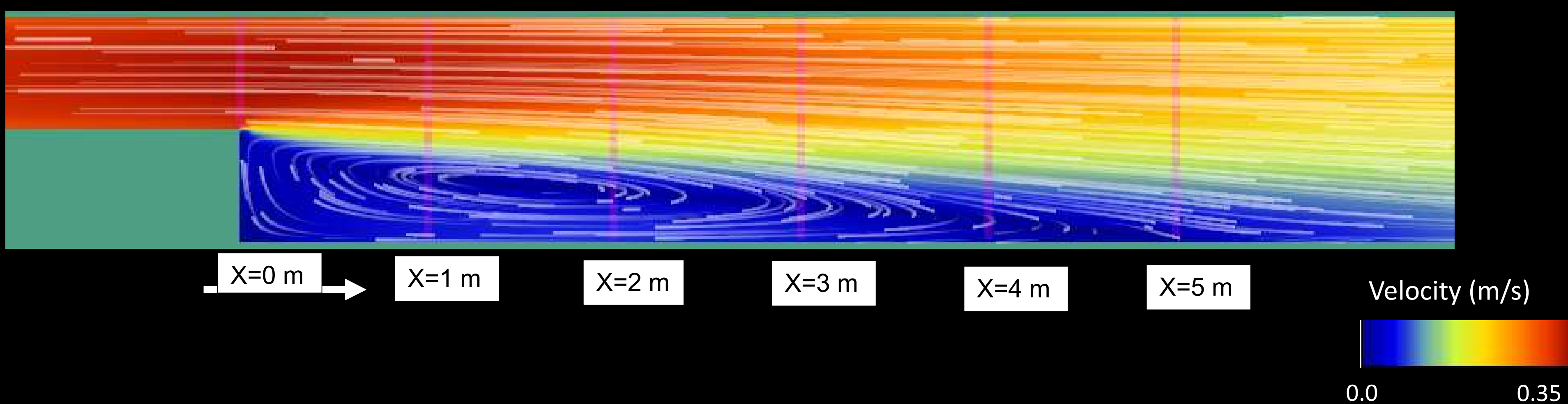
$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + fv = -g\frac{\partial H}{\partial x} + \frac{1}{h}\frac{\partial}{\partial x}\left(\nu_{t,xx} h\frac{\partial u}{\partial x}\right) - c_f u$$



