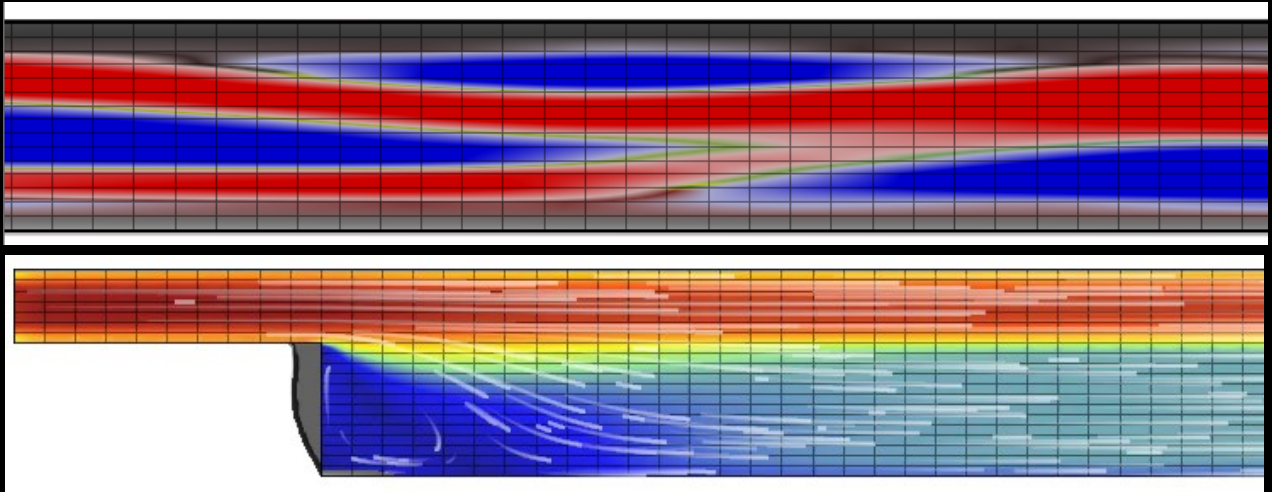


## Hydraulic Best Practices for 2D HEC-RAS Sediment Models



Stanford Gibson,  
Alex Sánchez, Cameron Ackerman

1

### Big Ideas

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

2

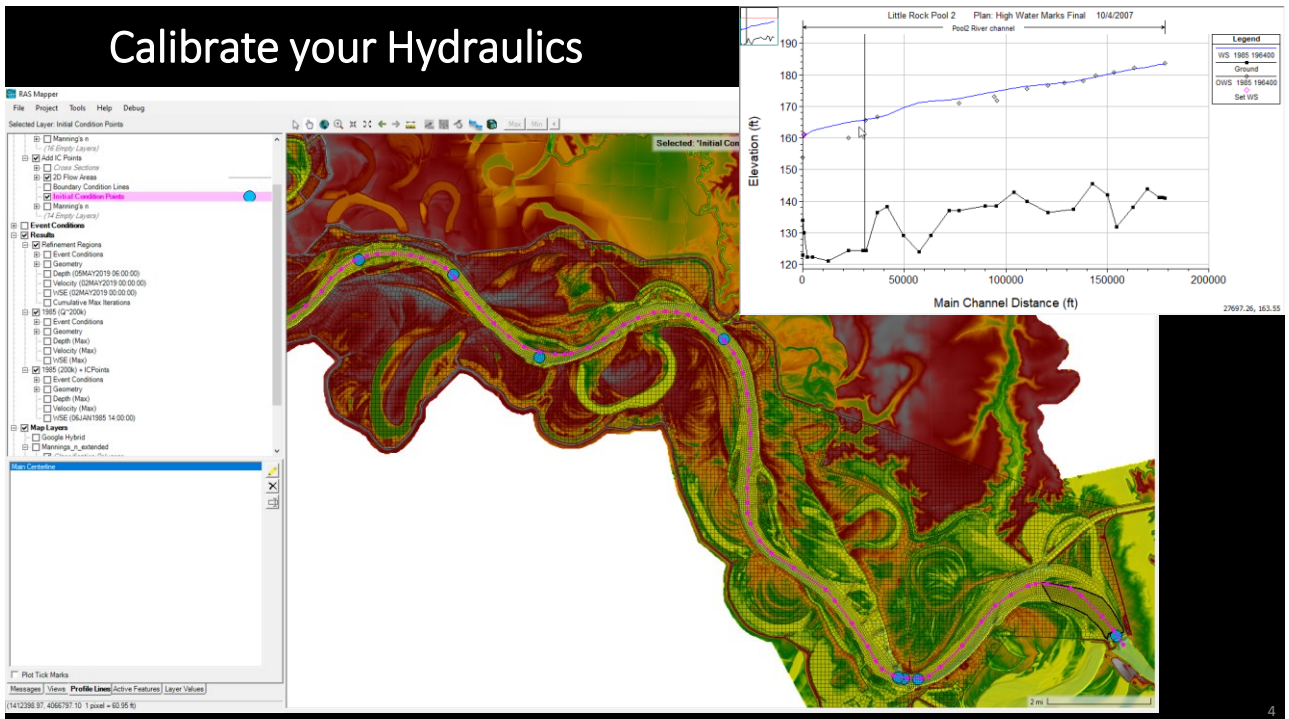
# Big Ideas

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

## Stages of Sediment Calibration

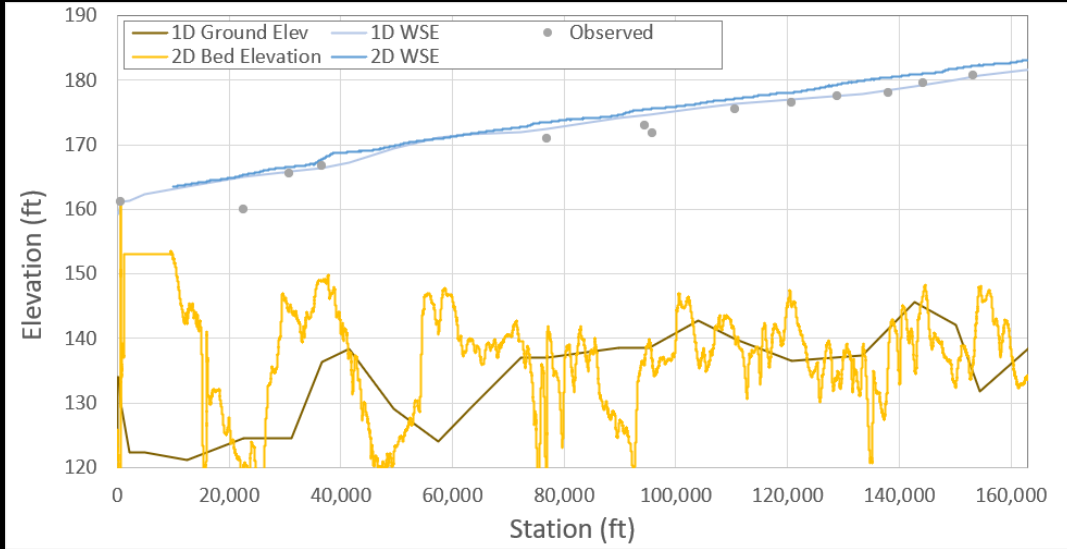
	Flow	Bed Elevation
Stage 1: Hydraulic Calibration	Variable	Fixed
Stage 2: Steady Flow Mobile Bed Analysis	Fixed	Variable
Stage 3: Dynamic Calibration	Variable	Variable
If Possible:		
Stage 4: "Validation" (Multiple Time Series Analysis)	Variable	Variable

3



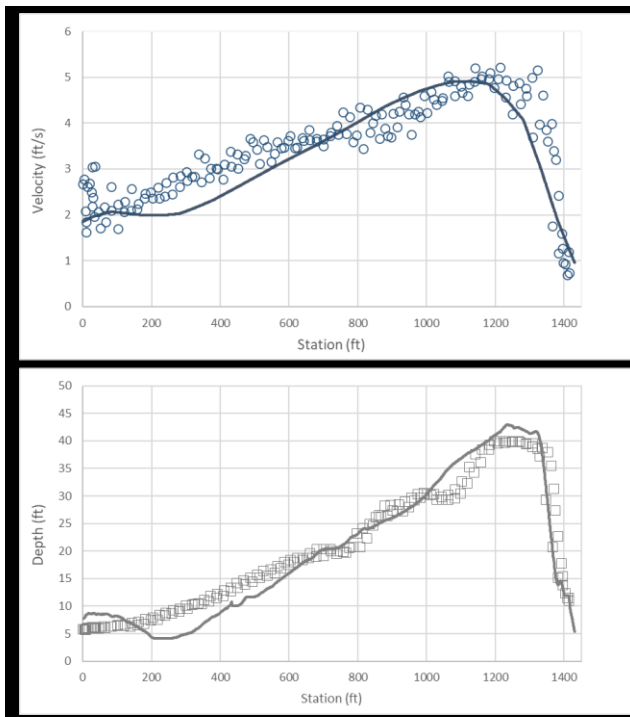
4

## How Do You Calibrate 2D Hydraulics?



One Option is a Qusi-1D Calibration

