Runtime Optimizations

Workshop

1 Objective

The goal of this workshop is to take a base hydraulic and sediment model that runs slow and has some issues and improve it so that it runs faster and more stable.

2 Introduction

The model is based on a small reach of the Arkansas River. For the purposes of the workshop, the model is setup is relatively simple and fast. The model extent is relatively small model, and the mesh has a coarse resolution. The computational mesh, boundary condition lines, and terrain are shown in the figure below.



The base model has a constant flow upstream of 70,000 cfs, and a constant stage downstream of 172.936 ft. It is important to note, that though the current model setup may not be good for final production runs of a project, the sensitivity analysis as applied here with a fast model setup is useful and recommended for projects.

- 1. Start HEC-RAS 🚟.
- 2. **Open** the HEC-RAS project names "ArkansasPool2.prj" in the "Advection-Diffusion" Workshop folder.
- 3. **Open** the **Unsteady Flow Analysis** ditor, and **Run** the plan called "Base Sed".
- 4. **Do NOT** run the plan. **Click** on the menu **Options | View Runtime Messages...** as shown below

上 Unsteady Flow Analysis >					
File Options Help					
Plan:	Stag Flov Flov Sea: Aut	ge and Flow Output Locations w Distribution Locations w Roughness Factors sonal Roughness Factors omated Roughness Calibration	ed	- - -	
<u>।</u> ।	Uns Ung	steady Encroachments gaged Lateral Inflows		~	
Sim	Dan Lev SA (Dam (Inline Structure) Breach Levee (Lateral Structure) Breach SA Connection Breach			
	Cor	nputation Options and Tolerances	e: :	0000	
Cor Cor Map	Out Fric Fric Initi	put Options tion Slope Method for Cross Sections tion Slope Method for Bridges ial Backwater Flow Optimizations	Sections erval: 30 s l: 30 ons jediment (3	30 Minute 💌 30 Minute 💌 nt (3 Da	
	Sed Sed Sed	iment Computation Options and Tolerances iment Output Options iment Dredging Options			
	✓ Che Viev	eck Data Before Execution w Computation Log File w Buntime Marcaner			
	VIC	w Kuntine messages in			

5. The message window should look something like this

Geometric Preprocessor HEC-RAS 6.4.1 June 2023	^
Finished Processing Geometry Geometry group from file 'ArkansasPool2.p01.tmp.hdf' copied to 'ArkansasPool2.g11.hdf'	
Performing Unsteady Sediment Flow Simulation HEC-RAS 6.4.1 June 2023	
Unsteady Input Summary: 2D Unsteady SWE-EM Equation Set (stricter momentum) 2D number of Solver Cores: 6	i
Sediment Input Summary:	
Transport Function: Sorting Method: Active Layer Fall Velocity Method: Soulsby Global deposition/erosion methods: Soulsby	
Overall Volume Accounting Error in Acre Feet: 0.000000 Overall Volume Accounting Error as percentage: 0.000000 Please review "Computational Log File" output for volume accounting details	
Writing Results to DSS	
Finished Unsteady Flow Simulation	
Computations Summary	
Computation Task Time(hh:mm:ss) Completing Geometry, Flow and Plan 4 Preprocessing Geometry <1	
Computation Speed Simulation/Runtime Unsteady Flow Computations with Sediment 1033x Complete Process 1027x	~

6. At the bottom of the messages, the run time for the unsteady flow and sediment as 13:56. This is how long it took to run a 10-day simulation. Dividing the simulation time by the runtime gives the computation speed of 1033x shown above. This is a good number to keep track of when optimizing the model performance because it can easily be used to compare the speed of different simulations of different lengths. It can also to compute how long a simulation will take to compute.

3 Flow Model Optimization

Before optimizing the sediment transport model, the flow will be optimized separately. It is often useful to optimize the model setup using a short simulation period. In this case a short steady state simulation is run to optimize the hydraulic simulation.

- 7. Save As... a new plan called "Flow Only".
- 8. **Change** the simulation time window to be 4-hours long. This should be sufficiently long for a steady simulation and long enough to compute a representative simulation computational speed.
- 9. **Run** the plan.
- 10. **Read** the simulation runtime and computational speed.
- 11. Add the Courant number output layer by right-clicking on the Results layer Flow Only and selecting Create a New Results Map Layer ...

