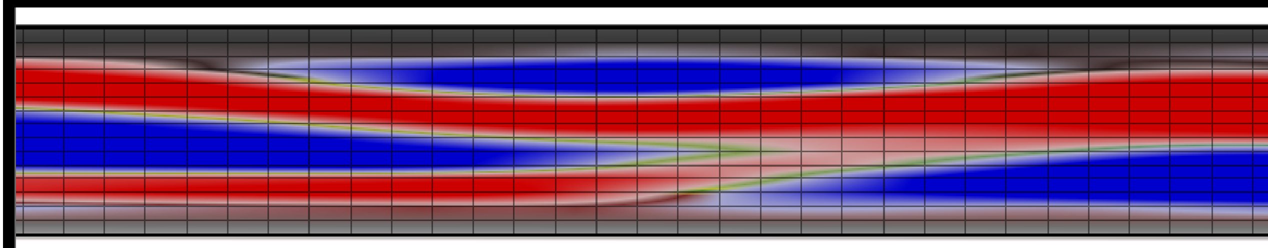
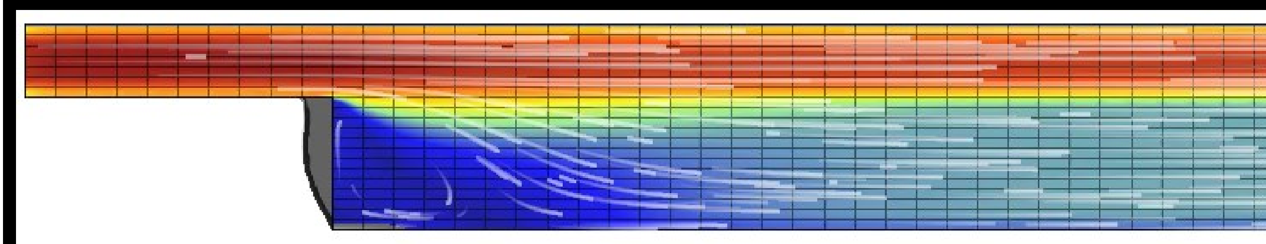
Hydraulic Best Practices for 2D HEC-RAS Sediment Models





Stanford Gibson,
Alex Sánchez, Cameron Ackerman

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Big Ideas

- Sediment transport amplifies hydraulic modeling errors (in 1D and 2D)
- Calibrate and refine your hydraulic model *before* you add sediment.

2

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

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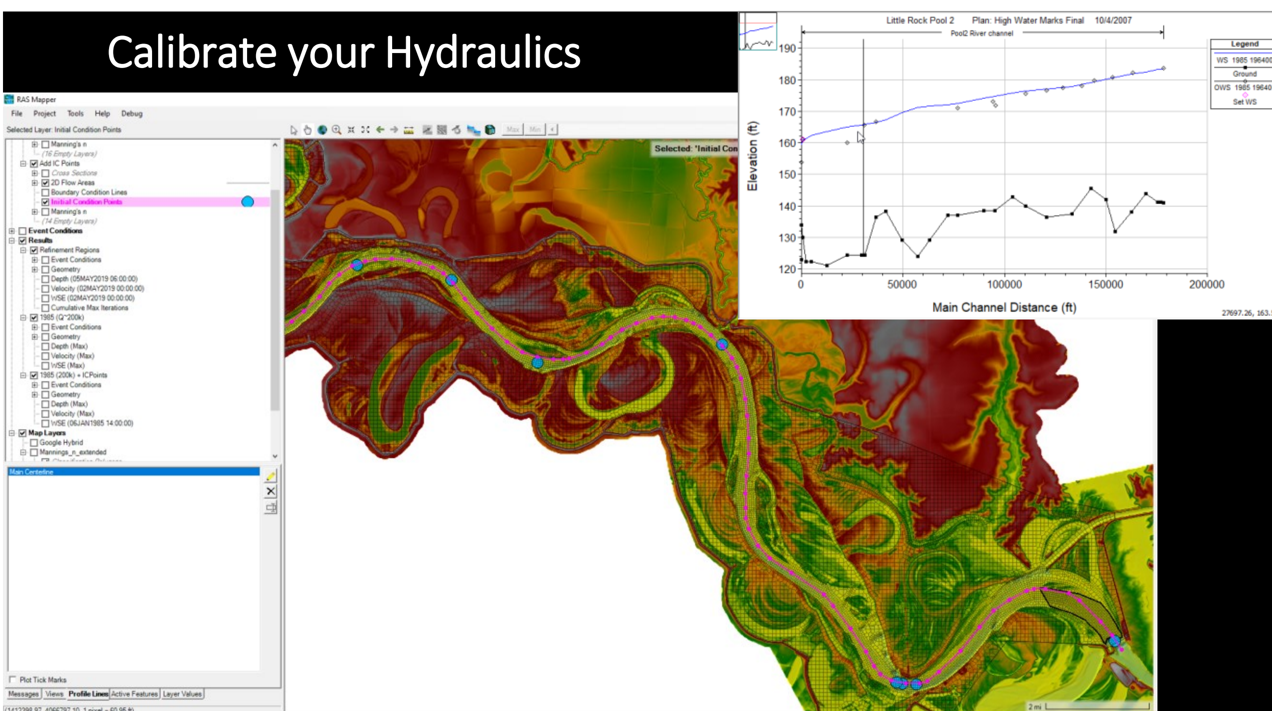
Calibrate your Hydraulics



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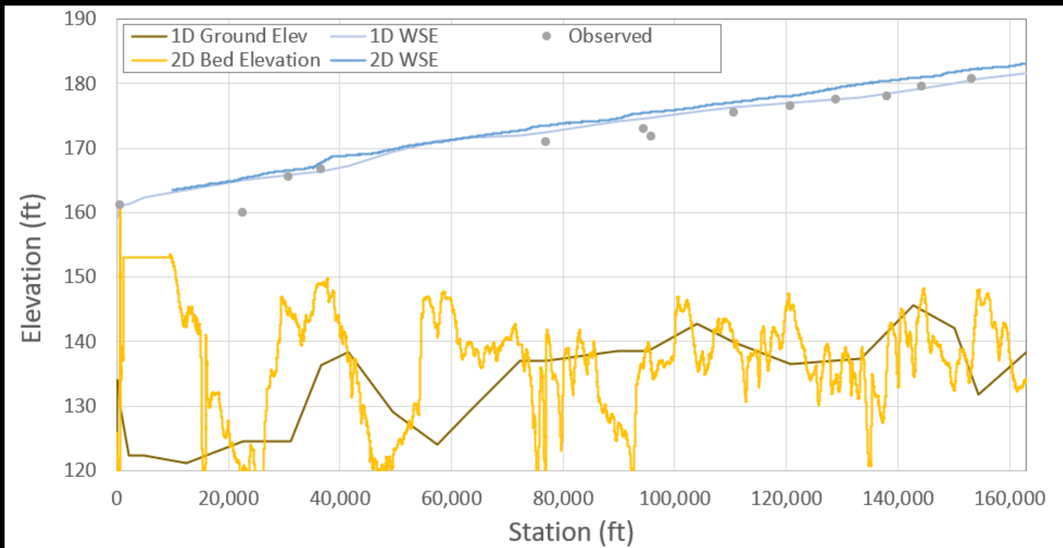
How Do You Calibrate 2D Hydraulics?