5



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



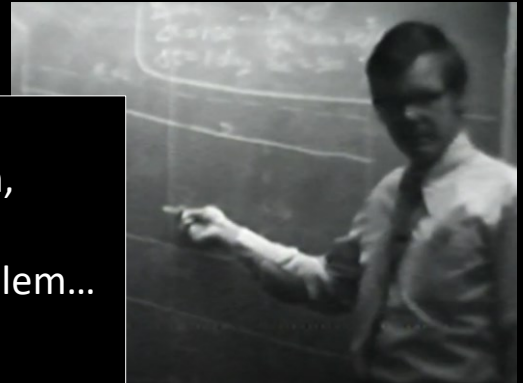
6

## 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

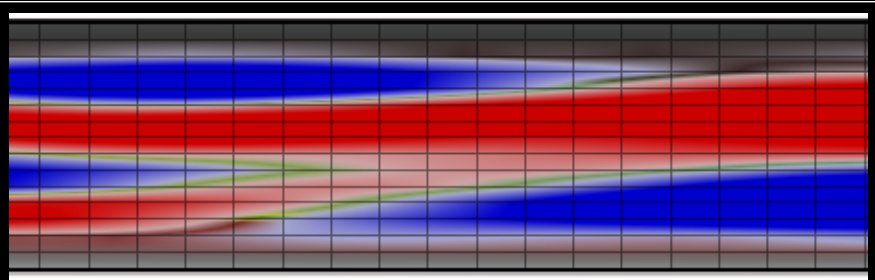


**If you don't calibrate a sediment model, it isn't one.**

7

## Hydraulic Model Quality Trouble Shooting

**Best Practices**



**Diagnostics**

- Time Step
- Hydraulic Equation
- Turbulence Method

8

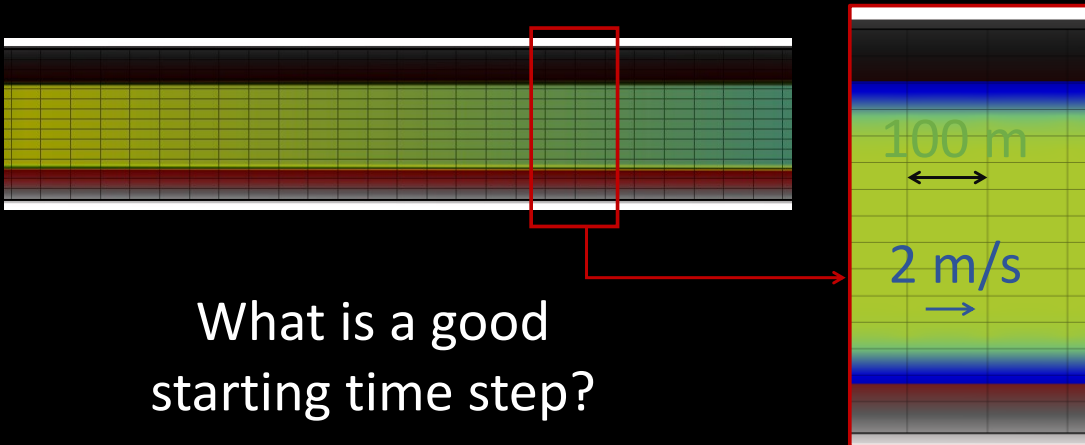


9

A 2D model has:  
a regular cell size of 100m and  
an average velocity of 2 m/s.

Hint:

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



10

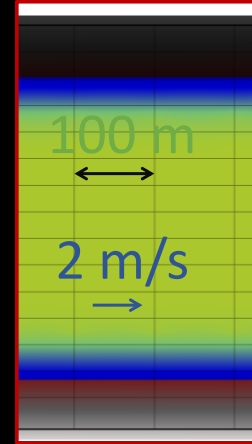
A 2D model has:  
 a regular cell size of **100m** and  
 an average velocity of **2 m/s**.