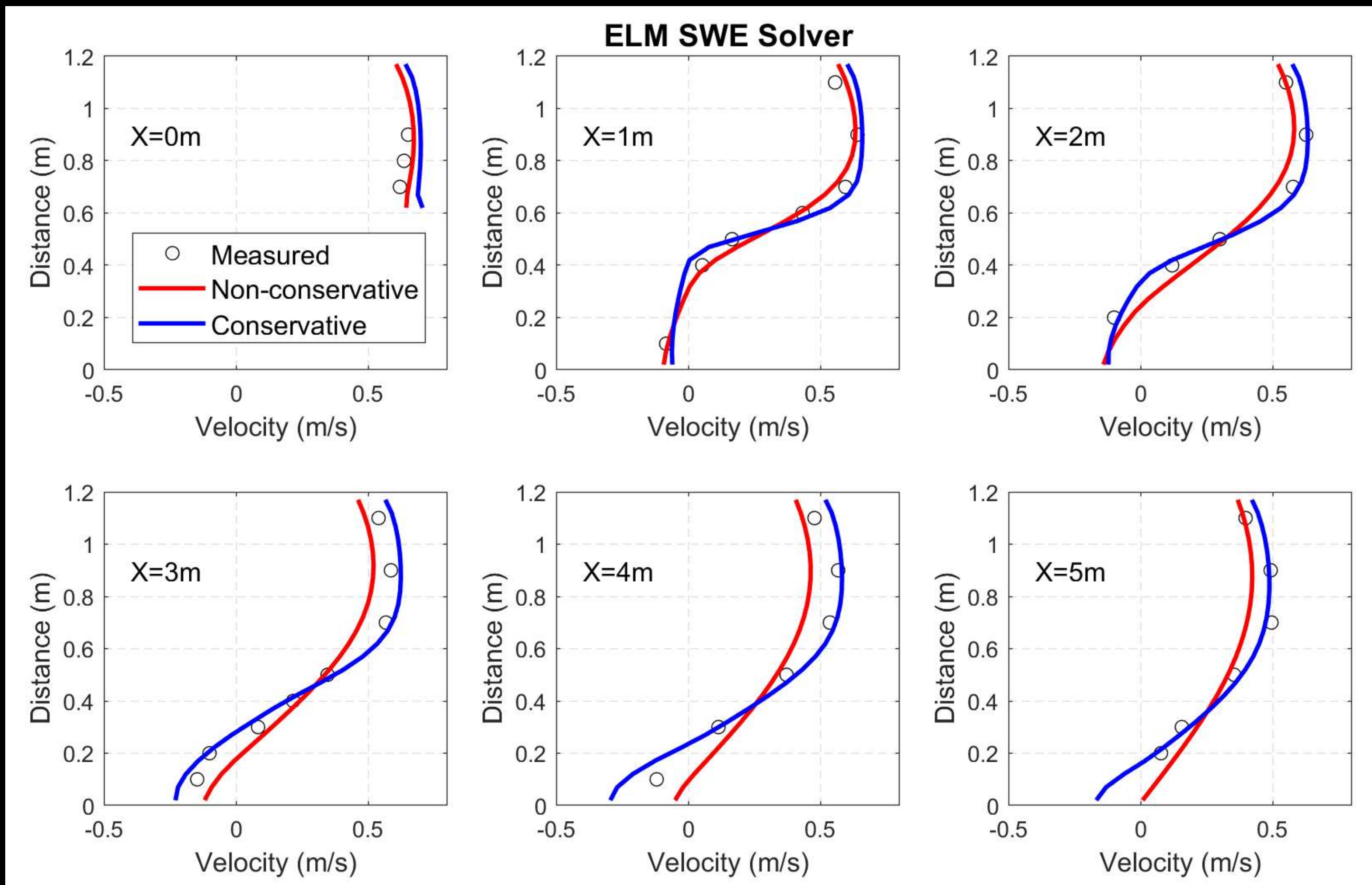
(Note: Equations one-dimensionalized for simplicity)

Example: Sudden Expansion Lab Experiment

- Inflow: 0.039 m^3/s
- Downstream depth: 11 cm
- Slope: 0.0001
- Grid Resolution: 2.5 cm
- Time step: 0.02 and 0.0333 s
- Manning's n: 0.015 $s/m^{1/3}$



Results: Sudden Expansion Lab Experiment



New Turbulence Approach in 6.0+

Old Method: Parabolic

$$\nu_t = D u_* h$$

Isotropic ($D_L = D_T$)
Sensitive to Roughness
Not sensitive to cell size

New Method: Parabolic-Smagorisnky

$$\nu_{txx} = D_{xx} u_* h + (C_s \Delta)^2 |\bar{S}|$$
$$\nu_{ty} = D_{yy} u_* h + (C_s \Delta)^2 |\bar{S}|$$

Anisotropic ($D_L \neq D_T$)
Sensitive to Roughness
Sensitive to cell size (Δ)
(As cell size decreases more of the sub-cell dispersion is accounted for explicitly, and the Smagorisnky term drops out)

u_* : Shear velocity
h : Water depth
D : Mixing coefficient
D_L : Longitudinal mixing coefficient
D_T : Transverse mixing coefficient
C_s : Smagorinsky coefficient

$$|\bar{S}| = \sqrt{2\left(\frac{\partial u}{\partial x}\right)^2 + 2\left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2}$$