One Option is a Qusi-1D Calibration

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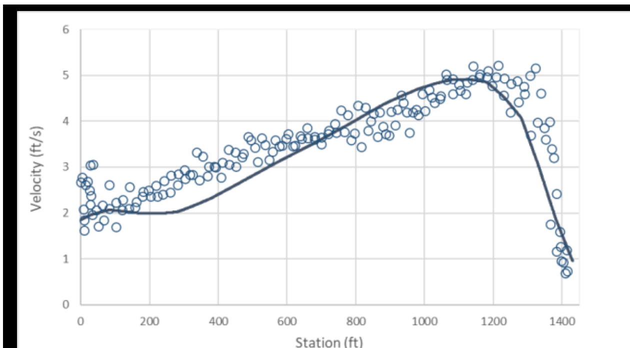
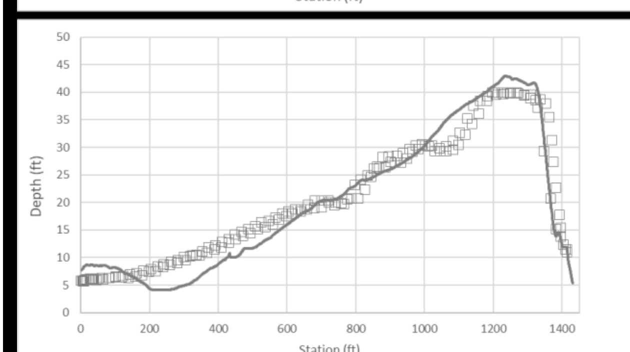
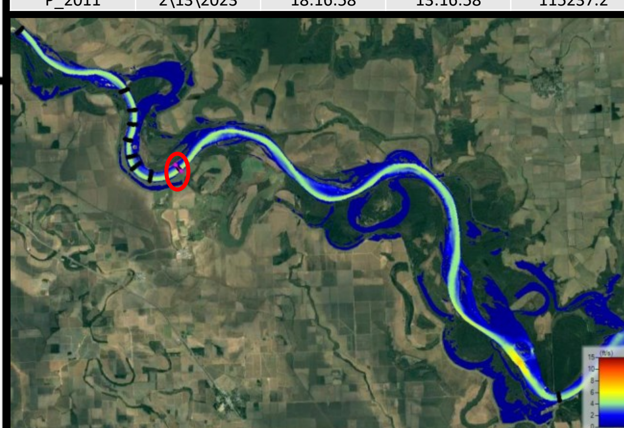
But a Lateral Depth and Velocity Calibration Can Improve Your 2D Sediment Model Performance Substantially





ID	Date	GMT	CMT	Flow (cfs)
P_2010	2\13\2023	18:12:53	13:12:53	115835
P_2011	2\13\2023	18:16:58	13:16:58	115237.2



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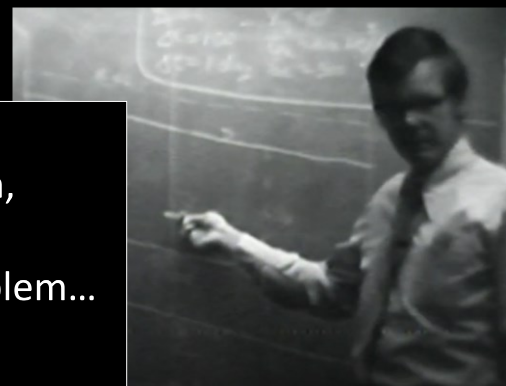
More on Calibration



"Often the available field data are not sufficient to permit a formal calibration, but computational modeling is still the best method for analyzing the problem…

The resulting studies are called *computational analysis studies*."

-Tony Thomas – ASCE Manual of Practice 110

If you don't calibrate a sediment model, it isn't one.

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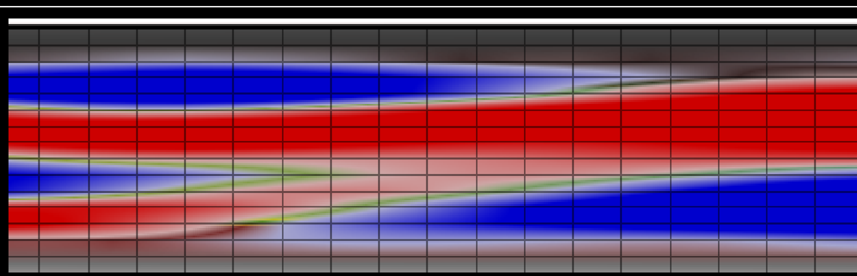
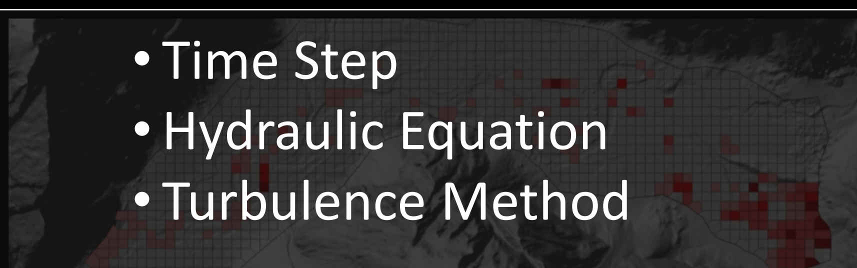
Hydraulic Model Quality Trouble Shooting

Best Practices



Diagnostics



- Time Step
- Hydraulic Equation
- Turbulence Method

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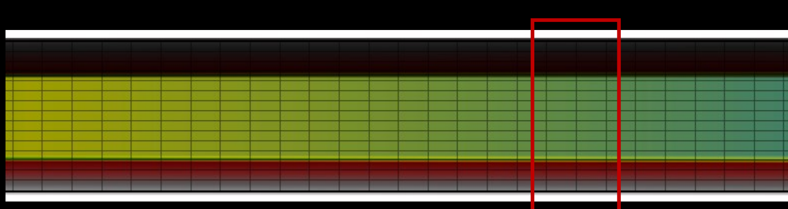
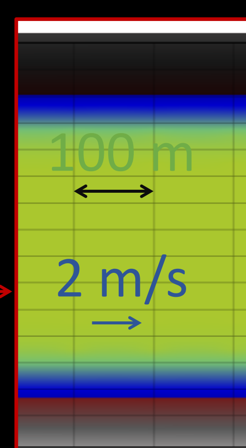
A 2D model has:

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?

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A 2D model has:

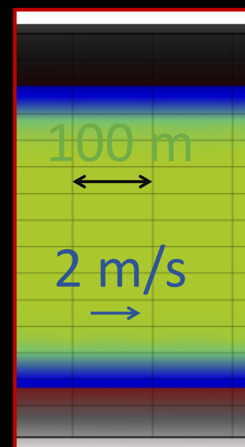
a regular cell size of 100m and
an average velocity of 2 m/s.