[

Event Conditi		RAS Results Information	
⊡⊡ Geometry ⊡ Velocity (Max	ı <u>م</u>	Zoom to Layer	
WSE (01MAY		Remove Layer	
Map Layers	č	Remove Layer and Delete Source Files	
Terrains		Move Layer 🕨	
Pool2_20221006		Open Folder in File Explorer	
		Show Compute Messages	
		Create a New Results Map Layer	
		Create a New Calculated Layer	

In the **Results Map Parameters** window, find and select **Courant** (Velocity/Length) and click on **Add Map** as shown below.

Results Map Parameters		×
Map Type 	Unsteady Profile C Maximum C Minimum Image: Comparison of the state s	Map Output Mode Generated for Current View (in memory) © Raster (with Associated Terrain) © Point Feature Layer: © Raster based to disk) © Raster based to disk) © Roint Feature Layer: © Polygon Boundary at Value: © Polygon Boundary at Value: © Map Type Layer Name ► Courant (Velocity/Length) Courant (Velocity/Length)
Map Type: A Map layer will be created for Courant (Map Mode: Map results are generated on the fly for	/elocity/Length) = cell's Maximum(face abs(velocity) * the current view.	dt / cell to cell distance).

12. The Courant number layer should look something like the figure below



- 13. From the **Courant** results, it is clear that the time step is too small and can be increased by a factor of 3 to 4.
- 14. **Set** the time step to **30 seconds**, rerun the plan, and check how long the simulation takes to run. The simulation run several times faster.
- 15. The next time is to optimize the computational options and parameters, In the **Unsteady Flow Analysis** editor, **click** on the menu **Options | Computation Options and Tolerances ...** as shown below.

声 Ur	为 Unsteady Flow Analysis Ana		
File	e Options Help		
Plan:	\checkmark	Stage and Flow Output Locations	nly
		Flow Distribution Locations	-
		Flow Roughness Factors	
		Seasonal Roughness Factors	
⊢Pro		Automated Roughness Calibration	
		Unsteady Encroachments	^
		Ungaged Lateral Inflows	
		Dam (Inline Structure) Breach	
		Levee (Lateral Structure) Breach	×
Sim		SA Connection Breach	e: 0000
		Computation Options and Tolerances	: 0400
Cor		Output Options	

16. The Equation Set is set to the SWE-EM solver, which is the slowest solver. For purposes of the workshop, the SWE-ELM should be fine. It is generally recommended to start with the SWE-ELM for river applications and only test the SWE-EM solver for comparison purposes. For most river applications, the two solvers will produce very similar results if the resolution and time step are appropriate. However, the SWE-ELM is generally faster and more stable. For these reasons, the SWE-ELM solver will be used here.

	HEC-RAS Unsteady Computation Options and Tolerances					
ſ	General 2D Flow Options 1D/2D Options Advanced Time Step Control 1D Mixed Flow Options					
	🔲 Us	se Coriolis Effects (not used with Diffusio	on Wave equation)			
		Parameter	(Default)	Pool2	1	
	1 Th	neta (0.5-1.0)	1		1	
	2 Theta Warmup (0.5-1.0)		1		1	
	3 W	ater Surface Tolerance [max=0.2](ft)	0.01	0.03	1	
	4 Volume Tolerance (ft)		0.01	0.03	1	
	5 Ma	aximum Iterations	20	20	0	
	6 Eq	uation Set	Diffusion Wave	SWE-EM (stricter momentum)	1	
	7 Ini	itial Conditions Time (hrs)		Diffusion Wave	1	
	8 Ini	itial Conditions Ramp Up Fraction (0-1)	0.5	SWE-ELM (original/faster)		
	9 Nu	umber of Time Slices (Integer Value)	1	SWE-EM (stricter momentum)		
	10 To	ula dana Madal	New Concentration Installed	ISWE-LIA (local inertia)		

- **17.Change** the number of cores to 4. Since this dataset is small, it is not efficient to utilize all of the cores on a computer.
- 18. This dataset is relatively small, so other computational options don't make a big difference.
- 19. **Run** the new plan setup. The model should be much faster. The model is now ready to add sediment transport

Question: What other kinds of model parameters and tolerances can be adjusted to speed up the flow model?