New Turbulence Approach in 6.0+

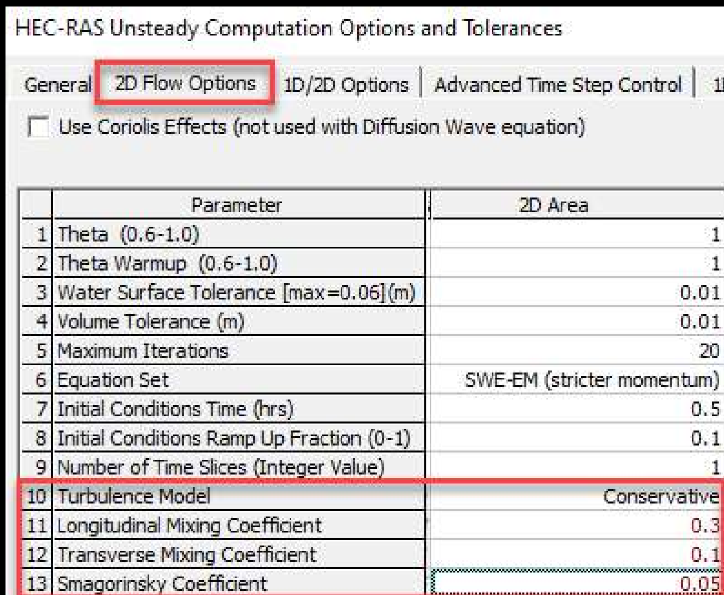
$$\nu_{tx} = D_{xx} u_* h + (C_s \Delta)^2 |\bar{S}|$$
$$\nu_{tyy} = D_{yy} u_* h + (C_s \Delta)^2 |\bar{S}|$$

"Vertical Stuff"
Bottom Friction
Dispersion From the Vertical Velocity Distribution

"Horizontal Stuff"
Dispersion across gradients in the horizontal plane

HEC made these changes with 2D sediment in mind.

Turbulence Coefficients


HEC-RAS Unsteady Computation Options and Tolerances

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

Use Coriolis Effects (not used with Diffusion Wave equation)

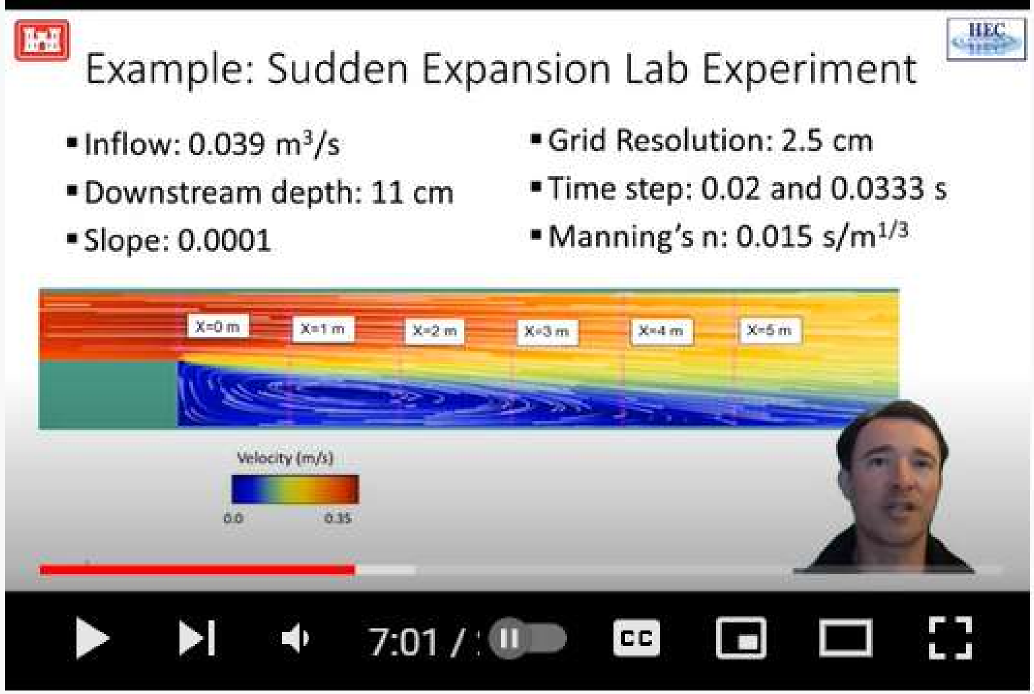
	Parameter	2D Area
1	Theta (0.6-1.0)	1
2	Theta Warmup (0.6-1.0)	1
3	Water Surface Tolerance [max=0.06](m)	0.01
4	Volume Tolerance (m)	0.01
5	Maximum Iterations	20
6	Equation Set	SWE-EM (stricter momentum)
7	Initial Conditions Time (hrs)	0.5
8	Initial Conditions Ramp Up Fraction (0-1)	0.1
9	Number of Time Slices (Integer Value)	1
10	Turbulence Model	Conservative
11	Longitudinal Mixing Coefficient	0.3
12	Transverse Mixing Coefficient	0.1
13	Smagorinsky Coefficient	0.05