Hint:

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

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

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



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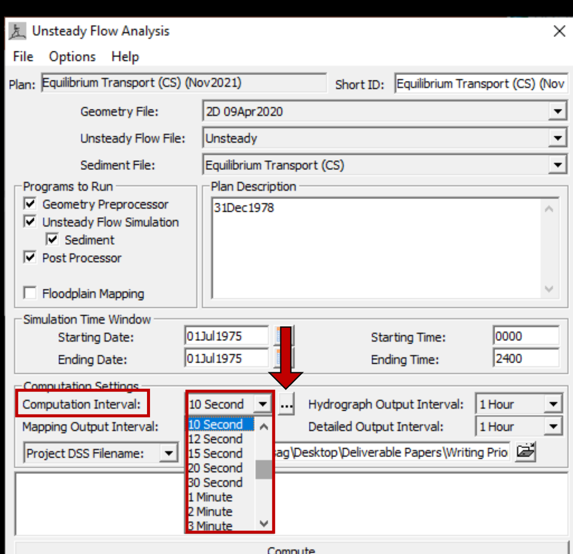
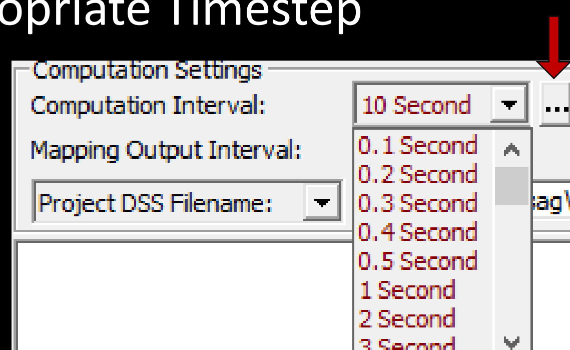
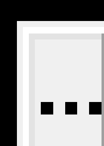
Selecting an Appropriate Timestep





Or….

…let RAS compute it



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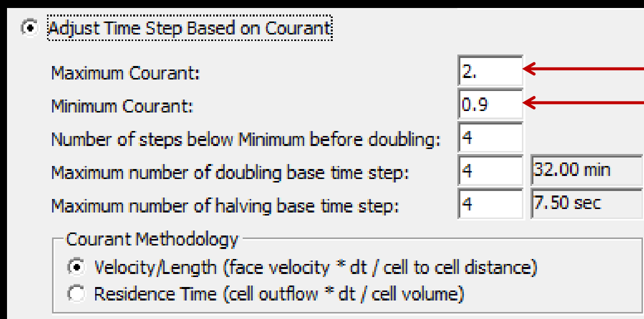
Selecting an Appropriate Timestep…

…Let RAS Do It



1,2,4

Just < Max/2

2-8

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

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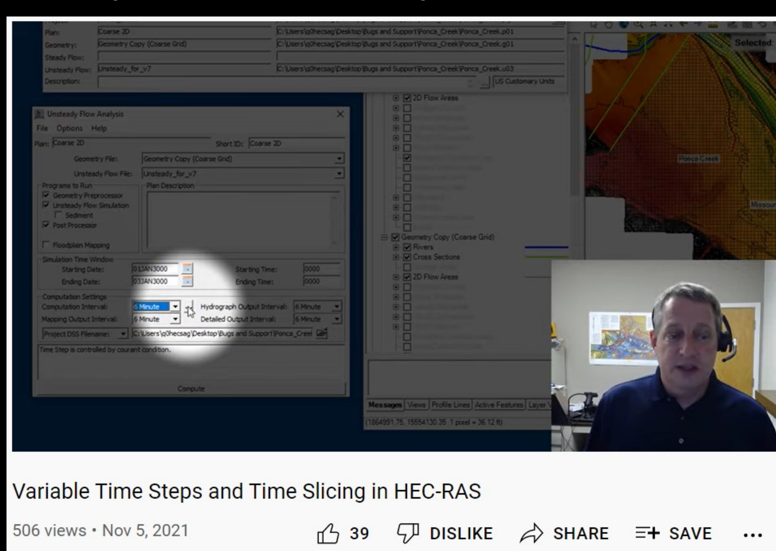
Adaptive Time Step Video Tutorial



https://youtu.be/kcBrOML3iS0

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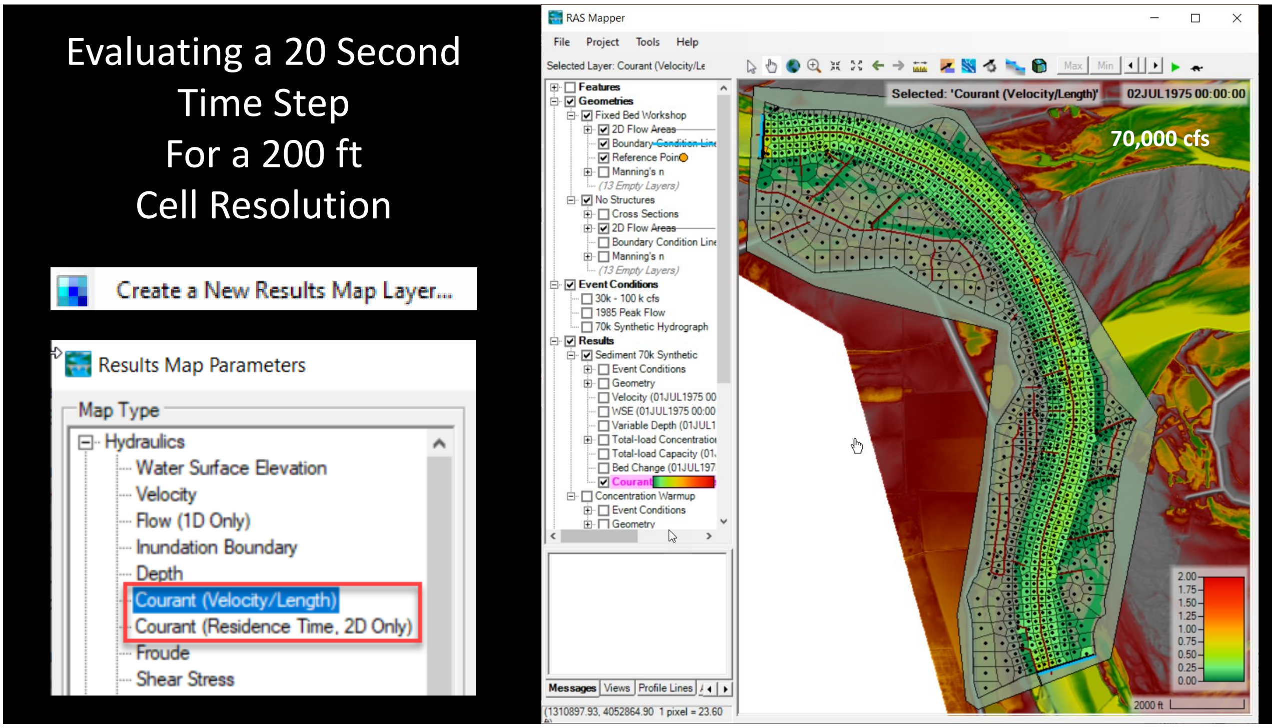
Evaluating a 20 Second
Time Step
For a 200 ft
Cell Resolution
Create a New Results Map Layer...
Results Map Parameters
Map Type
Hydraulics
Water Surface Elevation
Velocity
Flow (1D Only)
Inundation Boundary
Depth
Courant (Velocity/Length)
Courant (Residence Time, 2D Only)
Froude
Shear Stress
RAS Mapper
File Project Tools Help
Selected: 'Courant (Velocity/Length)'
02JUL1975 00:00:00
70,000 cfs
Features
Geometries
Fixed Bed Workshop
2D Flow Areas
Reference Point
Manning's n
No Structures
Cross Sections
2D Flow Areas
Boundary Condition Line
Manning's n
Event Conditions
30k - 100 k cfs
1985 Peak Flow
70k Synthetic Hydrograph
Results
Sediment 70k Synthetic
Event Conditions
Geometry
Total-load Concentration
Courant
Concentration Warmup
Event Conditions
Geometry
Messages Views Profile Lines
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
2000 ft