4 Sediment Model Optimization

The next step is to turn sediment back on and optimize the sediment transport model. A large part of the sediment model optimization can be done with shorter simulations and some cases, smaller domains, and coarser grid resolutions.

- 20. Save a new plan with Title and Shot ID "Sed 1day".
- 21. **Check** the box for sediment transport n the **Unsteady Flow Analysis** window.
- 22. Change the simulation window to be 1 day.
- 23. **Run** the plan as is and record the runtime and computational speed. You'll see that the model goes to maximum iterations for a few time steps.

Unsteady Input Summary: 2D Unsteady SWE-ELM Equation Set (faster) 2D number of Solver Cores: 4 Sediment Input Summary:				^
Transport Function: Sorting Method: Active Layer Fall Velocity Method: Soulsby Global deposition/erosion methods: Soulsby				
Maximum iteration location	Cell	WSEL	ERROR ITERATIONS	
0 1MAY2019 00:00:30 2D sediment went to max itera 0 1MAY2019 00:01:00 2D sediment went to max itera 0 1MAY2019 00:01:30 2D sediment went to max itera 0 1MAY2019 00:02:00 2D sediment went to max itera 0 1MAY2019 00:02:00 2D sediment went to max itera 0 1MAY2019 00:03:00 2D sediment went to max itera 0 1MAY2019 00:03:30 2D sediment went to max itera 0 Plase review "Computational Log File" output for vol 0 Vertiang Results to DSS 0 Finished Unsteady Flow Simulation 0 Computations Summary	itions tions tions tions tions tions .000001 0.000000 ume accounting details			
Computation Task Tim	e(hh:mm:ss)			
Preprocessing Geometry	<1			
Unsteady Flow Computations with Sediment Complete Process	<u>35</u> 36			
Computation Speed Simula Unsteady Flow Computations with Sediment Complete Process	<u>tion/Runtime</u> 2452x 2344x			~

4.1 Sediment Model Convergence

Before continuing, it is useful to look at the model convergence, since a large part of the computational time can be spent on iterating within a time step. This is also important from a stability and model robustness point of view. The sediment model always outputs the number of iterations at the mapping output interval in the HDF5 output file (*.p##.hdf). However, to view this file, the user needs to either run a program to read the file or open it in a program such as HDFView. Another way of looking at the model convergence is through the **Computations Log File**.

- 24. Open the Unsteady Flow Analysis editor.
- 25. Select the menu Options | Sediment Output Options ...
- 26. Set the Output Level to 4.

Sediment Output Options					
	-Sediment Output Optic	ons			
	Output Level:	4		• 🛛	1
	Mass or Volume?	1 2			
	Output Increment:	3 4			
	Primary Output Interv Bed R	5 6 Only Customized	45	t)	

Note: For an Output Level of 4, only the status of the last iteration is logged. For Output Levels 5 or 6, the status of each iteration is written. For Output Level 3 (default) or lower, no iteration convergence information is written to the Computations Log File.

- 27. Save the plan
- 28. Run the plan.
- 29. **Open** the **Computations Log File** by opening the **Unsteady Flow Analysis** editor, and selecting the menu **Options | View Computation Log File ...** The sediment log information is written at the **Mapping Output Interval** to avoid making the **Computations Log File** too large.

It is noted that the model went to maximum iterations and the first grain class (i.e. VFS) did not reach convergence. This could be avoided by increasing the maximum number of iterations. However, it is better to improve the model convergence and reduce the number of iterations. Inspecting the model convergence further, it is noted that the sediment model often went to 4 iterations.

For such a simple model as this one, the model is expected to have better convergence. This is an indication something about the model needs to be improved.

One of the common issues with model convergence is the failure to including hiding and exposure. The reason hiding and exposure improves model stability is because it decreases the erosion of the finer particles which represent a larger portion of the transport and therefore it tends to reduce the overall sediment transport and of finer particles especially (which is the one not converging in this case).

- 30. Open the Sediment Data editor
- 31. Click on the menu Options | Bed Mixing Options.