Hint:

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

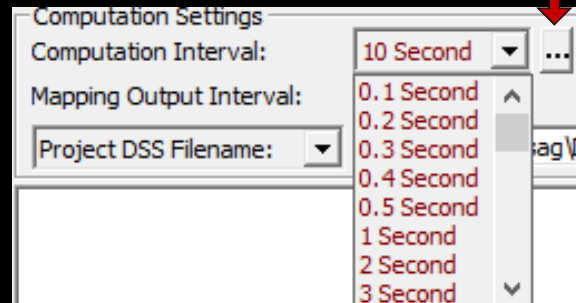
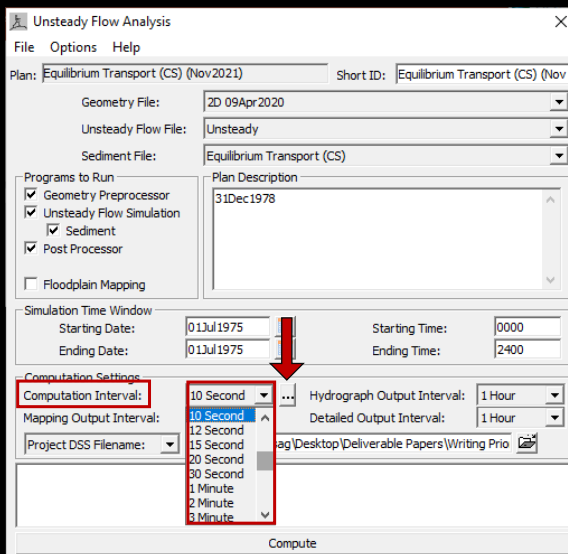
$$\Delta t = \frac{\Delta x C}{V}$$

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



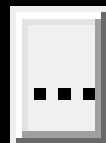
11

## Selecting an Appropriate Timestep



Or....

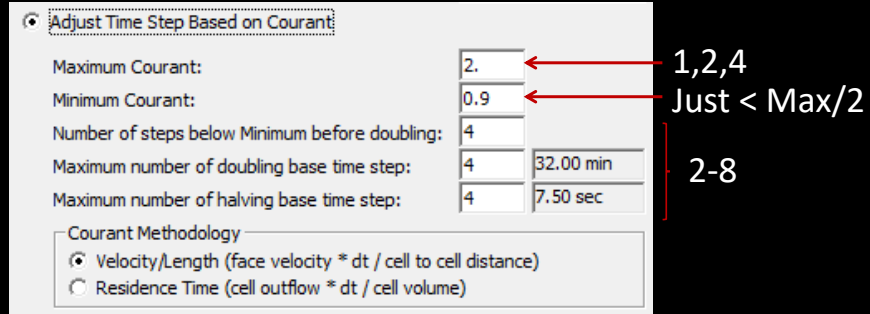
...let RAS compute it



12

# Selecting an Appropriate Timestep...

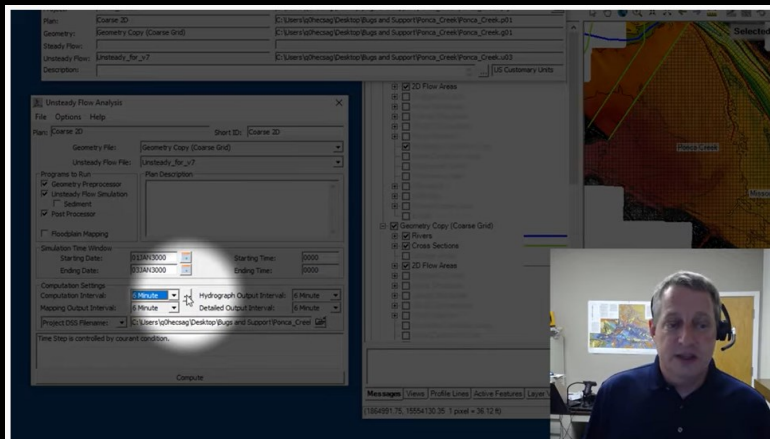
...Let RAS Do It



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

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# 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>

14



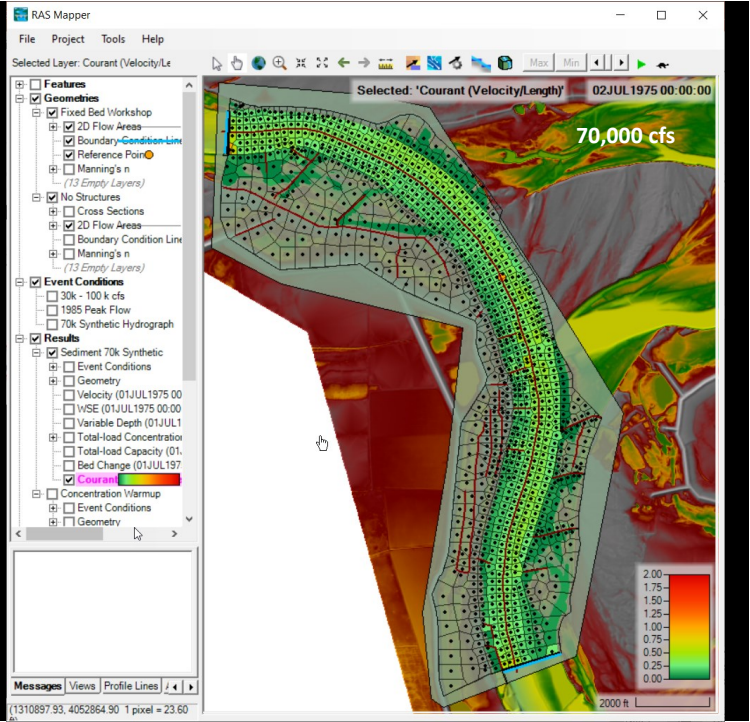
# Evaluating a 20 Second Time Step For a 200 ft Cell Resolution

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



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# Always Use the Full Momentum Equations