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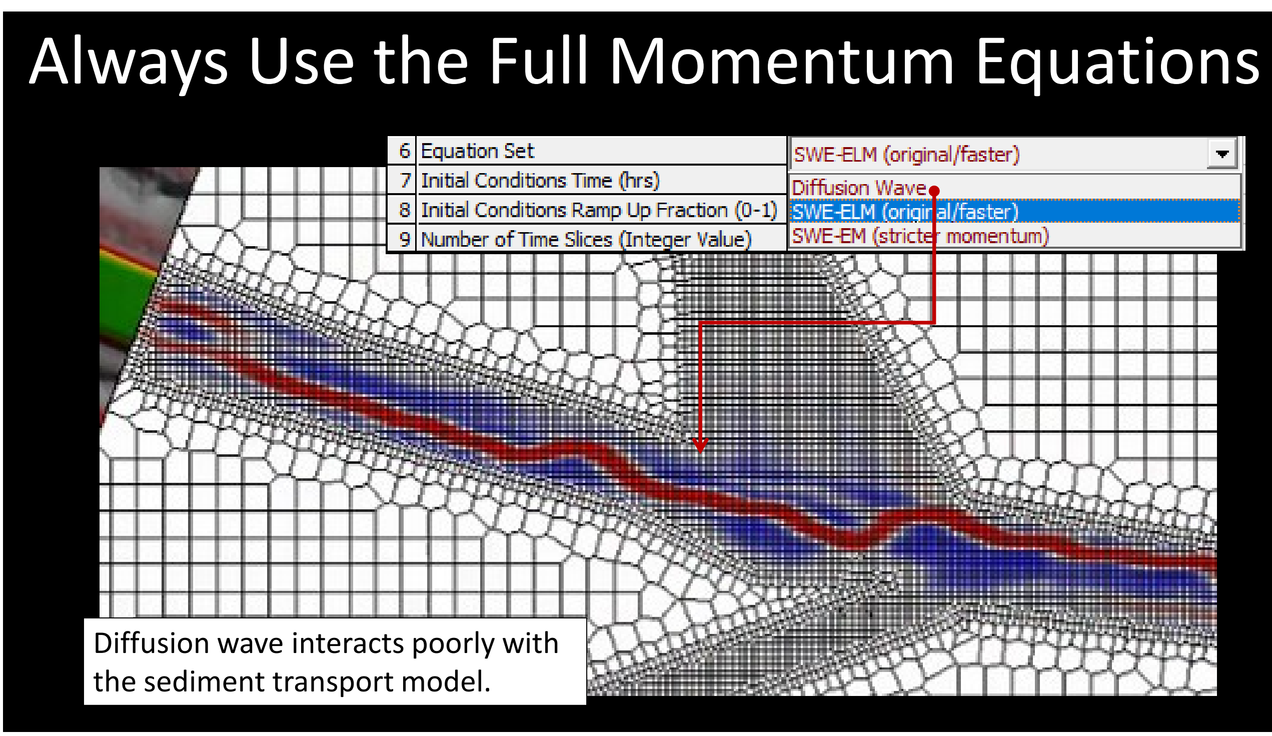
Always Use the Full Momentum Equations
6 Equation Set
7 Initial Conditions Time (hrs)
8 Initial Conditions Ramp Up Fraction (0-1)
9 Number of Time Slices (Integer Value)
SWE-ELM (original/faster)
Diffusion Wave
SWE-ELM (original/faster)
SWE-EM (stricter momentum)
Diffusion wave interacts poorly with
the sediment transport model.

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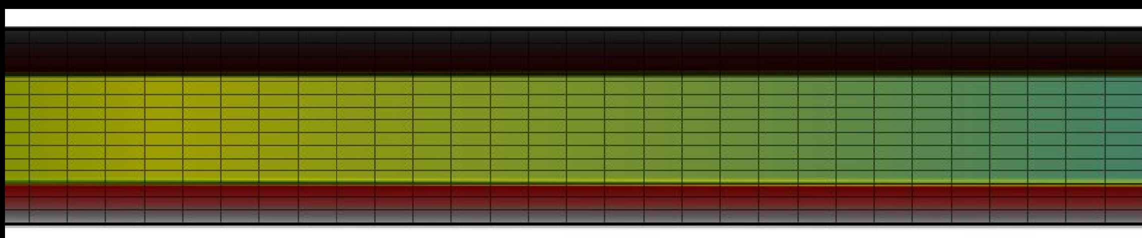
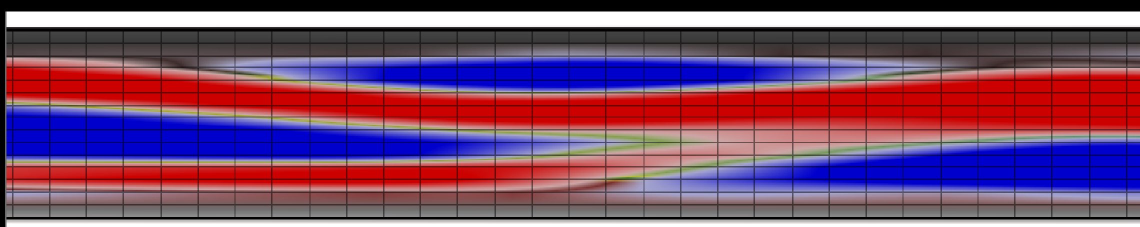
Always Use the Full Momentum Equations





Diffusion Wave Result

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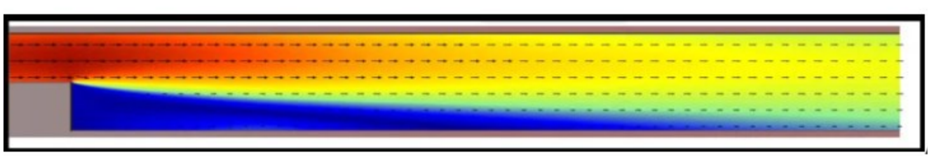
How does sediment transport laterally in RAS?
(Choose all that apply)