🤟 s	ediment Data - Base
File	Options View Help
Initia	User Defined Grain Classes
	Set Cohesive Options
	Bed Change Options (1D)
	Transport Methods
_	Calibrate Transport Function
<u>R</u>	2D Options
	BSTEM Options
	Lateral Weir Options
	Bed Mixing Options
	Subsidence

32. Select the **Wu et al.** hiding function and set the exponent to **0.6** as shown in the figure below and click **OK**.

🖪 Bed Mixing Options 🛛 🗕		\times
Capacity Partitioning (1D Only) Capacity Partitioning Method: Bed Gradation Only % Inflow Gradat	ion: 10	
Hiding Functions (Beta for 1D)	Shane E	actor
Hiding Function: Wu et al Hiding Exponent: 0.6	0.6	
Active Layer Options Active Layer Thickness: X d90 Multiplier: 1. Min Thickness: 0.1 Exchange Increment (1D Only): % Bedload: 70. % Active Layer: 30.	ft	
Cover/Active Layer Gradations (1D Only)		
Specify Seperate Cover/Active Layer Gradations		
Copeland Method Option (test) (1D Only)	Defau	ults

- 33. **Save As** the sediment data with the name "Base HE" for hiding and exposure.
- 34. Save a new plan with the Title and Short ID "1d HE"
- 35. Run the plan.
- 36. Open the Computation Log File by opening the Unsteady Flow Analysis editor, and selecting the menu Options | View Computation Log File ... Note how the number of iterations has decreased by adding hiding and exposure corrections. This also has a big impact on model stability and speed.

4.2 Sediment Computation Multiplier

The Sediment Computation Multiplier (CM) allows the model to use a larger time step for sediment transport compared to the hydraulic model. The sediment time step is computed as the hydraulic model time step times the CM. The default value for CM is 1, which means the hydraulic and sediment models have the same time step by default. The CM is a simple way to speed up the sediment model. However, the parameter can also make the sediment model unstable or cause the sediment model results to diverge from the results with a smaller time step. For this reason, the parameter should always be tested and verified against a base value of 1

- 37. Save As the plan with the Title and Short ID "1d HE CM".
- 38. **Open** the **Unsteady Flow Analysis** window.
- 39. Click on the menu Options | Sediment Computation Options and Tolerances...

声 Ur	🛓 Unsteady Flow Analysis 🛛 🕹 🗙				
File	File Options Help				
Plan:	×	Stag Flow Flow Seas Auto	e and Flow Output Locations / Distribution Locations / Roughness Factors onal Roughness Factors pmated Roughness Calibration	ay G	•
		Unst Ung Dam Leve SA C	teady Encroachments aged Lateral Inflows n (Inline Structure) Breach te (Lateral Structure) Breach Connection Breach	e:	0000
Cor Cor Maț Pro		Con Out Frict Frict Initia Sedi	nputation Options and Tolerances out Options ion Slope Method for Cross Sections ion Slope Method for Bridges al Backwater Flow Optimizations ment Computation Options and Tolerances	erval:	0000 30 Minute 30 Minute ent (3 D:
Sediment Output Options					

40. In the **General** tab, set the **Sediment Computation Multiplier** to 10. This number represents the number of flow time steps that are computed within sediment time steps.

HEC-RAS Sediment Computation Options and Tolerances				
General 2D Computational Options				
1D Computational Options Bed exchange iterations per time step (SPI)				
Min bed change before updating Cross Section (ft):				
Min XS change before recomputation of hydraulics (ft): 0.02				
Perform Volume Error Check/Carry Over:				
Transport Energy Slope Method: Local: (Q/K)^2				
Sediment Computation Multiplier: ¹⁰ X the hydraulic time step				

- 41. Save the plan.
- 42. **Run** the model. The runtime should significantly shorter. Note the sediment model has gone to maximum iterations for many time steps.

43. **Verify** that changing the CM, did not change the results significantly by comparing the **bed change** and other variables in **RAS Mapper**.

Open the **Computation Log File** and inspect the model convergence. In this case, the number of sediment iterations has increased indicating reduced stability. Again, it's time to take a closer look at the model setup and identify any parameters which need to change or could be adjusted to improve model stability.