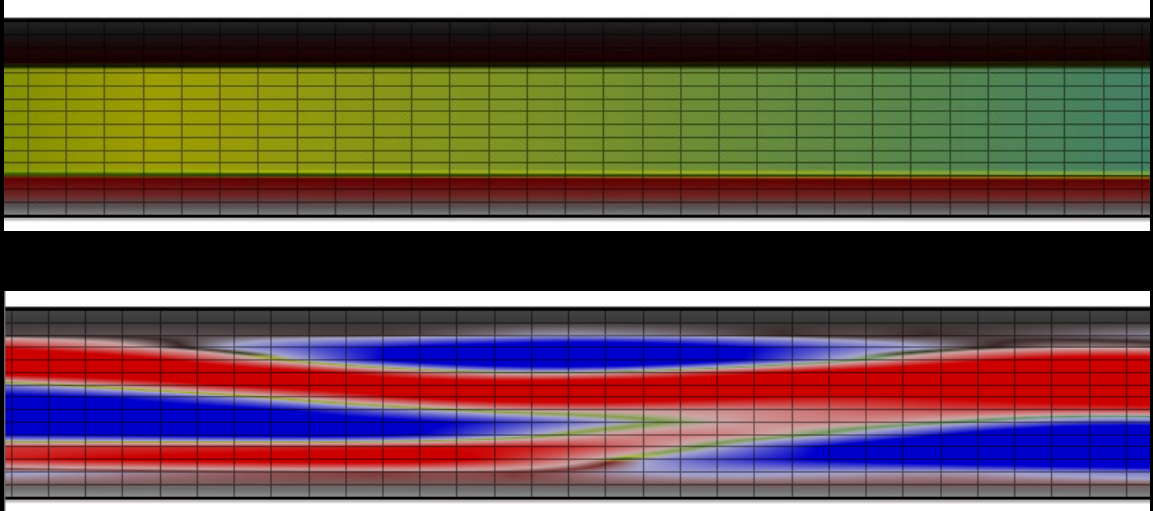
6 Equation Set	SWE-ELM (original/faster)
7 Initial Conditions Time (hrs)	Diffusion Wave
8 Initial Conditions Ramp Up Fraction (0-1)	SWE-ELM (original/faster)
9 Number of Time Slices (Integer Value)	SWE-EM (stricter momentum)

Diffusion wave interacts poorly with the sediment transport model.

16



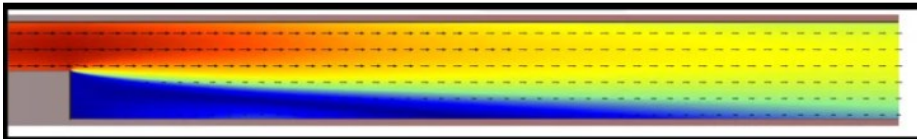
# Always Use the Full Momentum Equations



Diffusion Wave Result

17

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



Turbulence and mixing

Numerical Dispersion

Sediment Diffusion

Muskrat Metabolism

18

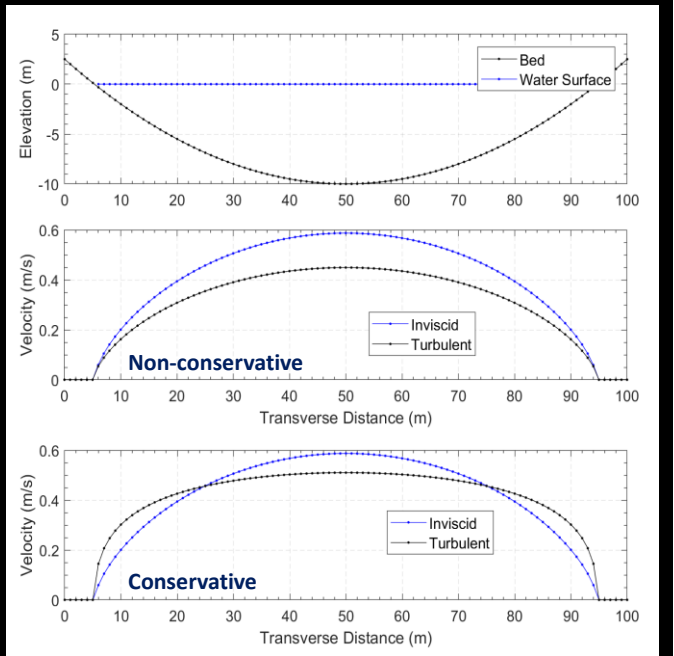
# Turbulence Equations

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=0.05](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	<input type="checkbox"/>	<input type="checkbox"/>



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# Turbulence Equations

Turbulence and mixing are essentially diffusion terms.

## Non-Conservative

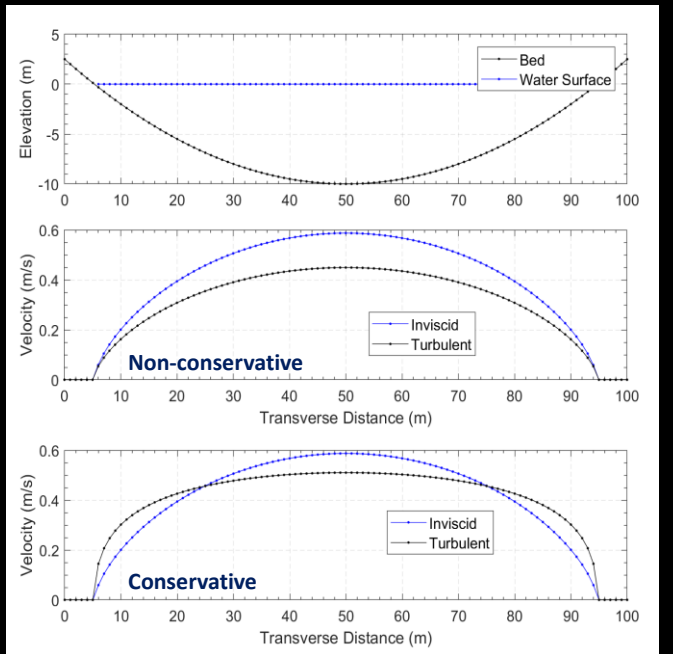
Assumes smoothly varying velocities (changes are gradual)  
 The eddy viscosity can come outside the derivative  
 But the spatial average drop – so this becomes a dissipation term not just a mixing term