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

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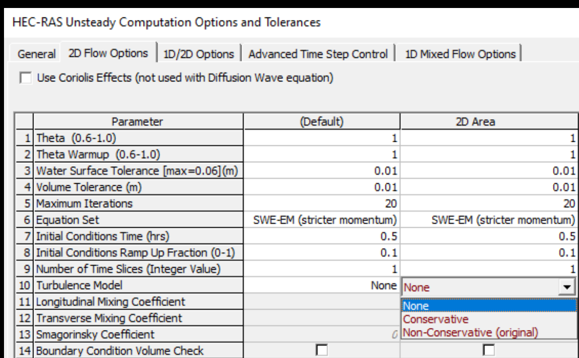
Turbulence Equations

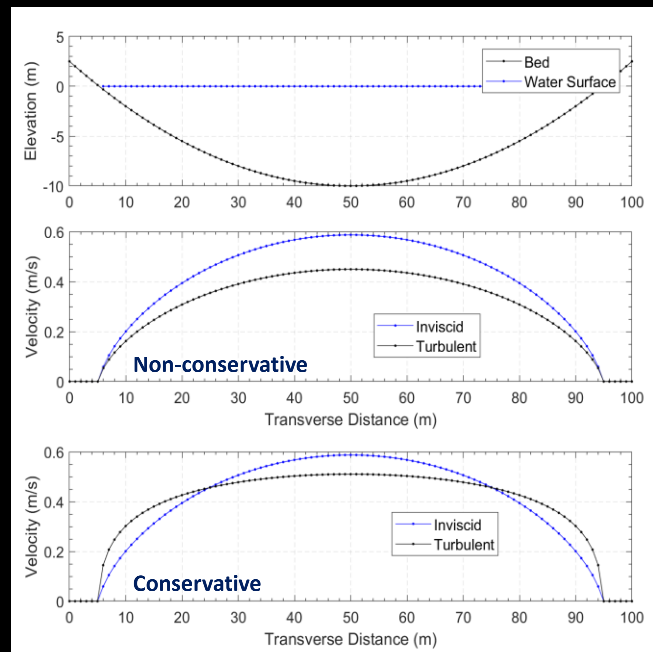


HEC-RAS Unsteady Computation Options and Tolerances

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	☐	☐



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Turbulence Equations

Turbulence and mixing are essentially diffusion terms.

<u>Non-Conservative</u>

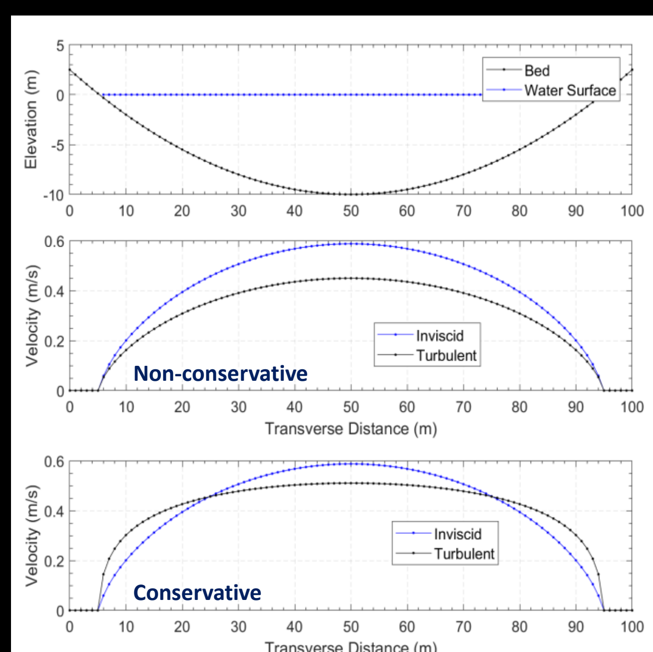
Assumes smoothly varying velocities (changes are gradual)
The eddy viscosity can come outside the derivative
But the spatial average drop – so this becomes a dissipation term not just a mixing term

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

<u>Conservative</u>

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)

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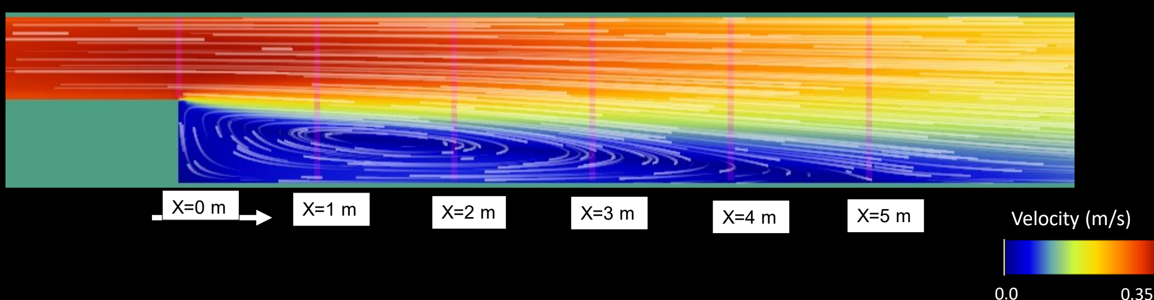
Example: Sudden Expansion Lab Experiment

- 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 $s/m^{1/3}$



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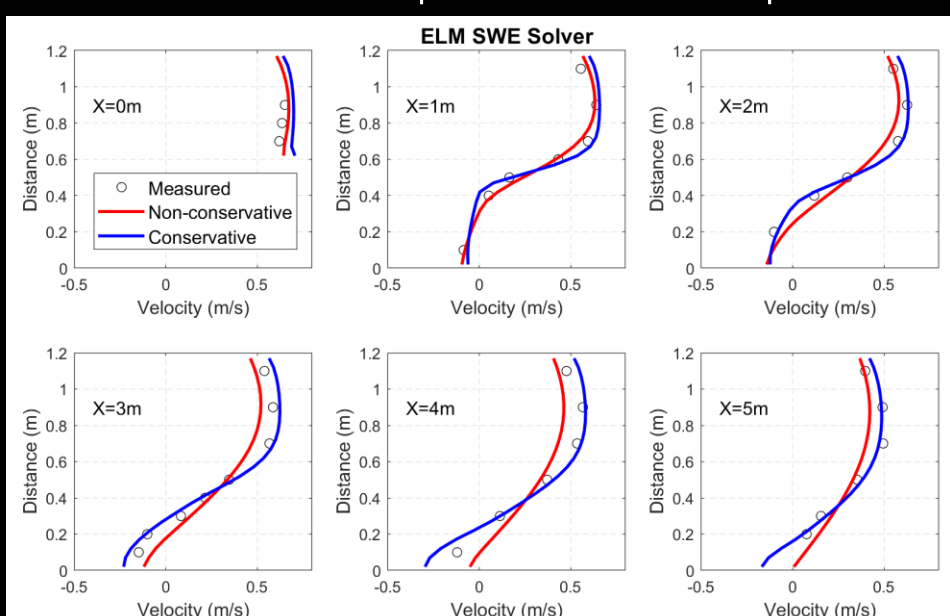
Results: Sudden Expansion Lab Experiment



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New Turbulence Approach in 6.0+

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

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

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

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

Anisotropic (D_L≠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)

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New Turbulence Approach in 6.0+

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

"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.