Mixing Intensity	Geometry and Surface	D_L	D_T
Weak	Straight channel Smooth Surface	0.1 to 0.3	0.04 to 0.1
Moderate	Gentle meanders Moderately irregular	0.3 to 1	0.1 to 0.3
Strong	Strong meanders Rough surface	1 to 3	0.3 to 1

Smagorinsky Coefficient: 0.05 to 0.2

- $D_L \sim 2\text{-}4\, D_T$
- If $D_L = D_T$ (isotropic) the model will overpredict floodplain deposition
- Non-conservative formulation generally requires larger values (2x) compared to the conservative formulation
- Calibrating to WSE without turbulence can get stages right but be wrong about how the water moves. Sediment will reveal that error. Calibrate hydraulics with reasonable turbulence and mixing.

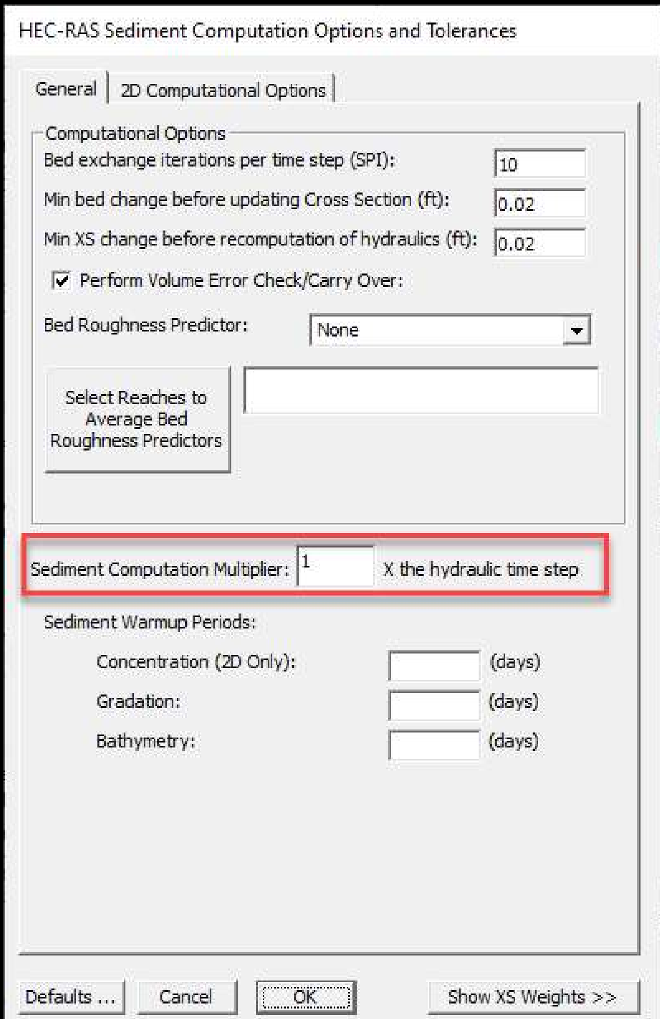
Turbulence Method



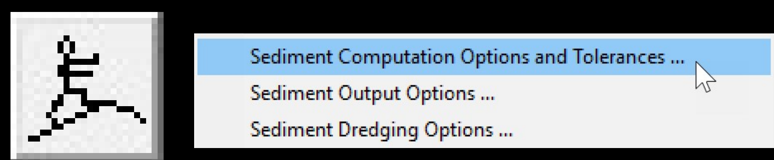
HEC-RAS 2D Class: 2.10 - Advanced Computation Options

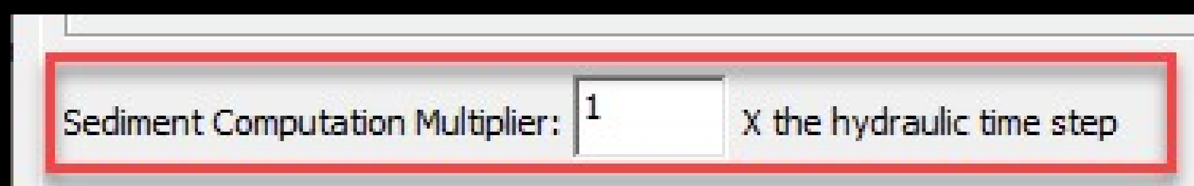
https://www.youtube.com/watch?v=nEr87YpHnzA

Fixed Bed Capacity Calculation

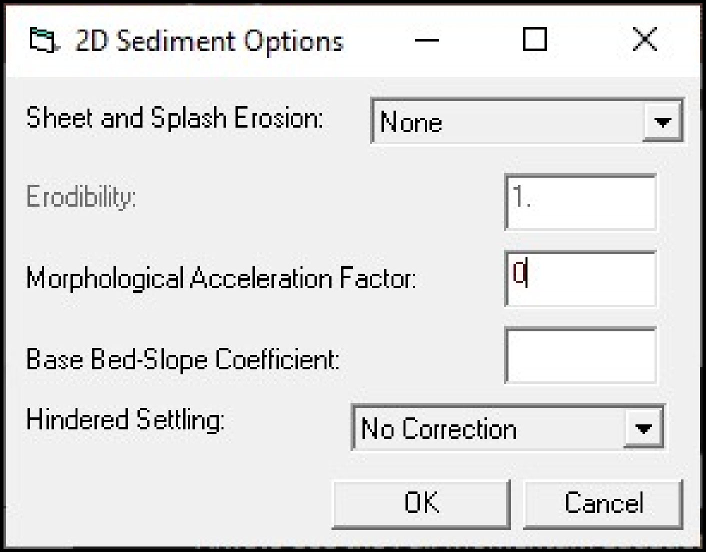


- Sediment transport does ~ and order of magnitude calculations than hydraulics.
- Carefully manage time step, cell size, and number of grain classes.
- HEC added a computational multiplier to help manage run times because rivers tend to erode and deposits on different time scale.