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

## 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

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

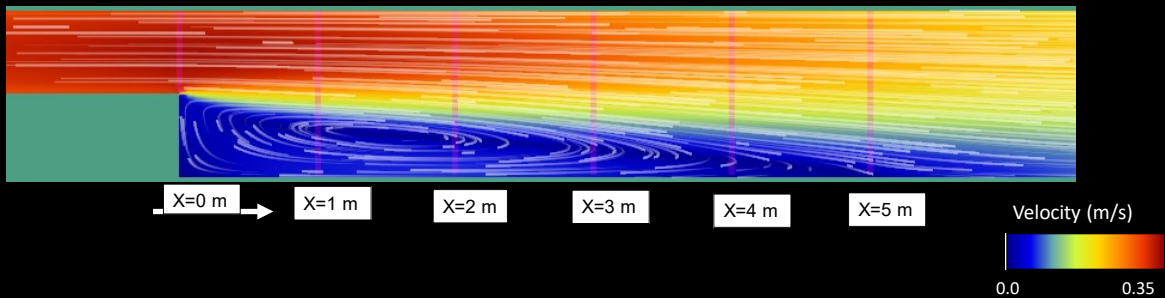


(Note: Equations one-dimensionalized for simplicity)

20

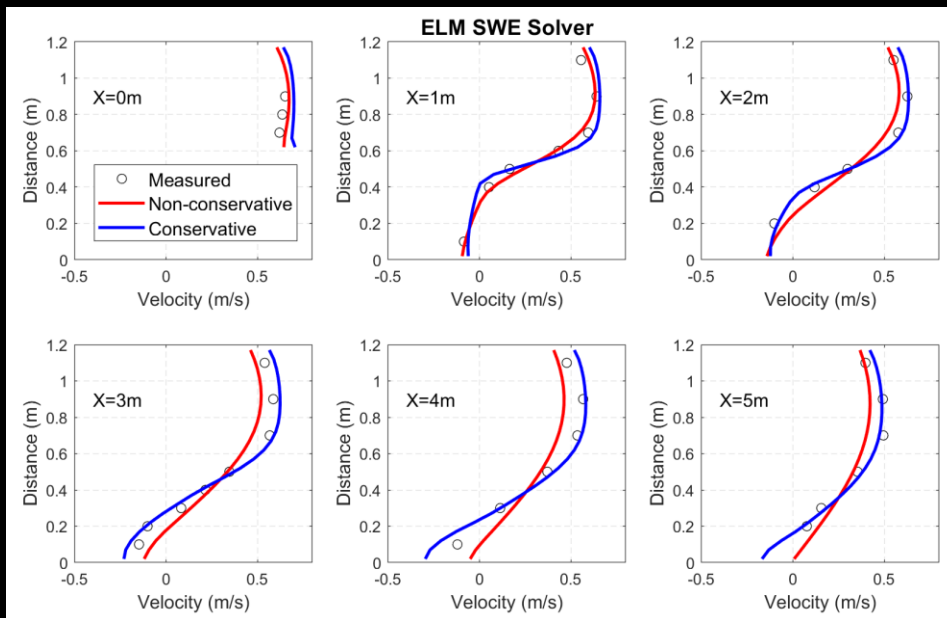
## Example: Sudden Expansion Lab Experiment

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



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## Results: Sudden Expansion Lab Experiment



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## New Turbulence Approach in 6.0+

### Old Method: Parabolic

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

$$v_t = Du_*h$$

### New Method: Parabolic-Smagorinsky

Anisotropic ( $D_L \neq D_T$ )  
 Sensitive to Roughness  
 Sensitive to cell size ( $\Delta$ )

(As cell size decreases more of the sub-cell dispersion is accounted for explicitly, and the Smagorinsky term drops out)

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

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

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

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

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## New Turbulence Approach in 6.0+

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

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

### “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

HEC-RAS Unsteady Computation Options and Tolerances

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

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

- $D_L \sim 2-4 D_T$
- 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.

25

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# Turbulence Method

Example: Sudden Expansion Lab Experiment

HEC-RAS

- Inflow: 0.039 m<sup>3</sup>/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<sup>1/3</sup>

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

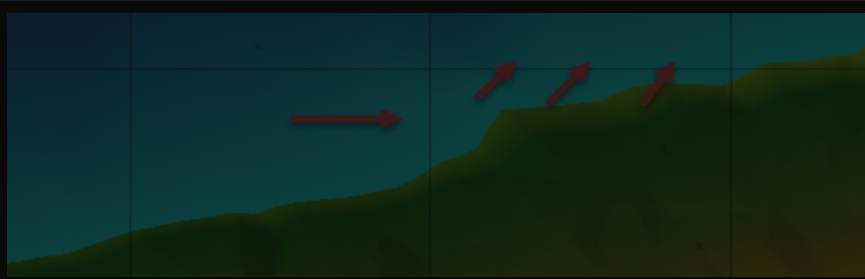
HEC-RAS 2D Class: 2.10 - Advanced Computation Options

26

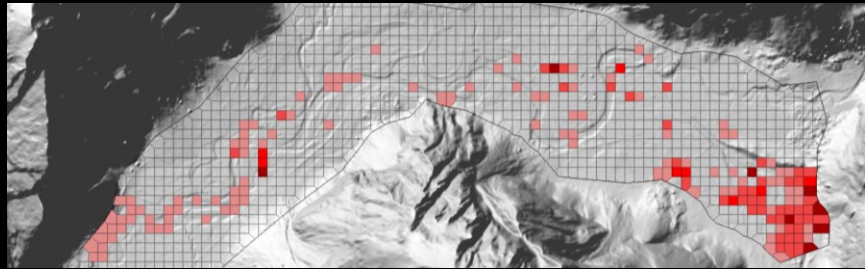


# Hydraulic Model Quality Trouble Shooting

Best Practices



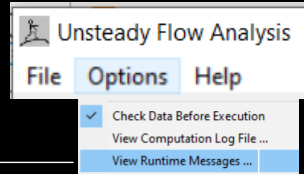
Diagnostics



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## Volume Accounting Check

07JAN1997 15:14:00	2DArea	Cell #	1085	4003.97	0.010	20
07JAN1997 15:37:00	2DArea	Cell #	1085	4003.97	0.010	20
07JAN1997 15:39:00	2DArea	Cell #	1085	4003.97	0.012	20
07JAN1997 16:06:00	2DArea	Cell #	1085	4003.96	0.010	20
07JAN1997 16:22:00	2DArea	Cell #	1085	4003.96	0.010	20
07JAN1997 16:24:00	2DArea	Cell #	1085	4003.96	0.011	20
07JAN1997 16:39:00	2DArea	Cell #	1085	4003.96	0.010	20
07JAN1997 16:52:00	2DArea	Cell #	1085	4003.96	0.011	20
07JAN1997 16:54:00	2DArea	Cell #	1085	4003.96	0.012	20
07JAN1997 17:28:00	2DArea	Cell #	1085	4003.96	0.010	20
07JAN1997 17:45:00	2DArea	Cell #	1085	4003.96	0.011	20