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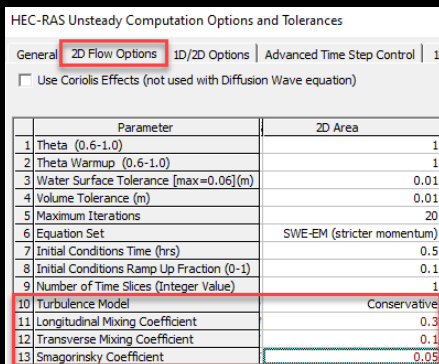
Turbulence Coefficients



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☐ Use Coriolis Effects (not used with Diffusion Wave equation)

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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 ~ 2-4 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.

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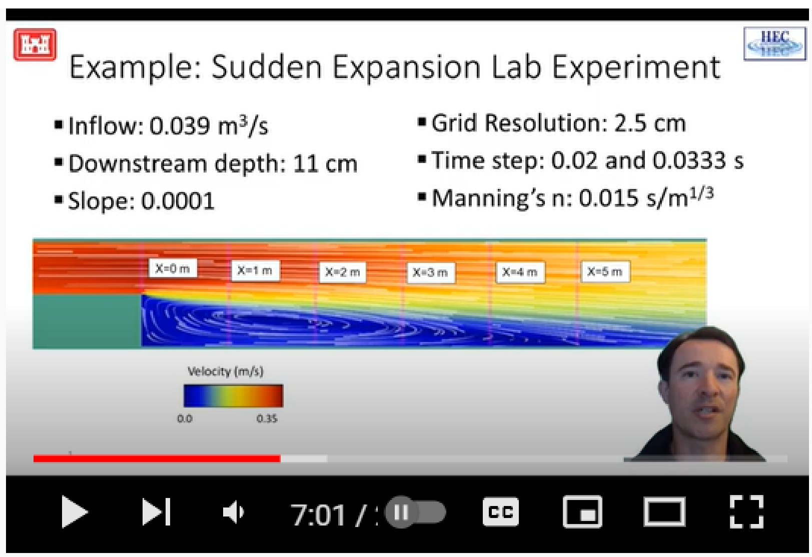
Turbulence Method



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

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

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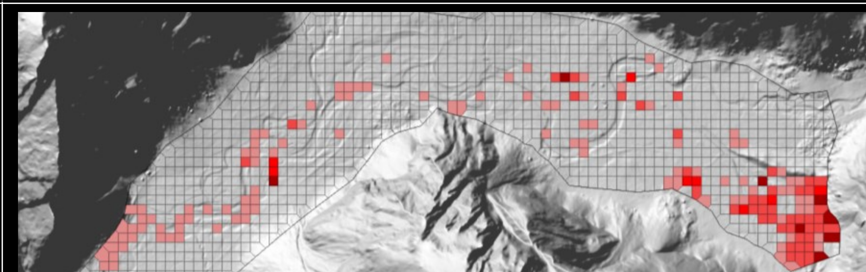
Hydraulic Model Quality Trouble Shooting

Best Practices	
Diagnostics	

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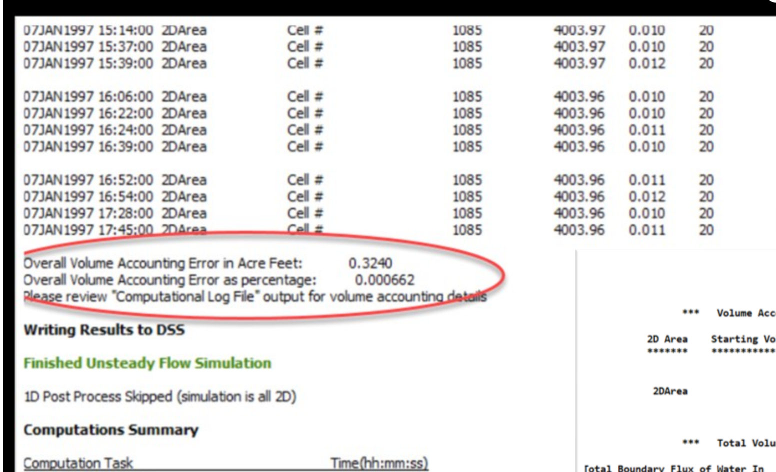
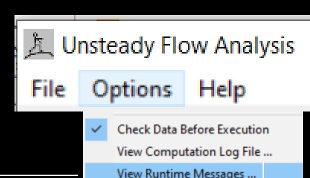
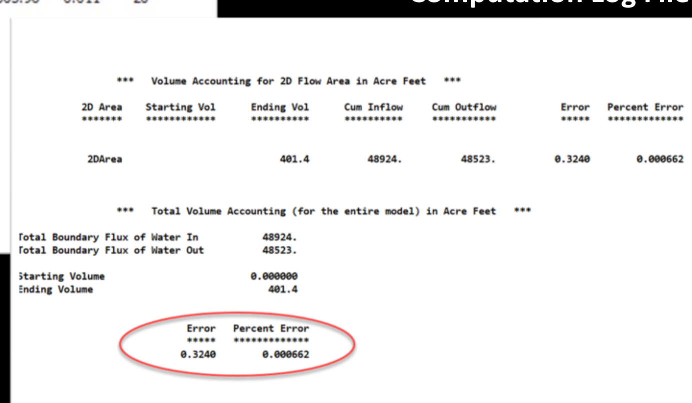
Volume Accounting Check





Computation Log File



Runtime Messages

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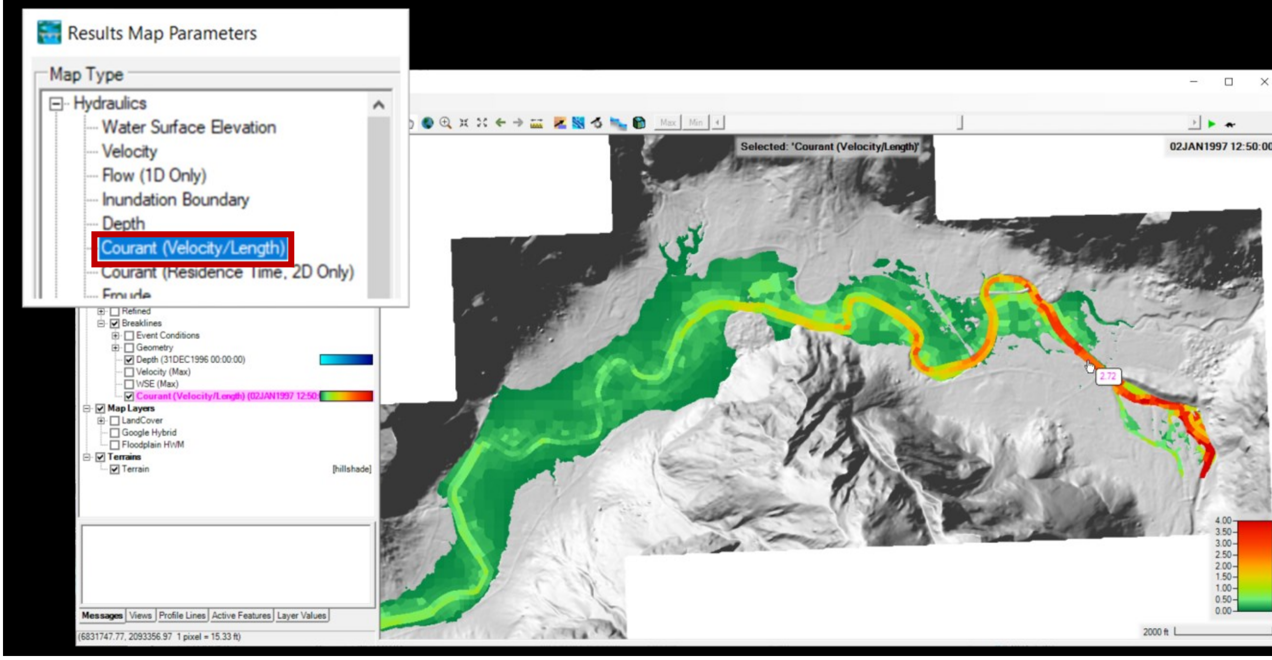
RAS Mapper Courant Number Map