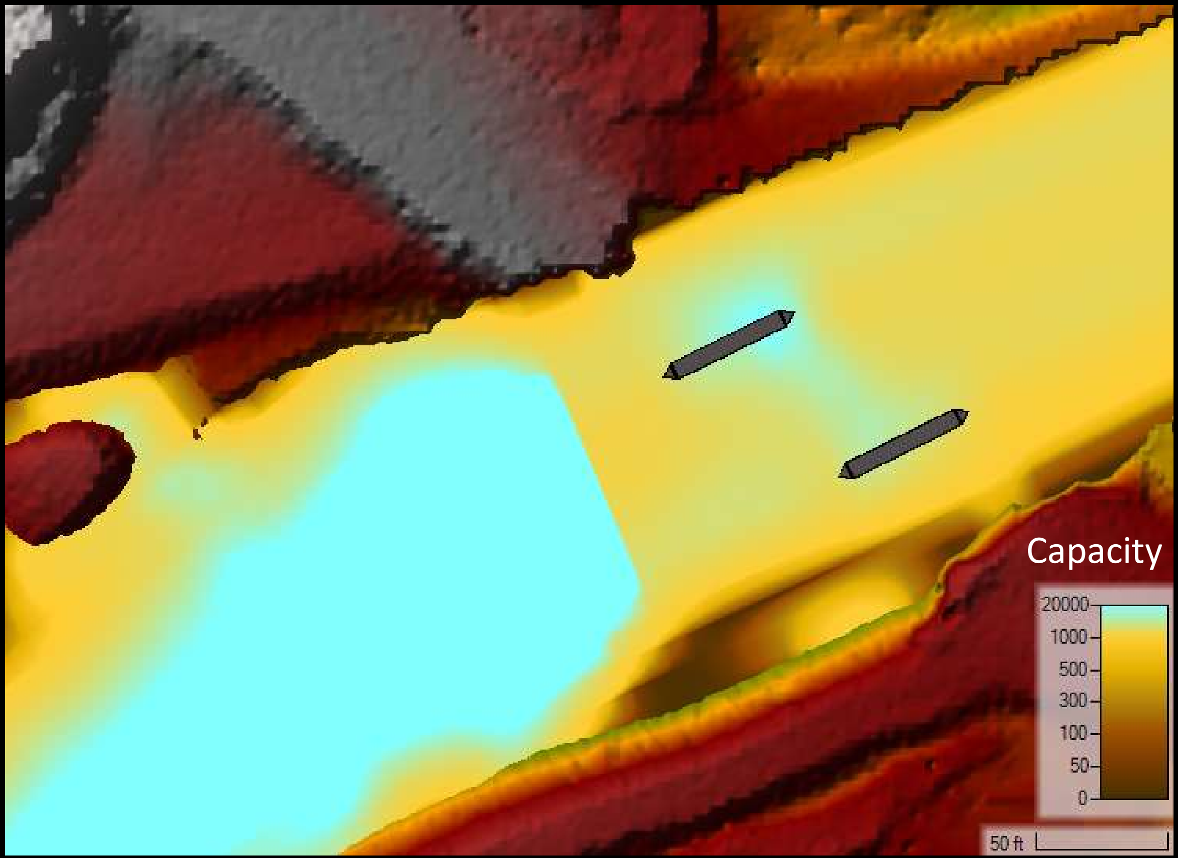




Fixed Bed Capacity Calculation



You can run 2D RAS as a fixed-bed capacity model by setting the morphological acceleration factor to zero



Making a Channel Mesh

Another use for the refinement region is around the main channel of a stream. Shown in Figure 3-10 is an example where a single refinement region was created for the entire main channel. By doing this, the user can control the cell size inside of the channel and ensure that cell faces are aligned with the high ground at the main channel banks. This approach ensure that flow does not spill out of the channel until the water is high enough to cross over the outer cell faces representing the high ground of the main channel bank lines. In addition to the refinement region, a break line was placed right down the center of the refinement region, following the path of the flow. The break line is used to align the cells in the middle of the channel with the direction of the flow. For the breakline in the example below, the number of near repeats was set to 4. For the refinement region, the near repeats was set to zero. Additionally, the option to "Enforce a 1 cell protection radius" was turned on for both the refinement region and the break line. Also, the break line was enforced after the refinement region. This combination of a refinement region and a break line down the center of the channel makes for a very nice channel mesh (Figure 3-10).

https://www.hec.usace.army.mil/confluence/rasdocs/r2dum/latest/development-of-a-2d-or-combined-1d-2d-model/development-of-the-2d-computational-mesh#id-.Developmentofthe2DComputationalMeshv6.0-MakingaChannelMesh