4.3 Active Layer Thickness

A common model parameter that affects the sediment model convergence is the active layer thickness. When the active layer is too thin, the whole layer can be eroded or exchanged within a single time step, and then can cause the convergence issues. The thicker the active layer is, the more stable the model will be because the active layer bed gradations will change more slowly.

- 44. Open the Sediment Data editor.
- 45. Save As the Sediment Data with the name "Base HE AL".
- 46. **Select** the menu **Options | Bed Mixing Options...** the window should look like the figure below.

🖏 Bed Mixing Options 🦳		×			
Capacity Partitioning (1D Only) Capacity Partitioning Method: Bed Gradation Only	n: 10	-			
Hiding and Exposure Functions Hiding Function: Wu et al Hiding Exponent:	Shape Fa	actor:			
Active Layer Options Active Layer Thickness: X d90 V Multiplier: 3 Min Thickness: 0.15 ft Exchange Increment (1D Only): % Bedload: 70. % Active Layer: 30.					
Cover/Active Layer Gradations (1D Only) Specify Seperate Cover/Active Layer Gradations					
Copeland Method Option (test) (1D Only) OK Cancel	Defau	lts			

- 47. The active layer thickness is set to the d90 with a minimum value of 0.01 ft ~ 3 mm. This active layer is small and should be increased. The coarsest grain class has an upper limit of 2 mm so using the d90 multiplier is unlikely to make any significant difference unless it is to values in the range of 10 to 20. Set the **Minimum Active layer Thickness** to **0.15 ft** ~ 5 cm.
- 48. Save a new plan with the Title and Short ID "1d HE CM AL".
- 49. **Run** the plan. Note that the computational speed increased by changing the active layer thickness because the sediment model is doing less iterations per time step. This illustrates the importance of good model convergence for computational speed.

Inspect the model convergence in the **Computation Log File**. Increasing the active layer thickness made a big difference in the model stability.

- 50. Save a new plan with the Title and Short ID "10d HE CM AL".
- 51. **Set** the simulation window to 10 days.

Simuli	ation Time Window ——			
Starting Date:		01MAY2019	Starting Time:	0000
	Ending Date:	11MAY2019	Ending Time:	0000

52. Run the plan.

4.4 Grain Classes

Another thing that significantly impacts the runtime and model convergence is the number of grain classes. Each grain class requires solving another transport equation (i.e. unsteady advection-diffusion equation), bed sorting, and bed change equation. In addition, the grain classes are coupled through hiding and exposure and other processes. Having many grain classes can decrease the model convergence. Therefore, it is useful to reduce the number of grain classes to reduce the simulation runtime and the improve the model robustness. However, special care should be taken in combining grain classes or ignoring grain classes in areas of the domain which do not affect the area of interest.

The effect reducing the number of grain classes has on the runtime depends on the simulation and especially the sediment Computation Multiplier (CM). The larger the CM, the less effect reducing the number of grain classes has, because the sediment calculations become a smaller portion of the overall computation time. For this reason, a plan is first created without the CM, but with the bed mixing option changes. Then the number of grain classes is reduced from 5 to 3 to compare runtimes.

- 1. Open the Sediment Data editor.
- 2. Save As the Sediment Data with the name "Base HE AL GC".
- 3. Click on the 2D Bed Gradations tab, and select the button Define/Edit Bed Gradations...

Vediment Data - Base	9		
File Options View H	lelp		
Boundary Conditions 2D	Bed Gradations		
Transport Function:	Wu	•	Define/Edit
Sorting Method:	Active Layer	-	Bed Gradation
Fall Velocity Method:	Soulsby		reate a new Bed Gradation or Edit an existing one

4. **Inspect** the **Reach 2** bed gradation which is used everywhere except for the non-erodible structures.



The sediment gradation has 5 grain classes. Two of these grain classes have 1% or less material (by weight). These grain classes can be ignored from the bed gradation.

- 5. **Save As** the sediment data as "Base HE AL GC". This sediment data file will contain the modified number of active grain classes. It's good practice to rename files in HEC-RAS before making changes to the data.
- 6. Open again the Bed Gradation editor.
- 7. **Remove** the VFS and VCS grain sizes.