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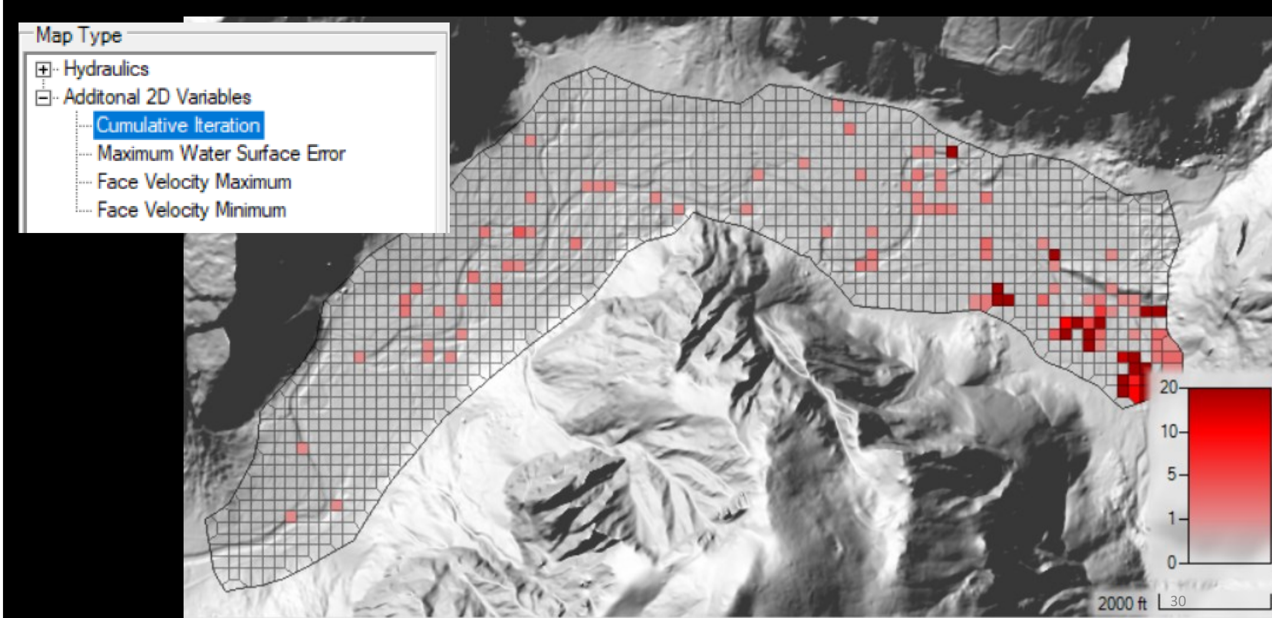
Cumulative Iterations



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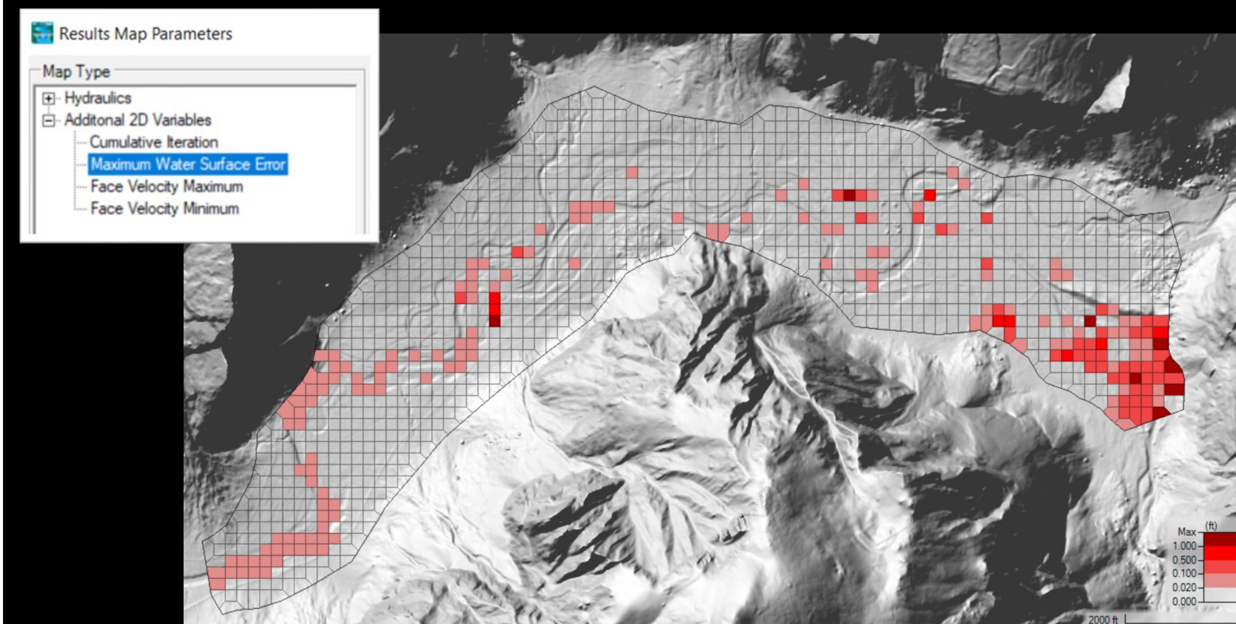
Maximum Water Surface Error