Computation Log File

Overall Volume Accounting Error in Acre Feet: 0.3240  
 Overall Volume Accounting Error as percentage: 0.000662  
 Please review "Computational Log File" output for volume accounting details

Writing Results to DSS  
 Finished Unsteady Flow Simulation  
 1D Post Process Skipped (simulation is all 2D)  
 Computations Summary

```

*** Volume Accounting for 2D Flow Area in Acre Feet ***
2D Area Starting Vol Ending Vol Cum Inflow Cum Outflow Error Percent Error
*****
2DArea 401.4 48924. 48523. 0.3240 0.000662

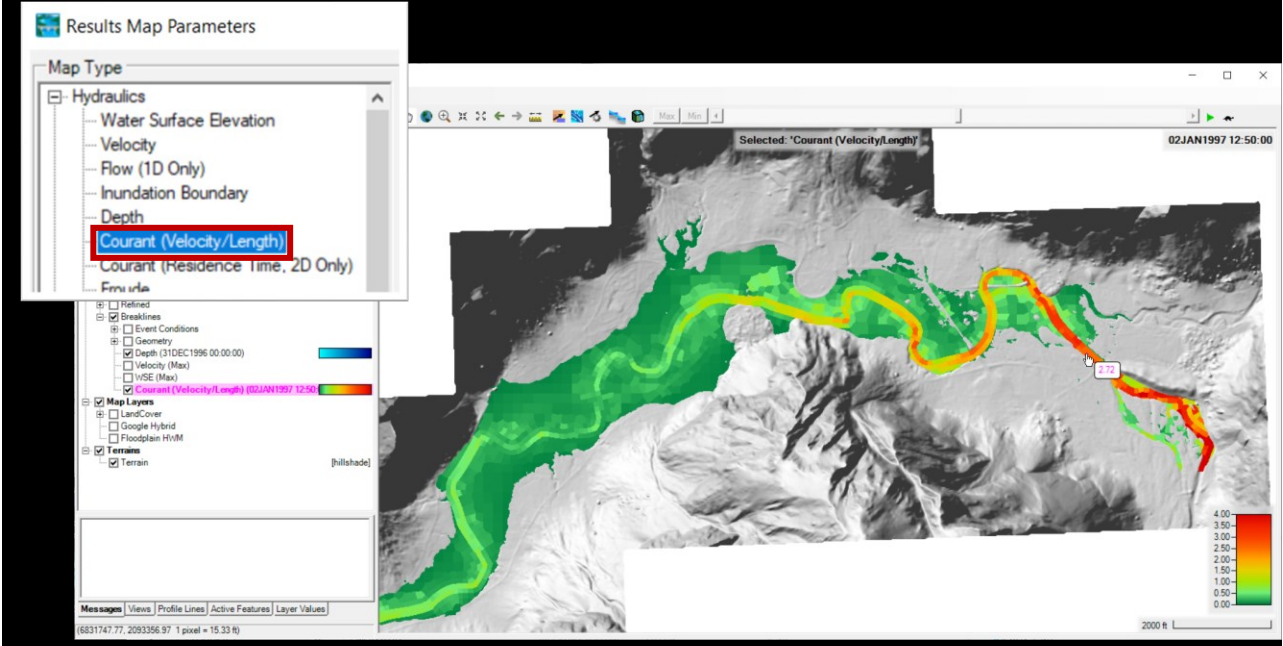
*** Total Volume Accounting (for the entire model) in Acre Feet ***
Total Boundary Flux of Water In 48924.
Total Boundary Flux of Water Out 48523.
Starting Volume 0.000000
Ending Volume 401.4

Error Percent Error
****
0.3240 0.000662
    
```