- 8. Save the plan with the Title and Short ID "10d HE CM AL GC".
- 9. **Run** the plan. The runtime should be much shorter.
- 10. **Compare** the bed change and other variables for the model with 3 grain classes compared to 5. The differences in this case should be negligible.

Note: For the purposes of the workshop, the comparison of using different number of grain classes is done with relatively short simulations. For a reallife project, this comparison should be done with a longer simulation comparable to the simulation length of the production runs.

Question: Since the number of grain classes is proportional to the simulation runtime, it seems reasonable to exclude grain classes which are part of the wash load since they do not contribute significantly to the bed change. However, this is not always the case. In what situations would it be useful to include wash load grain classes?

4.5 Iterative Solvers

A large portion of the computational time in the sediment model is spent solving a large sparse matrix related to implicit solution of the transport equation.

- 11. Open the Unsteady Flow Analysis editor.
- 12. Save As ... the plan with the Title and Short ID "10d HE AL GC IS".
- 13. Click on the menu Options | Sediment Computation Options and Tolerances.
- 14. In the **HEC-RAS Sediment Computation Options and Tolerances** editor, click on the **2D Computational Options** tab
- 15. In the **Transport** section, select the **FGMRES-ILUO** from the drop-down menu for the **Sediment Matrix Solver**, as shown in the figure below.

HEC-RAS Sediment Computation Options and Tolerances				
General	2D Computational Options	s		
Trar	nsport			
Adv	ection Scheme:	Upwind		
Sedi	ment Matrix Solver:	FGMRES-ILU0		
Impl	icit Sediment Weighting Fac	PARDISO FGMRES-SOR		
		FGMRES-ILU0		
└ Outer Loop Convergence Parameter:				

- 16. **Run** the plan. Note the reduction in run time. The reduction in run time is a function of the number of grain classes and the computation multiplier.
- 17. Check the Computation Log File.
- 18. **Inspect** the results in **RAS Mapper** and compare with the previous plans.

4.6 Morphologic Acceleration Factor

The Morphologic Acceleration Factor (MF) is a useful parameter to speedup sediment simulations. The MF can be used several ways, in this workshop, the goal is to simulate the bed change corresponding to design flow of 70,000 cfs for 10 days. By setting MF =10, 1 day of simulation time will represent 10 days of bed change. Since the upstream flow and downstream stage boundary conditions are constant, no changes are needed for these boundary conditions. Since the upstream sediment boundary condition is an equilibrium boundary condition, no changes are required for this boundary condition type either.

- 19. Open the Sediment Data editor.
- 20. Save As ... the sediment data as "Base HE AL GC MF".
- 21. Click on the menu Options | 2D Options as shown below.



22. In the **2D Sediment Options** window, set the **Morphologic Acceleration Factor** to **10** as shown below.

2D Sediment Options	_		×
Simulation Components:	All Com	ponents	•
Sheet and Splash Erosion:	None		•
Erodibility:		1.	
Morphological Acceleration Factor: 10			
Base Bed-Slope Coefficient:			_

- 23. Save the Sediment Data.
- 24. Open the Unsteady Flow Analysis window.
- 25. Save the plan with the Title and Short ID "10d HE CM AL GC IS MF".
- 26. Set the simulation window back to be 1 day. Note that since the morphological acceleration factor was set to 10, 1 day of model simulation time will represent 10 days of bed change.
- 27. **Set** the **Mapping Output** interval to **6 min**. This is so that the output is at an equivalent interval with the MF. 5
- 28. **Run** the plan. The simulation should be much faster. When interpreting the computational speed it is necessary to multiply the number by the morphologic acceleration factor in this case.
- 29. **Verify** that the MF did not significantly affect the results by comparing the new results with plan "10d CM HE AL GC IS". Below is an example of the computed bed change. Below is an example of the bed change after 10 days with and without morphologic acceleration factor.



When comparing time-series of bed change of results which have the morphologic acceleration factor, it is necessary to scale time with the morphologic acceleration factor. This can be done by copy-pasting the data to excel and plotting it there. However, the finial values of the bed change can also be used to quickly identify differences in the results due to the MF.

Compared to the base sediment run without any optimizations, this last run is approximately ${\bf 44x}$ faster.