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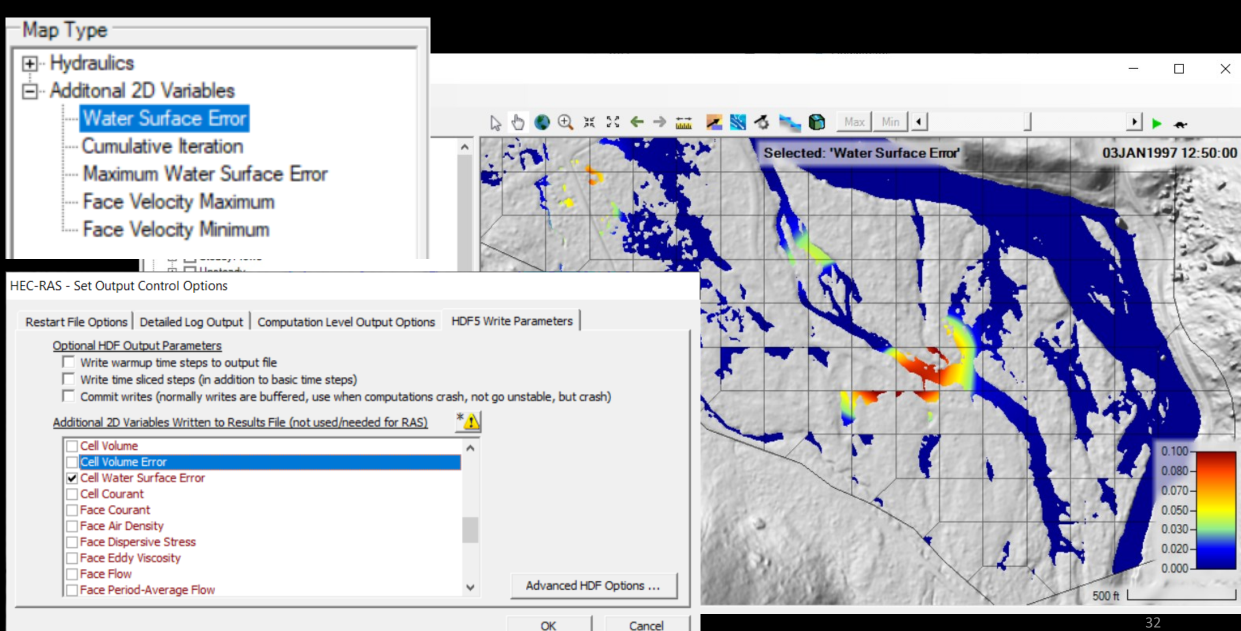
Cell Water Surface Error (For each time step)



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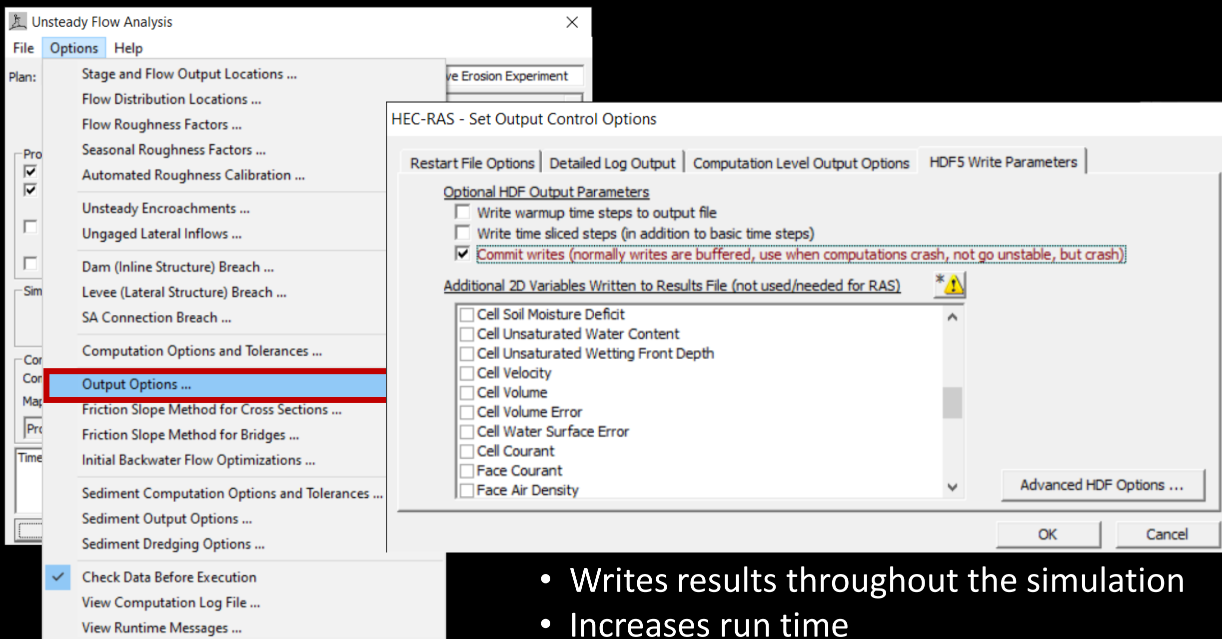
Write Intermediate Results Before a Crash



- Writes results throughout the simulation
- Increases run time

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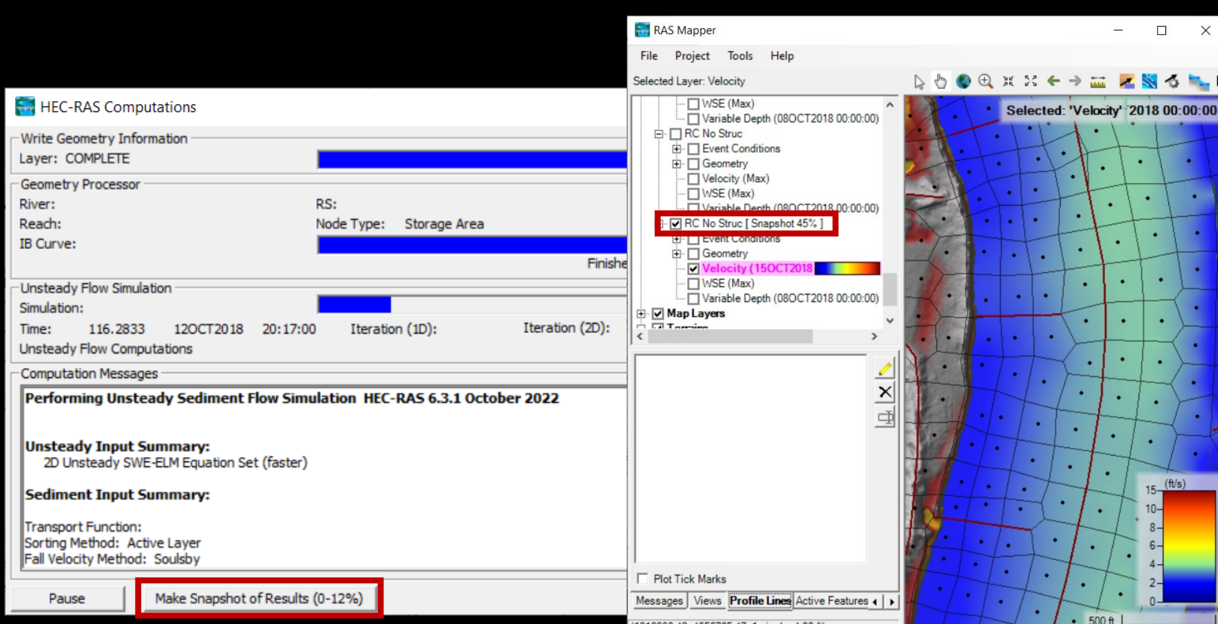
Snapshots



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