Runtime Messages

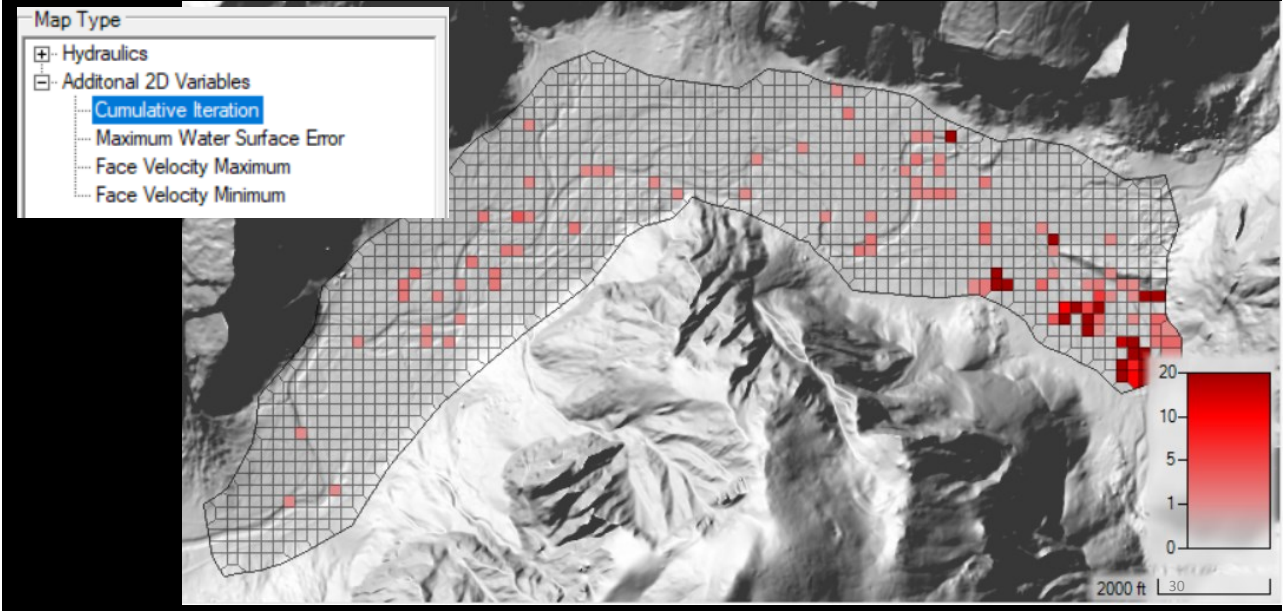
28

# RAS Mapper Courant Number Map



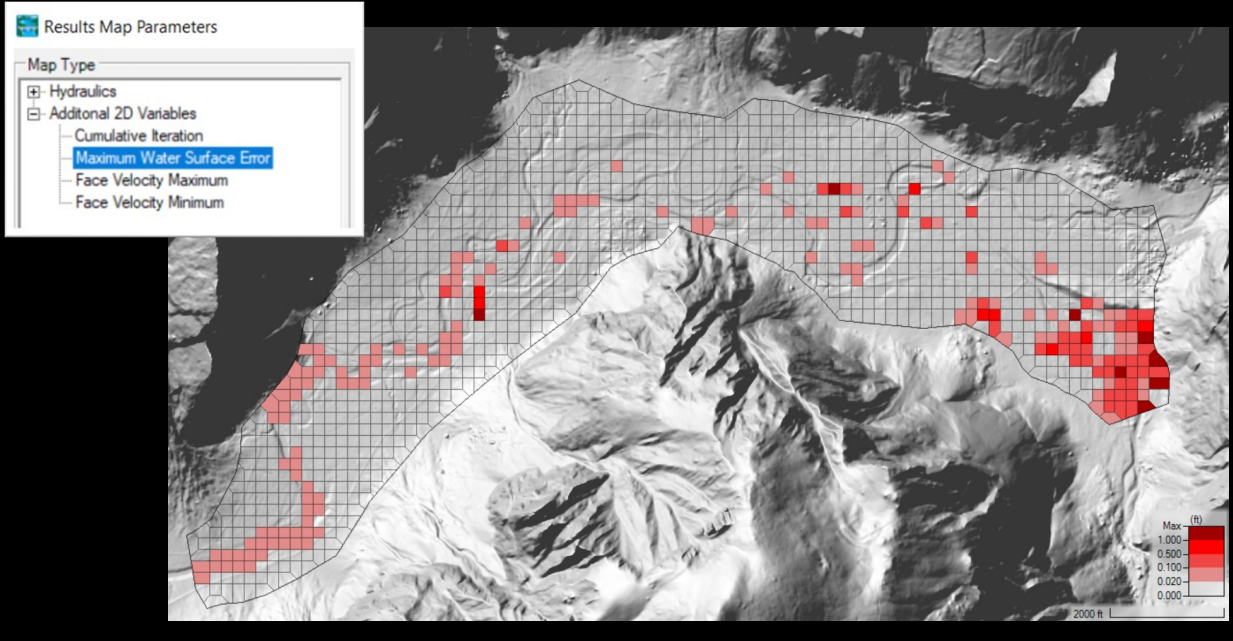
29

# Cumulative Iterations



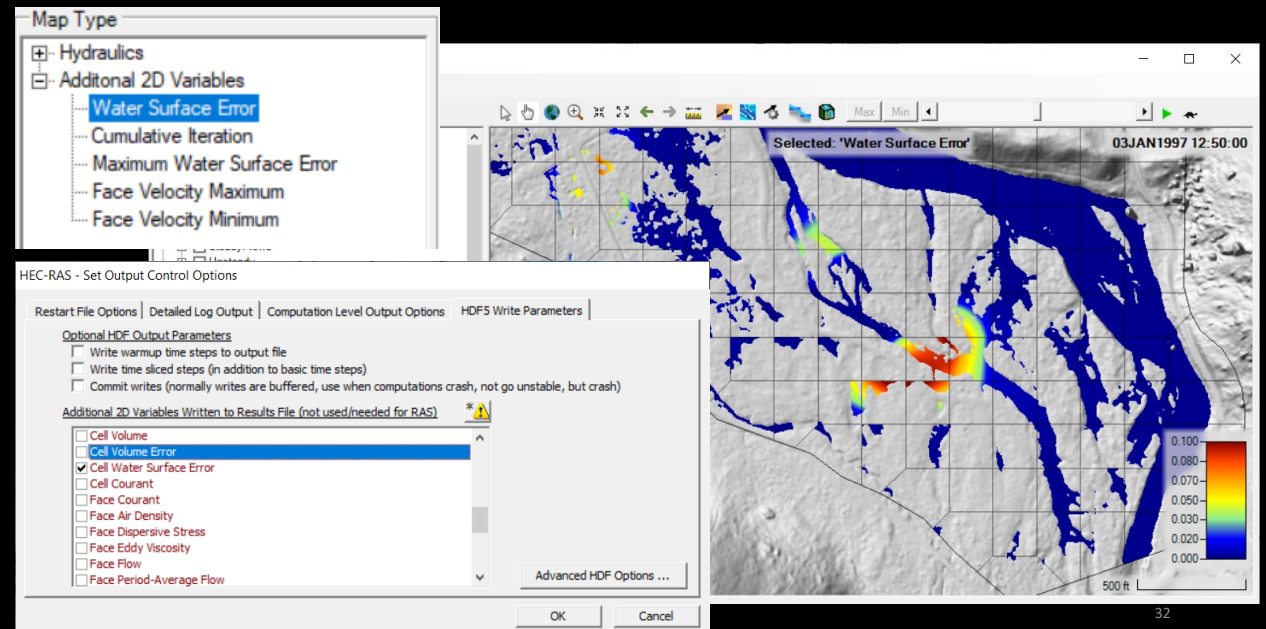
30

# Maximum Water Surface Error



31

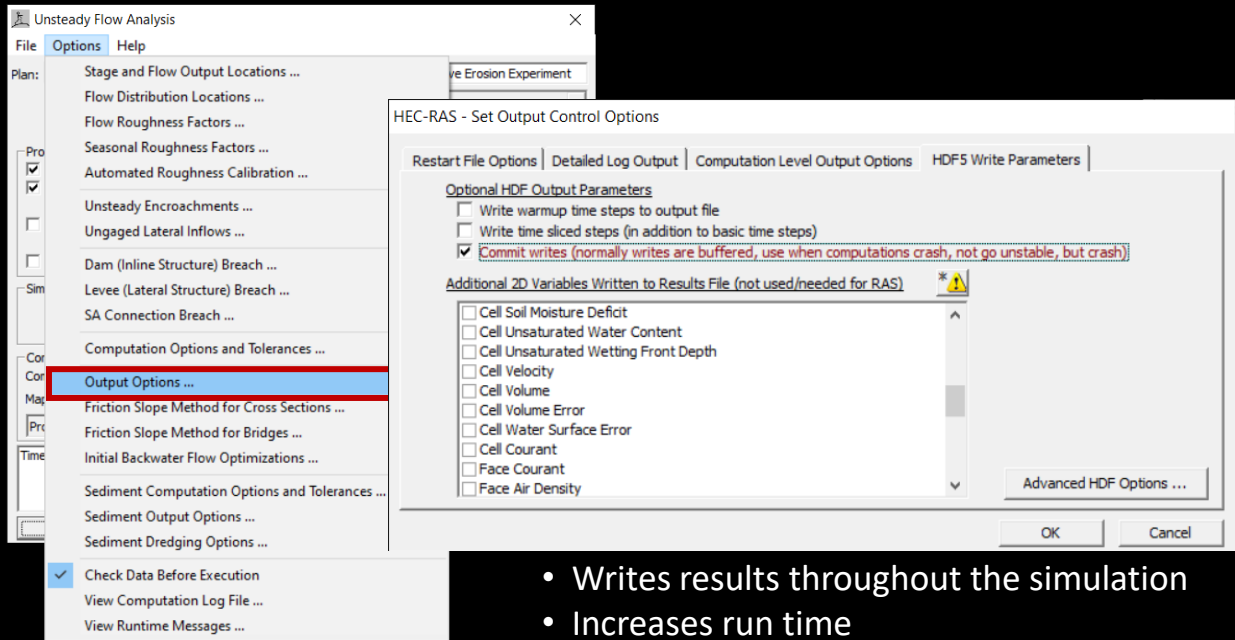
# Cell Water Surface Error (For each time step)



32



# Write Intermediate Results Before a Crash



HEC-RAS - Set Output Control Options

Restart File Options | Detailed Log Output | Computation Level Output Options | HDF5 Write Parameters

**Optional HDF Output Parameters**

- Write warmup time steps to output file
- Write time sliced steps (in addition to basic time steps)
- Commit writes (normally writes are buffered, use when computations crash, not go unstable, but crash)**

**Additional 2D Variables Written to Results File (not used/needed for RAS)** ⚠

- Cell Soil Moisture Deficit
- Cell Unsaturated Water Content
- Cell Unsaturated Wetting Front Depth
- Cell Velocity
- Cell Volume
- Cell Volume Error
- Cell Water Surface Error
- Cell Courant
- Face Courant
- Face Air Density

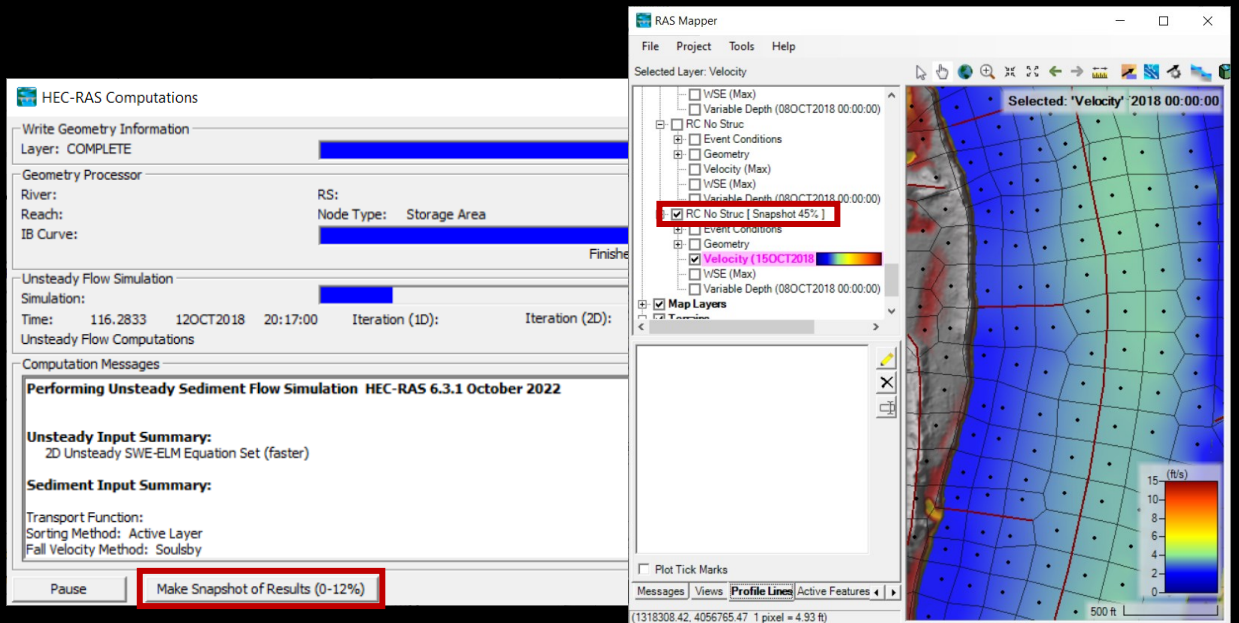
Advanced HDF Options ...

OK Cancel

- Writes results throughout the simulation
- Increases run time

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# Snapshots



HEC-RAS Computations

Write Geometry Information  
Layer: COMPLETE

Geometry Processor  
River: RS: Node Type: Storage Area  
Reach: IB Curve: Finish

Unsteady Flow Simulation  
Simulation:  
Time: 116.2833 12OCT2018 20:17:00 Iteration (1D): Iteration (2D):  
Unsteady Flow Computations

Computation Messages

**Performing Unsteady Sediment Flow Simulation HEC-RAS 6.3.1 October 2022**

**Unsteady Input Summary:**  
2D Unsteady SWE-ELM Equation Set (faster)

**Sediment Input Summary:**  
Transport Function:  
Sorting Method: Active Layer  
Fall Velocity Method: Soulsby

Pause **Make Snapshot of Results (0-12%)**

RAS Mapper

File Project Tools Help

Selected Layer: Velocity

- WSE (Max)
- Variable Depth (08OCT2018 00:00:00)
- RC No Struc
- Event Conditions
- Geometry
- Velocity (Max)
- WSE (Max)
- Variable Depth (08OCT2018 00:00:00)
- RC No Struc [ Snapshot 45% ]**
- Event Conditions
- Velocity (15OCT2018)**
- Geometry
- WSE (Max)
- Variable Depth (08OCT2018 00:00:00)

**Map Layers**

Plot Tick Marks

Messages Views Profile Lines Active Features

(1318308.42, 4056765.47 1 pixel = 4.93 ft)

Selected: 'Velocity' '2018 00:00:00'

15 (ft/s)

500 ft

34